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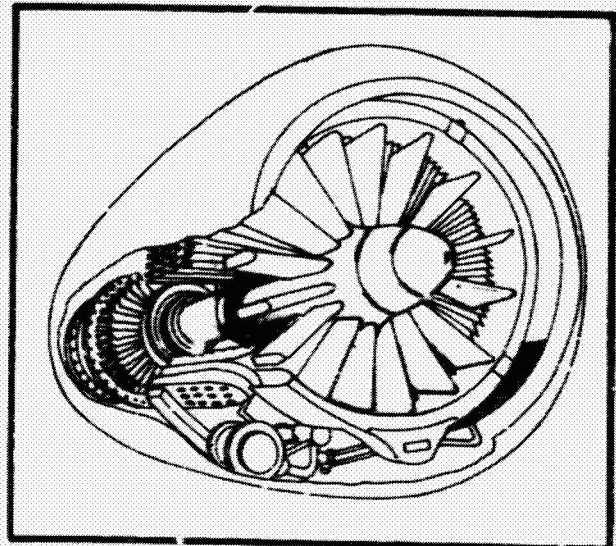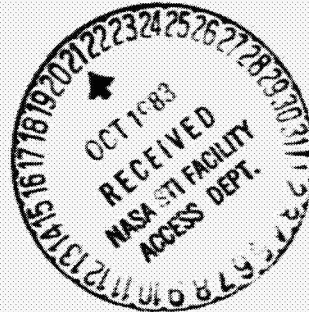
NDE Detectability of Fatigue Type Cracks in High-Strength Alloys

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16. Abstract

This program was conducted to produce specimens suitable for investigating the reliability of production nondestructive evaluation (NDE) to detect tightly closed fatigue cracks in high strength alloys representative of those materials used in spacecraft engine/booster construction. Inconel 718 was selected for this program as representative of nickel base alloys and Haynes 188 was selected as representative of cobalt base alloys used in this application. Cleaning procedures were developed to insure the reusability of the test specimens and a flaw detection reliability assessment of the fluorescent penetrant inspection method was performed using the test specimens produced to characterize their use for future reliability assessments and to provide additional NDE flaw detection reliability data for high strength alloys.

The statistical analysis of the fluorescent penetrant inspection data was performed to determine the detection reliabilities for each inspection at a 90% probability/95% confidence level. This was accomplished by determining the least size consecutive group of thirty flaws that were successfully detected and by using a data grouping and "count down" method based on actual crack lengths and predicted crack depths. Overlapping of data groups (independent observations) was used to smooth the data for graphical presentation. Lower confidence limits for each data group were estimated by binominal distribution analysis and were plotted with the reliability data.

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IN HIGH STRENGTH ALLOYS

PREFACE

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HIGH STRENGTH ALLOYS

By Brent K. Christner and Ward D. Rummel
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SUMMARY

This program was conducted to produce specimens suitable for investigating the reliability of production nondestructive evaluation (NDE) to detect tightly closed fatigue cracks in high strength alloys representative of those materials used in spacecraft engine/booster construction. Inconel 718 was selected for this program as representative of nickel base alloys and Haynes 188 was selected as representative of cobalt base alloys used in this application. As part of the program, cleaning procedures were developed to insure the reusability of the test specimens and a flaw detection reliability assessment of the fluorescent penetrant inspection method was performed using the test specimens produced to characterize their use for reliability assessments and to provide additional NDE flaw detection reliability data for high strength alloys.

A total of 281 fatigue cracks were grown in 110 Inconel 718 specimens and 102 Haynes 188 specimens were produced containing 284 fatigue cracks. The specimens were milled to a thickness of 0.190 inch (0.483 cm) using a shell cutter in multiple swaths to provide a random surface texture (125 RMS or better surface finish) with respect to the crack. Following machining, the specimens were etched to remove the smeared material from the specimen surfaces.

Three fluorescent penetrant inspection sequences were performed on the completed Inconel 718 specimens independently by qualified personnel using one fluorescent penetrant system acceptable per MIL-I-25135 and MIL-I-6866. In addition, three inspection sequences were performed on the Haynes 188 specimens using the same inspector with three different penetrant systems all acceptable per MIL-I-25135 and MIL-I-6866. These inspection sequences were performed to demonstrate the suitablity of both test specimen sets for assessing NDI reliability and to provide data for determining the detection reliability of select fluorescent penetrant systems for these alloys.

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I. INTRODUCTION

Fracture control for the NASA Space Transportation System (STS) and other advanced spacecraft programs has been assured by a combination of fracture mechanics analysis and by nondestructive evaluation. Design allowable criteria have been established from careful analysis of loads and load interactions, service environments, basic material properties, and nondestructive evaluation capabilities. Although considerable engineering effort has been devoted to characterizing basic material properties, much less is known about the capabilities and reliability of nondestructive evaluation, particularly in manufacturing and maintenance environments. The task of providing a sound engineering basis for nondestructive evaluation engineering analysis is emerging as a major challenge to the engineering community and to the design, production, and maintenance of high technology systems.

Traditional nondestructive testing technology has been oriented to detection of small flaws, and thus, the thrust of most nondestructive evaluation programs has been the identification of the smallest flaw that can be detected by a given technique. In a 1972 NASA Survey, Neuschaefer and Beal reported that "virtually no statistically reliable flaw detection data for various NDT methods are available" (Ref. 1). The scarcity of such data is an indicator of the infant state of nondestructive test engineering technology and of the complexity and cost of generating such statistical data.

Experience has shown that tightly closed cracks are one of the most difficult flaw types to detect, and are one of the flaw types most detrimental to load-carrying structures. Detection of such cracks is in turn affected by many variables such as crack orientation, crack location, part geometry, surface finish, stress state, and the service history of the structure. A tight crack can be closely simulated by artificially induced fatigue cracks. By using the fatigue crack as a primary flaw type, the influence of crack orientation, location, etc., can be evaluated by systematic variation of sample preparation and inspection application.

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The program described herein was designed to acquire the capability for reliability assessment of nondestructive evaluation methods as applied to high strength alloys, specifically Inconel 718 and Haynes 188. Test specimens and data were produced for evaluating nondestructive testing conducted as part of on-going programs managed by the George C. Marshall Space Flight Center and to provide an addition to the nondestructive evaluation technology data base for materials that have not been previously investigated by rigorous techniques.

Nondestructive evaluation is a major tool in assessing the soundness of engine components in commercial aviation and in military aircraft. Reliability of space booster and spacecraft engines is due in part to the use of nondestructive evaluation in production. At present, nondestructive evaluation is a major tool in assessing the capabilities of Space Shuttle engines in production and certification for reuse. Inconel 718 and Haynes 188 are representative of high strength alloys which constitute a major portion of the materials used in spacecraft/booster engines and are of primary interest for nondestructive evaluation capability assessment.

II.   SUMMARY OF PROGRAM APPROACH

A.   Program Orientation

In the NASA Space Transportation System (STS) and other advanced air- and spacecraft programs, fracture control has been assured by a combination of (1) linear elastic fracture mechanics in design and analysis and (2) nondestructive testing in structural assessment and verification. The detectable flaw size as determined by nondestructive testing, was used as a basis for establishing design allowables for the Space Shuttle program. A program to assess the inspection capabilities at the Space Shuttle original manufacturer and overhaul facilities is now required to assure that flaws of critical dimensions are detected with a high degree of reliability.

Inconel 718 and Haynes 188 are high-temperature alloys used in critical hardware on the Space Shuttle engines and must be assessed by nondestructive testing techniques for soundness during manufacture and overhaul. These materials differ from other structural materials in their susceptibility to fatigue, flaw growth rates and in physical response to nondestructive evaluation. Criticality of application and unique NDT method interaction make specific assessment of NDT flaw detection reliability for these materials necessary.

In order to assess the specific NDT flaw detection reliability at individual facilities, a set of reusable test specimens of each alloy type, containing a wide range of flaw sizes encompassing flaw lengths of critical dimensions are required to generate the necessary data. Experience from related NDT reliability programs was used to select the general approach for the program, the specimen preparation methods, the format for the data generated and the data analysis methods applied.

B.   Program Approach

Experience has shown that small, tightly closed cracks are one of the most difficult types of flaws to detect and are one of the flaw types most detrimental to load-carrying structures. Tightly closed flaws may be simulated by artificially induced fatigue cracks. The size and shape of such cracks may be varied and controlled over a wide range of conditions, thus making it a good selection for experimentally evaluating NDT flaw detection reliability.

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Based on this experience, artificially induced fatigue cracks
in flat Inconel 718 and Haynes 188 plate were selected for the
production of test specimens suitable for assessing NDT
reliability for this program.

A second objective of the program was to perform an NDT
reliability assessment using the Inconel 718 and Haynes 188
panels produced to verify their suitability for use in NDT
reliability assessment programs. Fluorescent penetrant
inspection was selected as the NDT technique to be examined.
The panels were treated as typical aerospace production
hardware utilizing properly qualified personnel and inspection
techniques.

Having established the program objectives, performance
requirements, test conditions, and analysis methods, a program
test plan was formulated and completed. The overall program
was divided into the following elements:

1. Flaw growth process development and validation.

2. Specimen cleaning procedure development and
   validation.

3. Test specimen preparation.

4. NDE validation of test specimens and documentation.

5. NDE reliability assessment using test specimens.

6. Data analysis and final reporting.

The sequence of the performance of these tasks is shown in
Figure 1.

Figure 1 - Sequence of Test Program Tasks
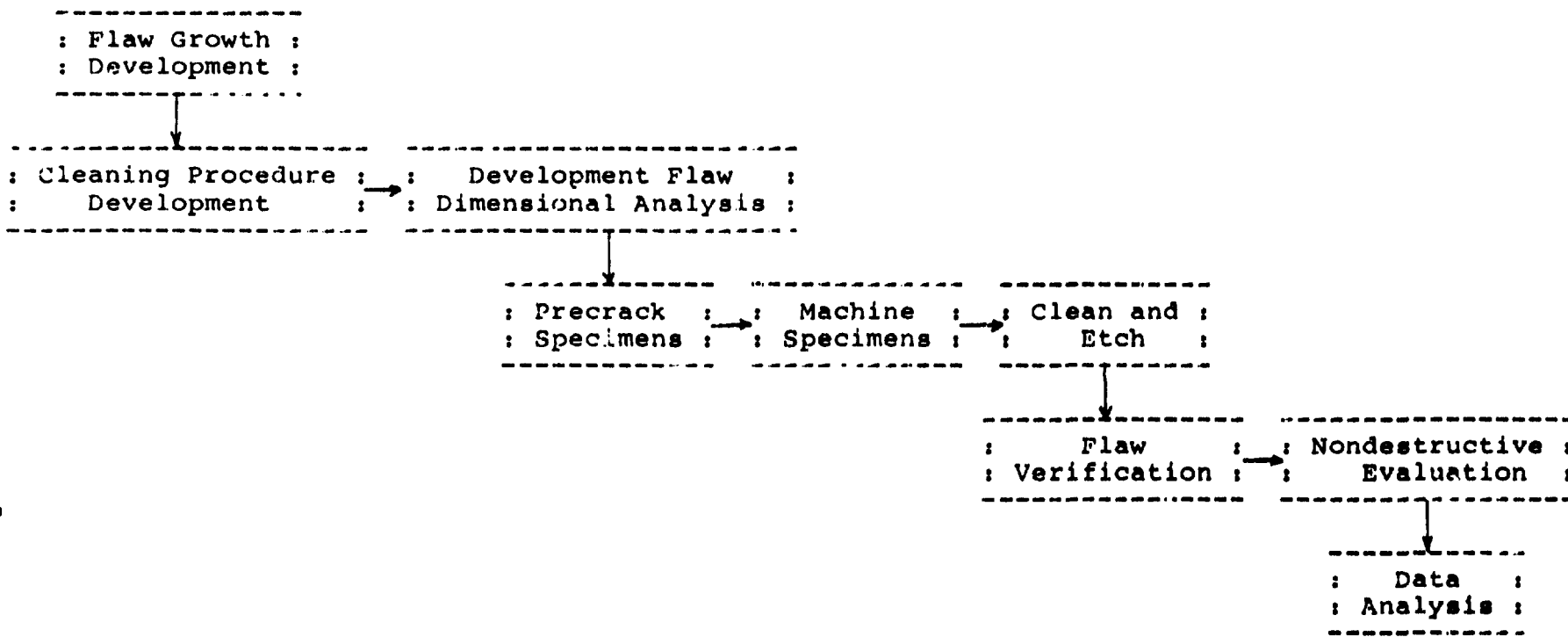
Each program task repeated for the Inconel 718 and Haynes 188 programs except as noted below.

1. Cleaning procedure development performed during Inconel 718 program only.

2. Three inspection sequences were performed on Inconel 718 specimens. One inspection sequence was performed on Haynes 188 specimens.

III. SPECIMEN PREPARATION

The preparation of test specimens for use in reliability demonstration programs is a critical step. Factors which must be considered in preparing suitable test specimens include:

Specimen Material - type, alloy condition, and thickness

Specimen Geometry - size, and configuration

Flaw Types - size, shape, orientation, and location

Flaw Growth - initiation method, and conditions of growth

Flaw Starter Notch Removal - method, and depth

Final Specimen - configuration, thickness, and surface
                 condition

A.   Material and Specimen Geometry

For this program, Inconel 718 and Haynes 188 were selected as being representative of the nickel and cobalt base alloys used in the manufacture of spacecraft engines.

Inconel 718

The Inconel 718 was obtained from the mill in the form of two hot-rolled 36 x 144 x 1/4 inch sheets in the annealed condition meeting AMS specification 5596C. All material used was from the same heat. The sheets were sheared into 162 - 4 x 16 inch panels. Ninety panels were cut longitudinal to the rolling direction. The remaining seventy-two panels were cut transverse to the rolling direction. Those panels falling outside the width dimensions of 4 ± 1/8 inch were marked for use as crack growth development panels.

Haynes 188

The Haynes 188 was furnished by Marshall Space Flight Center. This material had been sheared into 162 - 4 x 16 inch panels from two 36 x 80 x 1/4 inch sheets and two 36 x 64 x 1/4 inch sheets. The material was hot-rolled plate from a single heat meeting specification AMS 5608A in the annealed condition.

Ninety of the Haynes 188 panels were cut longitudinal and the remaining seventy-two panels were cut transverse to the rolling direction. Again, those panels falling outside 4 ± 1/8 inch in width were marked for use in crack growth procedure development.

The mechanical properties for each alloy in the as received condition are listed in Table 1. Table 2 lists the heat chemistries for each alloy.

B. Fatigue Crack Growth Procedure Development

In order to vary crack sizes and configurations, variations in both crack initiation and growth techniques were required. Several evaluation specimens were prepared, fractured and analyzed in both the Inconel 718 and Haynes 188 alloys to verify the selection of crack growth procedures and to provide a data base from which crack depths in the reliability test specimens could be predicted.

Forty Inconel 718 development flaws and fifty-three Haynes 188 development flaws were grown using the parameters shown in Table 3 for each crack configuration.

In both alloys, two different starter notch configurations were used to produce flaws with varying aspect ratios. Bending fatigue, as applied to the panels in this program, produces a ratio of rate of crack depth growth to crack length growth of approximately 0.3. The aspect ratio of the finished crack (before machining to remove the starter notch) can be altered from 0.3 by the shape of the starter notch. The aspect ratio can be increased above 0.3 to a maximum of approximately 0.5 by using a very short, deep starter notch. Cracks with a final aspect ratio less than 0.3 can be grown by using a long shallow starter notch. Machining to remove the starter notch, reduces the final crack aspect ratios as a function of the depth of material removed. In both the Inconel 718 and Haynes 188 panels, the target aspect ratios (after machining) were 0.15 (Case A) and 0.25 (Case B). To obtain the shorter crack lengths, cracks proportionately longer than the desired length were grown and machined to near the bottom of the crack. As a consequence, the aspect ratios of these cracks tend to drop off due to the flattening of the crack that occurs near the bottom of the flaw. Cross-section macrophotographs of representative development flaws, illustrating the starter notch shapes used for each case and the corresponding crack configurations are shown in Figures 2 and 3.

Table 1
Mechanical Properties

	Tensile Test At Room Temperature			Annealed
Material	Ultimate psi	0.2% Yield psi	Elongation %	Hardness Rb
Inconel 718	138,000	70,000	42.0	98
Haynes 188	138,000	68,000	55.0	100

Table 2
Material Composition

Material	Percentage of Composition									
	Ni	Co	Cr	Mo	Mn	Fe	C	Al	Ti	Other
Inconel 718	53.08*	<0.10	18.08	3.12	.180	Bal.	.050	0.50	1.01	5.27 Ta+Cb
Haynes 188	22.92	Bal.	21.86	----	----	2.03	0.10	----	----	.043 La, 14.3 W

Note: Both alloys contain .004% Boron.

* Ni + Co

Table 3
Fatigue Crack Growth Parameters

FLAW LENGTH RANGE INCHES (CM)	MATERIAL	CASE	NOTCH SIZE LENGTH IN. (CM)	NOTCH SIZE DEPTH IN (CM)	TYPE OF LOADING	MAXIMUM FATIGUE STRESS psi (N/m)	MAXIMUM FATIGUE STRESS % of YS
.010 - .050 (.025-.127)	Inconel 718	B	.037-.052 (.094-.132)	.020-.026 (.051-.066)	3-Point Bending	58,320 (8.46)	83%
	Haynes 188	B	.029-.043 (.074-.109)	.024-.028 (.061-.071)		55,870 (8.10)	82%
.051 - .100 (.130-.254)	Inconel 718	A	.037-.052 (.094-.132)	.010-.015 (.025-.038)	3-Point Bending	58,320 (8.46)	83
		B	.037-.052 (.094-.132)	.015-.023 (.038-.058)			
	Haynes 188	A	.055-.070 (.140-.178)	.015-.018 (.038-.046)		55,870 (8.10)	82
		B	.029-.043 (.074-.109)	.023-.026 (.058-.066)			
.101 - .150 (.257-.381)	Inconel 718	A	.090-.153 (.229-.389)	.008-.016 (.020-.041)	3-Point Bending	58,320 (8.46)	83
		B	.039-.051 (.099-.130)	.015-.025 (.038-.064)			
	Haynes 188	A	.084-.113 (.213-.287)	.015-.017 (.038-.043)		55,870 (8.10)	82
		B	.029-.042 (.074-.107)	.023-.026 (.058-.066)			
.151 - .250 (.384-.635)	Inconel 718	A	.150-.235 (.381-.597)	.009-.016 (.023-.041)	3-Point Bending	58,320 (8.46)	83
		B	.035-.052 (.089-.132)	.015-.022 (.038-.056)			
	Haynes 188	A	.162-.256 (.411-.650)	.013-.016 (.033-.041)		55,870 (8.10)	82
		B	.029-.040 (.074-.102)	.024-.026 (.061-.066)			

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a/2c = 0.34 (Before Machining)

0.250"
Stock

0.190"

INCONEL 718 - CASE A FLAW

Development Flaw # 1TB/5

Flaw Length - 0.255"

Flaw Depth - 0.086"

a/2c = 0.37 (Before Machining)

0.250"
Stock

0.190"
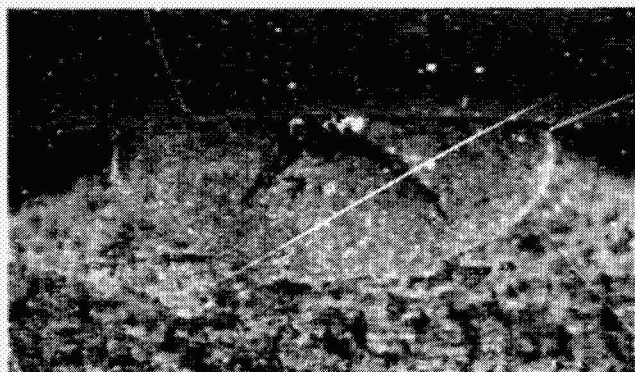
INCONEL 718 - CASE B FLAW

Development Flaw # 1TA/5

Flaw Length - 0.233"

Flaw Depth - 0.086"

Figure 2 - Side View of Crack Starter Notch Shape and
Final Crack Configuration for Inconel 718
Case A and Case B Flaws

a/2c = 0.33 (Before Machining)

0.250"
Stock   0.190"

HAYNES 188 - CASE A FLAW

Development Flaw # GL/1

Flaw Length - 0.255"

Flaw Depth - 0.086"

a/2c = 0.44 (Before Machining)

0.250"
Stock   0.190"

HAYNES 188 - CASE B FLAW

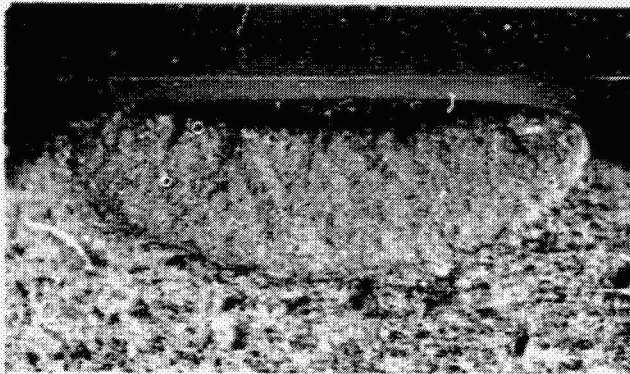Development Flaw # ET/4

Flaw Length - 0.139"

Flaw Depth - 0.061"

Figure 3 - Side View of Crack Starter Notch Shape and
Final Crack Configuration for Haynes 188
Case A and Case B Flaws

The development flaws were broken open as they were grown
to verify crack dimensions. Measurements were made using a
stereo-microscope with a reticle eye-piece. The measurements
taken included notch depth and length, surface crack depth and
length, and final (after machining) crack depth and length.
The final dimensional data for the development cracks was
sorted and ordered by length. Regression analysis was applied
using polynomials of varying degree to fit the data, and plots
of final surface length versus final crack depth were made for
each flaw case and alloy.

The equations for ? polynomials generated from the
analysis of the devel... ...nt flaws were used for predicting
crack depths in the reliability test specimens. Figures 4
through 7 show the plots of final crack dimensions made for the
development flaws. Tables listing the complete dimensional data
for the development cracks for both alloys are included in
Appendix A.

During the course of the crack growth development for the
Haynes 188 alloy, it was determined that longer EDM starter
notches were required to achieve an aspect ratio near 0.15 than
was originally anticipated. As a result, only those
development flaws grown with the modified starter notch were
used to generate the graph in Figure 6. Better success was
achieved in varying the aspect ratios in the Haynes 188
specimens than was obtained in the Inconel 718 panels. Table 4
lists the average aspect ratios for the development flaws in
each crack length range for both alloys.

TABLE 4
Average Aspect Ratios for
Crack Growth Procedure Development Flaws

Crack Length Range	Case	Aspect Ratios	
		Inconel 718	Haynes 188
.010 - .050"	B	.12	.19
.051 - .100"	A	.16	.14
	B	.16	.24
.101 - .150"	A	.21	.19
	B	.25	.21
.151 - .250"	A	.25	.20
	B	.27	.25

CRACK DEPTH INCHES

0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0

0   .05   .1   .15   .2   .25   .3   .35
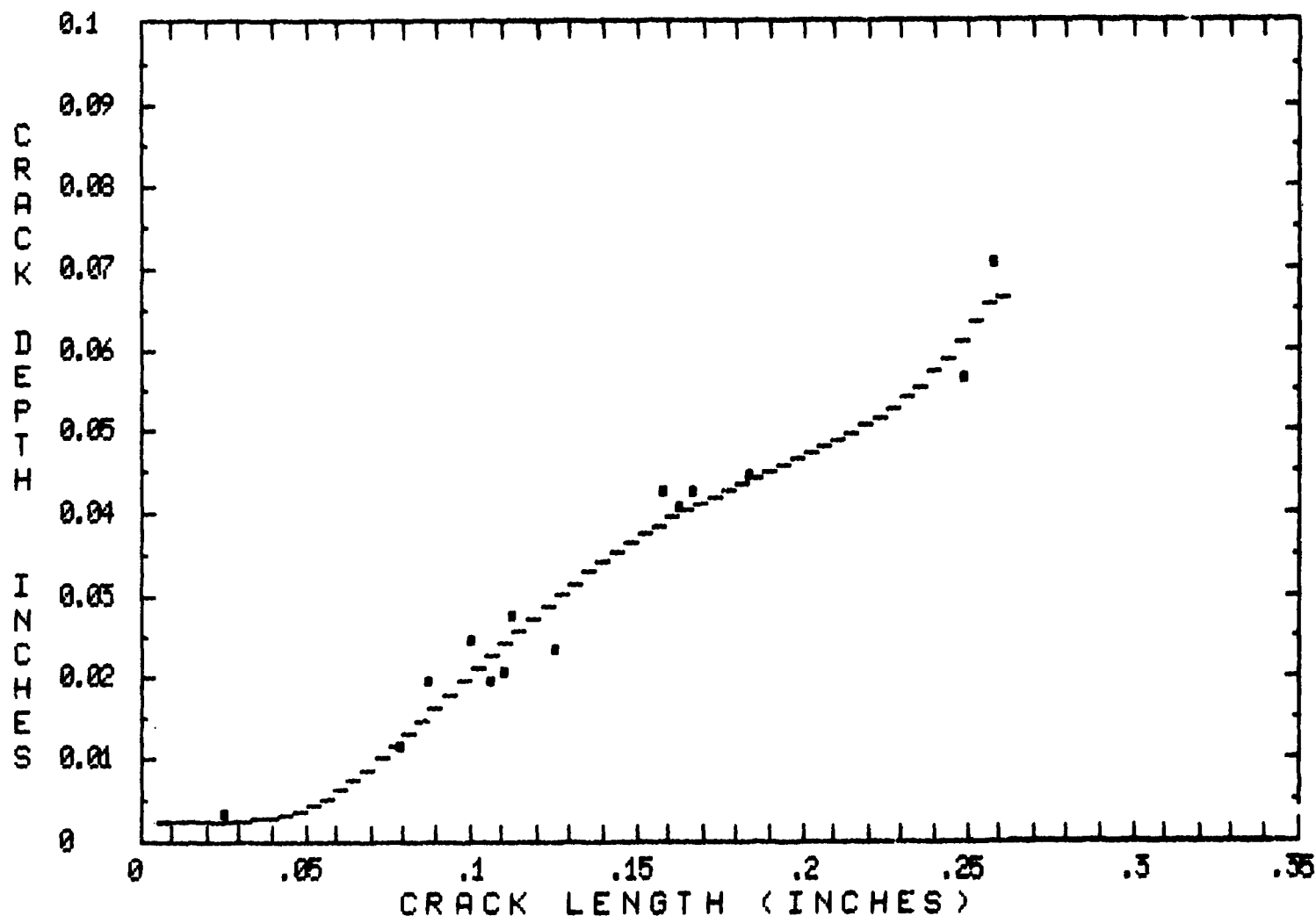
CRACK LENGTH (INCHES)
INCONEL 718
DEVELOPMENT CRACK FINAL DIMENSIONS
CASE A FLAWS

Figure 4 - Final Dimensions (After Machining) of Inconel 718
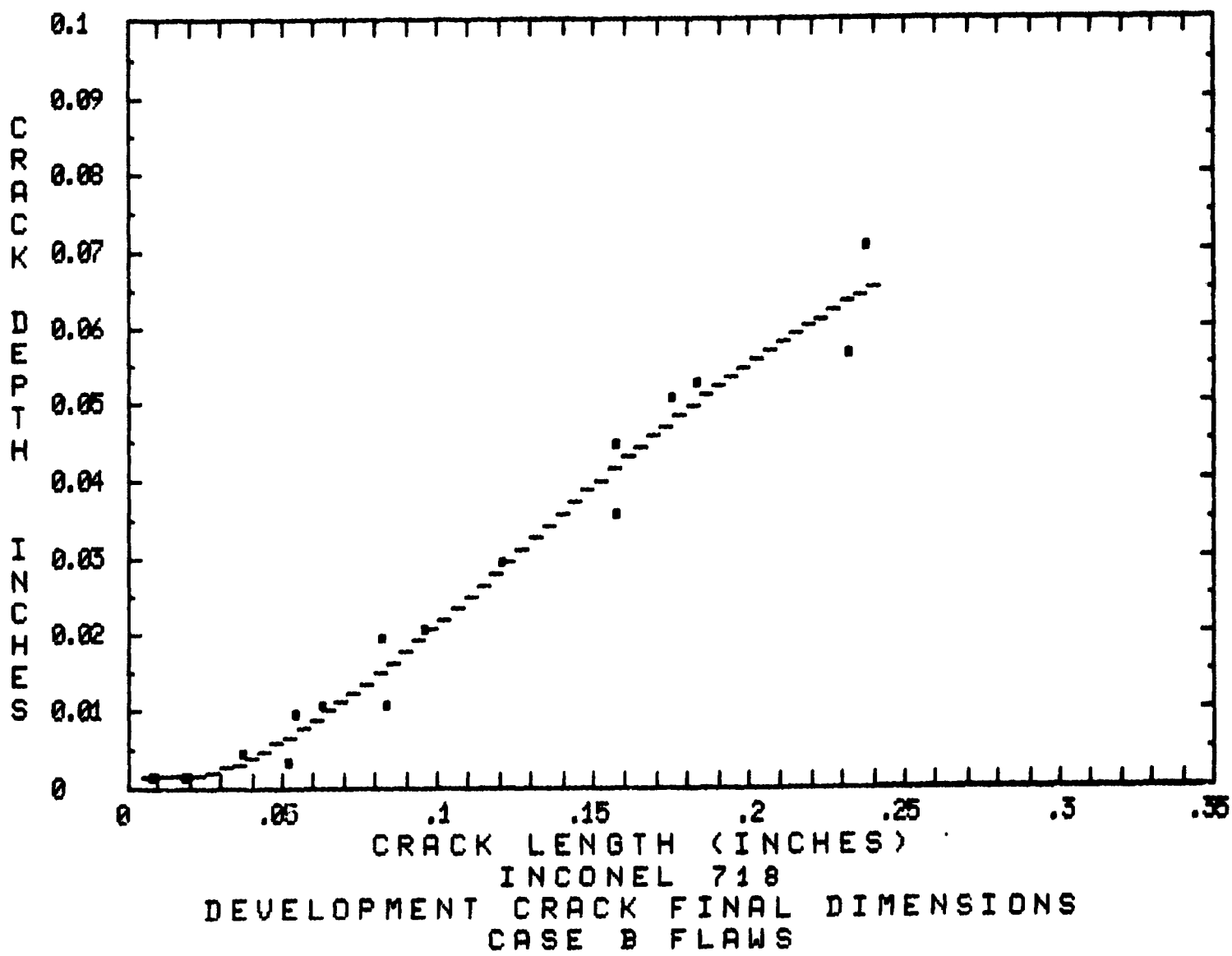Case A Development Flaws

Figure 5 - Final Dimensions (After Machining) of Inconel 718
Case B Development Flaws

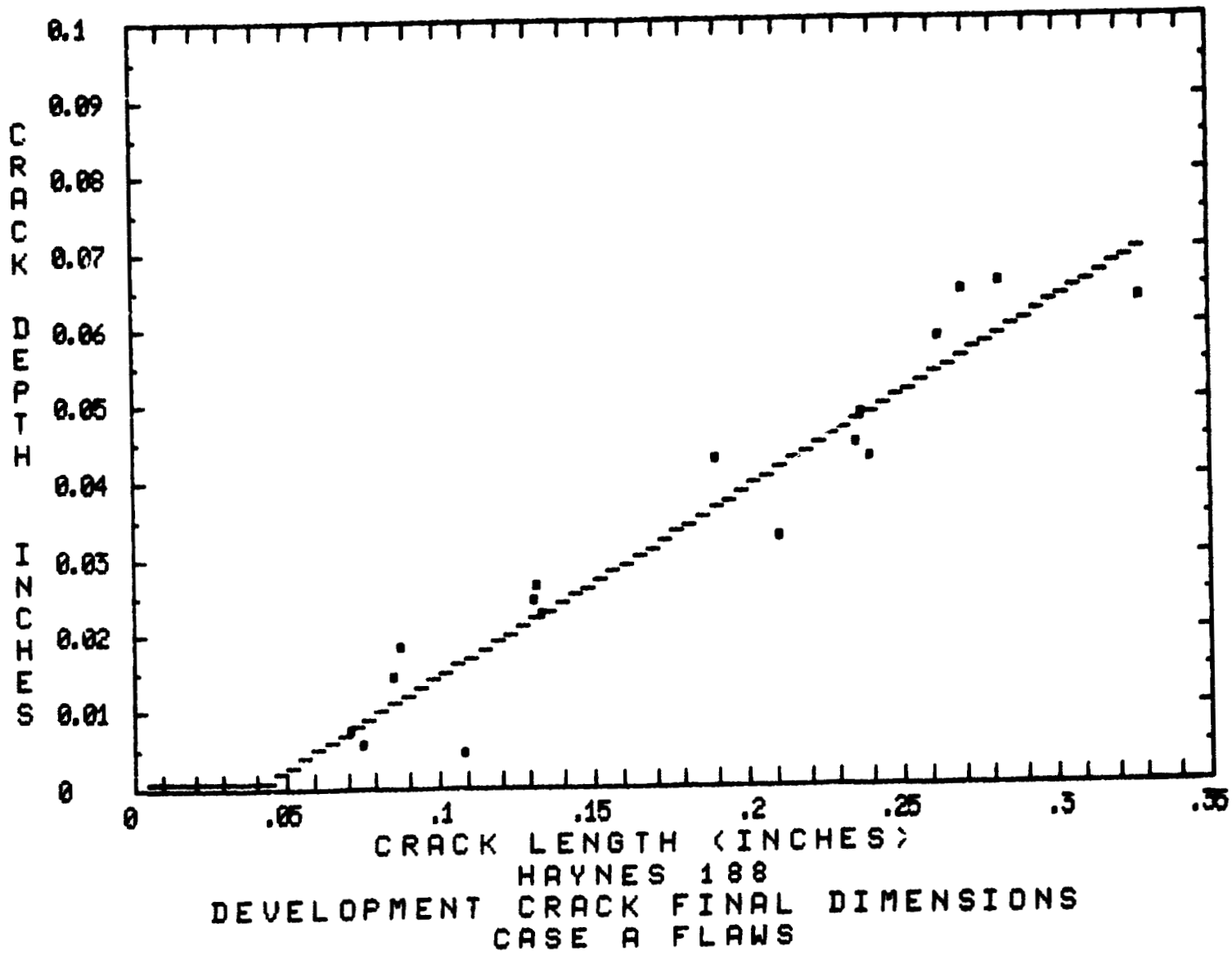Figure 6 - Final Dimensions (After Machining) of Haynes 188
Case A Development Flaws

CRACK DEPTH INCHES

CRACK LENGTH (INCHES)
HAYNES 188
DEVELOPMENT CRACK FINAL DIMENSIONS
CASE B FLAWS
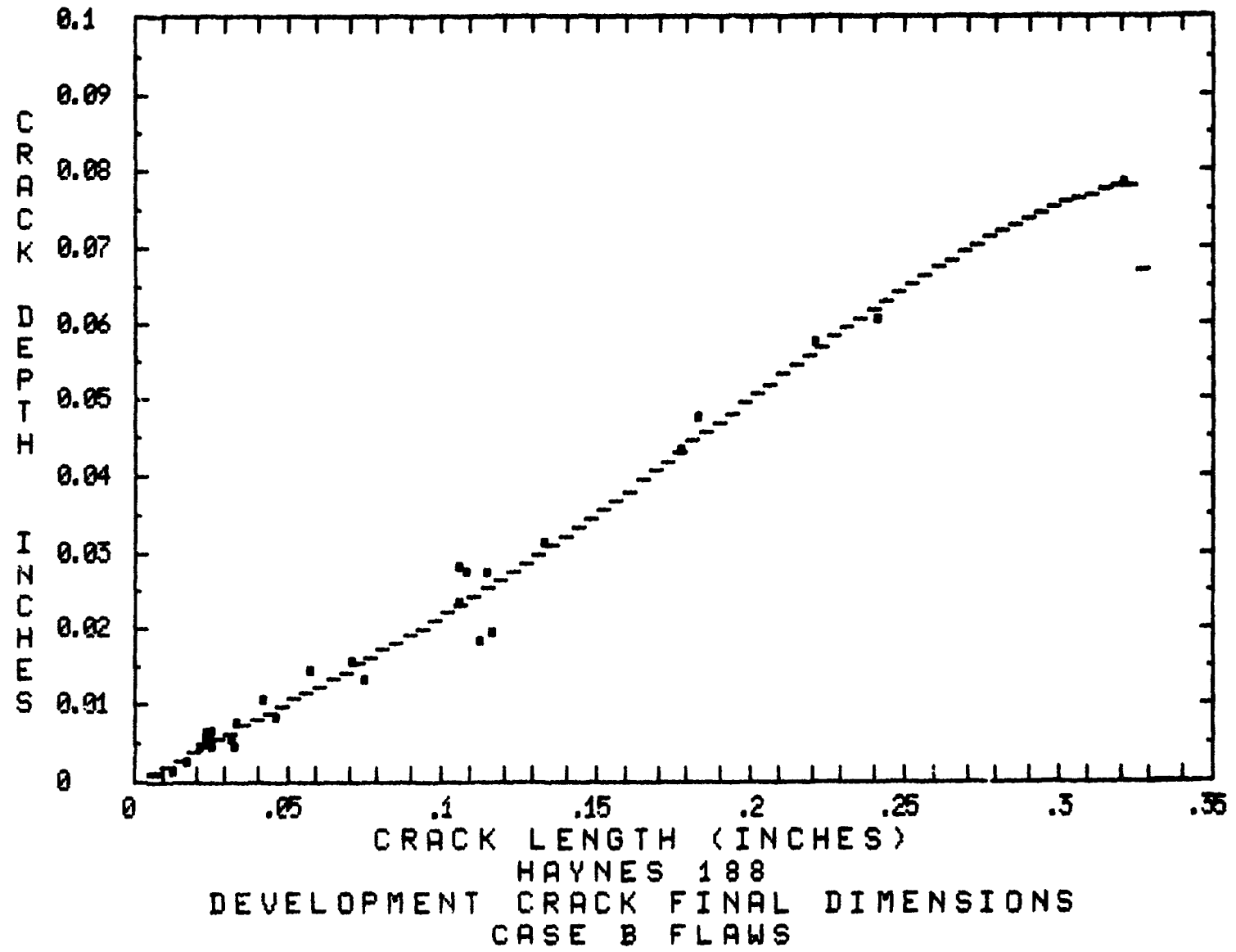
Figure 7 - Final Dimensions (After Machining) of Haynes 188
Case B Development Flaws

The average aspect ratios for the Haynes 188 Case A flaws were calculated using only those development flaws grown with the modified (longer) starter notches. As seen, the differentiation between the Case A and Case B aspect ratios in the Inconel 718 was less than anticipated due the material's fatigue response. The aspect ratios obtained in the Haynes 188 specimens were nearer the target values of 0.15 and 0.25. However, at the longer crack lengths, the Case A flaw aspect ratios begin to increase above 0.15 due to the material tendency for cracks to grow at a (delta) a/2c of 0.3.

C. Introduction of Fatigue Cracks in Test Specimens

Cracks were initiated and grown in the Inconel 718 and Haynes 188 test panels using the information gained during the crack growth procedure development. A total of 281 confirmed fatigue flaws were grown in ninety-five Inconel 718 panels. Fifteen unflawed panels were included at random in the panel numbering system to yield a total of 110 panels Eighty-five Haynes 188 panels were prepared containing 284 confirmed flaws. Seventeen unflawed panels were included at random yielding 102 total Haynes 188 specimens. For both alloys, the number of cracks in the flawed specimens was varied from one to five, with the flaws located on either the panel front or back, to randomize the inspection results. The distribution of the cracks in each crack length range for both alloys are shown in Table 5.

Table 5
Final Flaw Distribution by Flaw Length Range

| Crack Length | Number of Flaws | |
Range (Inch)	Inconel 718	Haynes 188
< 0.010	2	1
0.010 - 0.050	63	65
0.051 - 0.100	60	68
0.101 - 0.150	60	68
0.151 - 0.250	60	60
> 0.250	36	22
TOTALS	281	284

The panels were identified by electrochemically etching
serial numbers on the lower left-hand corner of each panel
using a I7xxx numbering system for the Inconel 718 panels and a
Hlxxx system for the Haynes 188 specimens.

D.   Specimen Machining

The cracked specimens were mechanically machined on both
sides to remove the starter notches and to produce surface
finishes representative of typical aerospace machining
practices. The final specimen configuration is shown in Figure
8.

Machining was done with a .ace mill and shell cutter so
multiple 2-1/2 inch swaths were cut across the Haynes 188
panels. A 4 inch cutter was utilized on the Inconel 718
specimens. For the Haynes 188, a 64-rms surface finish or
better was produced at a spindle speed of 80 rpm and a table
feed of 3 inches (7.62 cm) per minute. The Inconel 718 was
machined at a spindle speed of 95-rpm and a table feed rate of
3-4 inches (7.62-10.2cm) per minute and mechanically buffed to
produce a surface finish of 125-rms or better. This method of
machining produced a surface finish such that the fatigue flaws
were located at random with respect to the machining marks.
This variation of crack orientation with respect to the
machined surface finish provides further randomization of the
inspection opportunities.

E.   Specimen Characterization

The specimens were vapor-degreased and ultrasonically
cleaned in 1,1,1 trichloroethane following machining. The
specimens were then etched to remove the material smeared
during the machining operation. Both the Inconel 718 and
Haynes 188 panels were etched using 40% hydrochloric acid
(HCl), 40% deionized water, and 20% hydrogen peroxide. This
etchant provided sufficient material removal, and an acceptable
surface finish at an easily controlled rate. In addition,
Lepito etch (ASTM E340), an etchant comprised of hydrochloric
acid, nitric acid, iron chloride, ammonium sulfate and
demineralized water was tested and found acceptable for etching
the Inconel 718 panels. Trial Haynes 188 panels were also
successfully etched during testing using 10% oxalic acid
electrolytically, and 50% hydrochloric acid and 50% hydrogen
peroxide.
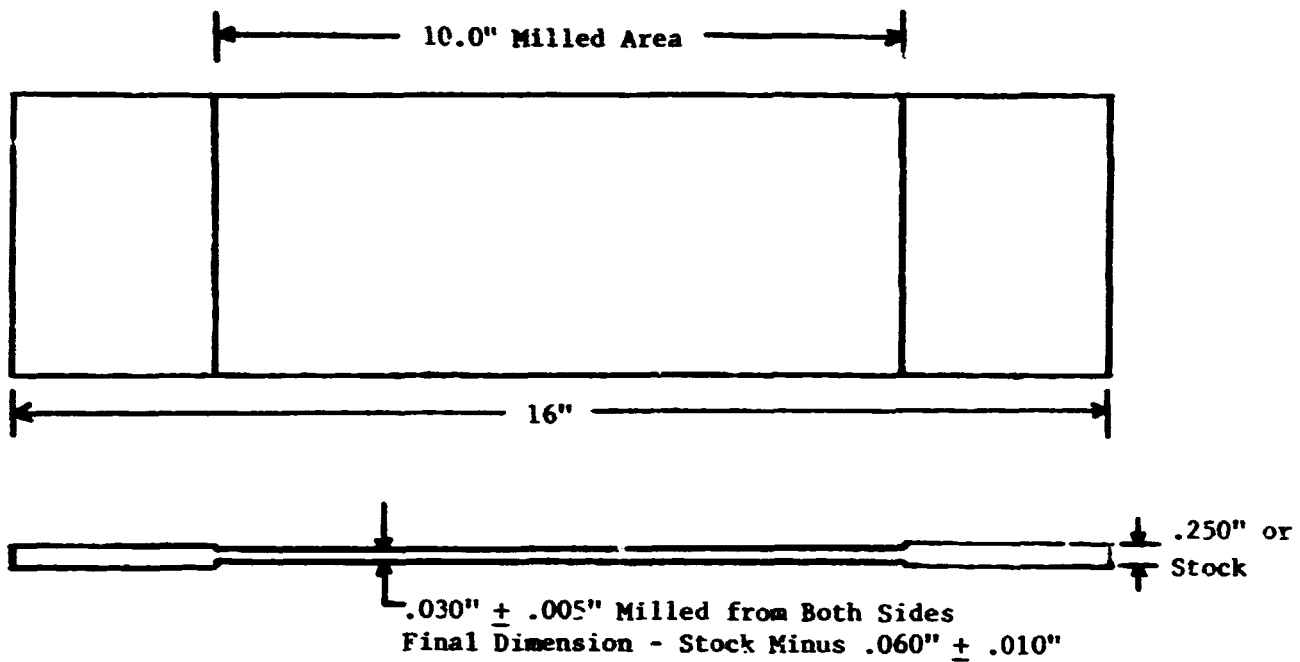
Surface Finish - 125 RMS or Better

Figure 8 - Specimen Configuration for
Inconel 718 and Haynes 188 Flawed Panels

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Flaw location confirmation was accomplished by inspecting each panel in a laboratory environment using a solvent-removable, high-sensitivity fluorescent penetrant (Uresco P-149). For those flaws which were not detected during the initial inspection, an additional spot etch was performed on the area of the panel containing the crack and the area was re-inspected. This procedure was repeated a second time as necessary to verify the flaw location. Precise flaw length measurements were made by loading the panels in bending using a load equal to or less than that used during flaw growth. The flaw area was examined using a stereo-microscope at 20x magnification and the flaw length measured using a reticle with 0.005 inch (.013 cm) divisions. Those flaws which could not be located with either flucrescent penetrant or under load were assumed to have been inadvertently removed during machining.

IV. CLEANING PROCEDURE DEVELOPMENT

An investigation into the effectiveness of several cleaning procedures and solutions was conducted as part of the program to demonstrate the reuseability of the test specimens for NDE reliability studies. The Inconel 718 development specimens were utilized to test various panel cleaning procedures. Prior to fracturing the development specimens to obtain flaw dimensional data, the panels were subjected to several inspection-cleaning cycles to evaluate cleaning procedures.

A. Specimen Cleaning Test Procedures

The panels were processed through a production fluorescent penetrant inspection using Magnaflux ZL-2A penetrant and examined under blacklight to confirm that penetrant was present in the fatigue cracks. The specimens were then prepared for cleaning by removing any developer on the specimen surfaces by flushing and wiping the surface with water. Diligence should be applied in removing the developer prior to further cleaning because vapor degreasing and ultrasonic cleaning in a solvent are not effective in removing many developers from specimen surfaces. The panel surfaces were cleaned by vapor degreasing in 1,1,1 trichloroethane for 10 to 15 minutes to insure good surface wetability. Care must be exercised to prevent overheating of the specimens during vapor degreasing. Excessive heat can cause drying of the penetrant in the cracks and make removal difficult. Degreasing is not essential and can be omitted if degreasing equipment is not available or, to eliminate the chance for overheating of the specimens.

Ten different ultrasonic cleaning mediums were tested to determine their effectiveness in removing penetrant from the development cracks. The panels were placed in the ultrasonic cleaner for one hour periods and then examined for penetrant remaining in the cracks by reapplying developer and examining under blacklight. If fluorescent crack indications remained, the panel was placed in the cleaner and re-examined after another hour. If no sign of fluorescence remained, the total cleaning time was recorded. Table 6 lists the cleaning solutions evaluated and the total time required for complete penetrant removal from the fatigue cracks. The times listed in Table 6 should be used as guidelines only. The actual time required is dependent on the ultrasonic tank size, the power and frequency of the transducers, and the number and arrangement of the panels in the tank.

Table 6

RESULTS OF PANEL CLEANING
PROCEDURE DEVELOPMENT

SOLUTION	TIME TILL CLEAN	REMARKS
100% ISOPROPANOL	--------	5 HOURS INADEQUATE FOR COMPLETE REMOVAL OF PENETRANT FROM FATIQUE CRACKS
50% FREON- 50% ISOPROPANOL	5 HOURS	--------------
100% TRICHLOROETHANE	5 HOURS	---------------
50% TRICHLOROETHANE 50% ISOPROPANOL	4 HOURS	------------
CHEM-CREST 200 *	--------	ALKALINE DETERGENT IN WATER SOLUTION 6 HOURS INADEQUATE FOR COMPLETE CLEANING
CHEM-CREST 14 *	--------	ALKALINE LIQUID IN WATER SOLUTION 5 HOURS INADEQUATE FOR COMPLETE CLEANING
50% ISOPROPANOL 50% H O-TRISODIUM PHOSPHATE SOLUTION	--------	5 HOURS INADEQUATE FOR COMPLETE CLEANING
MAGNAFLUX ZR-10	---------	HYDROPHILIC EMULSIFIER 5 HOURS INADEQUATE FOR COMPLETE CLEANING
GENESOLV DA +	3 HOURS	BLEND OF TRICHLOROTRIFLUOROETHANE ACETONE, AND NITROMETHANE
GENESOLV 404 +	3 HOURS	BLEND OF TRICHLOROTRIFLUOROETHANE, ACETONE, AND n-HEXANE

* Chem-Crest is a registered trademark of Crest Ultrasonics Corp.

+ Genesolv is a registered trademark of Allied Chemical Corp.

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The crack surfaces were examined under blacklight after the panels had been fractured to confirm complete removal of penetrant by the cleaning process. No traces of fluorescence were found on any of the development crack surfaces after undergoing a complete cleaning cycle.

In general, the solvents were more effective for removing penetrant than the water-base solutions. The most effective solvent examined was Allied Chemical Genesolv DA which is a blend of acetone (9.4%), trichloro- trifluoroethane (90.3%), and nitromethane (0.3%). Genesolv 404 was equally effective but is not considered as stable in the presence of white metals. Both Genesolv solvents can be used for either degreasing or ultrasonic cleaning. Appendix B documents the cleaning procedure found most effective for complete removal of penetrant from fatigue cracks and is the recommended procedure for panel cleaning following all penetrant inspections and to remove other incident contamination.

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V. NONDESTRUCTIVE EXAMINATION

A. Selection of Penetrant Materials

The ability of a fluorescent penetrant inspection process to detect tightly closed fatigue cracks is dependent on (1) the penetrating characteristics of the penetrant allowing it to fill the cracks, and on (2) its visibility after processing. The reliability of the complete process is dependent on its tolerance to variations. Since a liquid penetrant inspection is the result of a multi-step process, the outcome is dependent, in part, on the host material, the penetrant materials selected, and control of the individual inspection processes.

As a result of previous work performed for NASA Johnson Space Flight Center (Refs. 2,3), Uresco P-149 was selected as the fluorescent penetrant to be used on for the inspection of the Inconel 718 specimens. P-149 was used in production applications on the Saturn/Apollo programs and is currently in use on some NASA Space Transportation System (STS) components. The test specimens were treated as high volume production hardware, hence post-emulsification processing was utilized. Previous reliability studies performed using P-149 as a post-emulsifiable penetrant with Uresco E-153 lipophilic emulsifier and D-499C nonaqueous wet developer have shown this family of materials to have excellent sensitivity for detecting small fatigue type cracks (Ref. 4). This group of materials are acceptable per MIL-I-25135 and MIL-I-6866.

B. Penetrant Inspections

The fluorescent penetrant inspection procedure that was utilized is detailed in Appendix C. A total of three independent inspections were performed by qualified inspectors on the Inconel 718 parels numbered I7001 - I7102. Panels I7103 - I7110 were not included in the specimen inspections.

Three penetrant inspections were performed on the Haynes 188 panels numbered H1001 - H1102 utilizing three different penetrant systems and the same inspector. In addition to using the Uresco P-149, E-153, and D-499C family of materials for the first Haynes 188 inspection, Magnaflux ZL-37 fluorescent penetrant was used in combination with ZR10A hydrophilic remover and ZP9B nonaqueous wet developer for the second inspection.
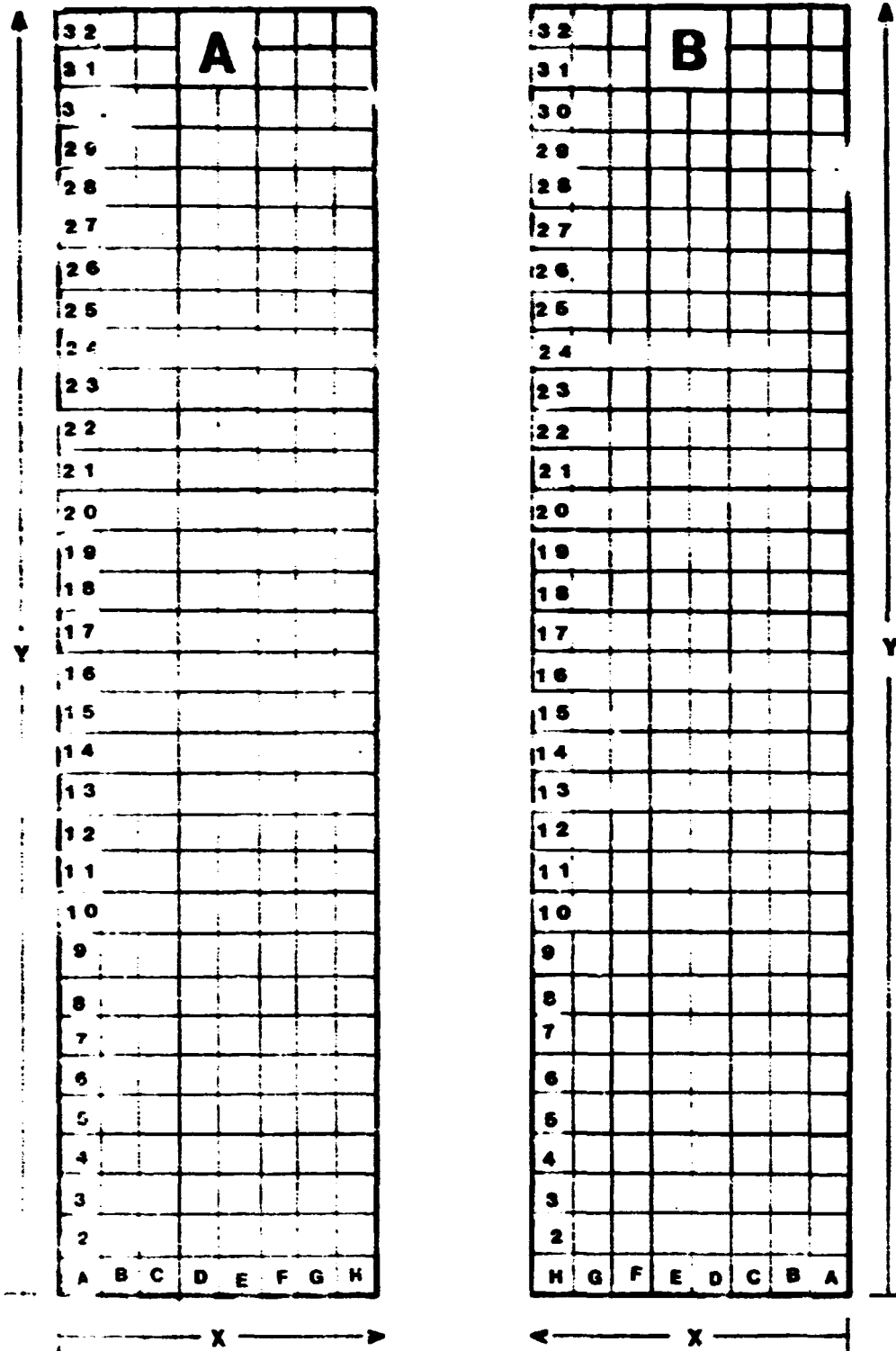
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The third inspection was performed using Sherwin I-319 water
wash fluorescent penetrant and Sherwin Dubl-Chek D-100
nonaqueous wet developer. All three penetrant systems utilized
are acceptable per MIL-I-25135 and MIL-I-6866.

The results of the inspections were documented and input
directly into a microcomputer for disc storage of the data.
The data collected during the inspections included the panel
number, the panel side and x-y coordinates of the flaw
locations and the approximate flaw lengths (flaw lengths were
not documented for Haynes 188 inspections 2 and 3). The
lengths were determined by measuring the fluorescent
indications under a stereo microscope at 20x magnification with
a reticle marked with .005 inch (.013 cm) divisions. The x-y
coordinates of the flaw locations were determined by placing a
clear acetate grid over the panel surface. Figure 9 shows
diagrams of the coordinate grids utilized.

A separate grid was used for the front and back sides of
the panels as shown. Computer listings of the inspection data
taken are included in Appendix D.

Following each inspection, the panels were thoroughly
cleaned for a minimum of eight hours using the technique
developed in the cleaning procedure investigation portion of
this program and documented in Appendix B.

FRONT SIDE   BACK SIDE

Figure 9 - Sketch of Acetate Grids Used for
Documentation of Flaw Locations

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Upon completion of the inspection sequences, all overcalls were documented and the specimens were reinspected in the laboratory to determine the cause of the called indications. This inspection was made using Uresco P-149 as a solvent removable penetrant. In those cases where the suspected overcalls were determined to be cracks, this information was added to the actual flaw data and included as such in all data analysis. Those indications determined to be overcalls were caused primarily by machining marks in the Inconel 718 panels and by small pits in the Haynes 188 specimens. The total number of actual overcalls (non-crack) for each inspection is listed in Table 7.

Table 7
Overcall Totals for Specimen Inspections

Inspection #	Total Number of Overcalls
Inconel 718 #1	8
Inconel 718 #2	3
Inconel 718 #3	7
Haynes 188 #1	3
Haynes 188 #2	6
Haynes 188 #3	13

VI. DATA ANALYSIS

A. Actual Crack Data Documentation

The actual crack data collected during specimen characterizaton was input into the computer for compiling and analysis. An actual data file was assembled by ordered panel number and crack numbers. This file was used as the basis for all data sorting and analyses. A tabulation of the actual crack data and related crack information is located in Appendix E for the Inconel 718 specimens and in Appendix F for the Haynes 188 specimens. The information contained in the crack lists is self explanatory with the exception of two items. The column labeled "G.O." gives the panel grain orientation. The column labeled "Case" indicates the starter notch shape used to grow the flaws. The Case A flaws were grown with a long shallow notch to produce an a/2c of approximately 0.15 and the Case B flaws were grown with a short deep notch to produce an a/2c of approximately 0.25. In both cases, the aspect ratio tends to decrease at shorter flaw lengths, due to the flattening out of the flaw that occurs near the bottom of the crack. The crack depths listed in the table are approximate and were calculated by applying regression analysis to the crack dimensional data obtained during crack growth procedure development. The equations of the polynomials used to calculate the crack depths are shown below:

Inconel 718

Case A:
$$D = 0.0151 - 0.7940L + 14.7906L^2 - 77.0038L^3 + 134.1791L^4$$

Case B:
$$D = 0.0016 - 0.0962L + 4.4730L^2 - 17.7775L^3 + 22.5369L^4$$

Haynes 188

Case A:
$$D = -0.0101 + 0.2443L$$

Case B:
$$D = -4.69 \times 10^{-4} + 0.2133L - 0.2647L^2 + 4.2378L^3 - 9.7024L^4$$

Where D = the calculated crack depth, and
      L = the actual crack length.

B. Data Ordering

The information contained in the actual crack list was sorted and ordered by decreasing actual crack length and by decreasing estimated crack depth. These sorted data were assigned file numbers and were stored on disc for use in subsequent statistical analyses. The sorted crack data lists are found in Appendices E and F.

C. Inspection Reliability

The sorted crack data were analyzed to determine the reliability of each of the inspection sequences by determining the least group of thirty existing (real) flaws that were detected. The boundary flaw lengths comprising this flaw group for each inspection are listed in Table 8.

Table 8
Inspection Reliability
Least Group of Thirty Flaws Detected

| | Least Group of 30 Flaws Detected |
Inspection Number	Boundary Flaw Lengths (inches)
Inconel 718 #1	0.027 – 0.057
Inconel 718 #2	0.073 – 0.100
Inconel 718 #3	0.034 – 0.060
Haynes 188 #1	0.025 – 0.040
Haynes 188 #2	0.040 – 0.054
Haynes 188 #3	0.073 – 0.095

In most cases individual flaws were not detected which exceeded the lower bound of these flaw groups. It was felt however, that these misses were individual cases caused by human error and were not statistically relevant or indicative of the true inspection capability. The above boundaries were determined by the smallest group of thirty consecutive flaws that were detected.

Those overcalls (false calls) exceeding the upper bound of the
least group of thirty flaws detected were also documented and
are listed in Table 9 by inspection number.

Table 9
Overcalls Exceeding the Upper Bound of the
Least Group of Thirty Flaws Detected

Inspection Number	Number of Overcalls Exceeding the Upper Bound of the Least Group of Thirty Flaws Detected
Inconel 718 #1	1
Inconel 718 #2	0
Inconel 718 #3	1
Haynes 188 #1	1

Flaw indication lengths were not documented on Haynes 188
inspections #2 and #3 so false call indication lengths were not
available.

D.   Statistical Analysis

In addition to the above basic analysis, more formal
traditional reliability methods were applied to establish
detection probabilities from the Inconel 718 and Haynes 188
panel inspection data. Reliability is concerned with the
probability that a failure will not occur when an inspection
method is applied. One of the ways to measure reliability is
to measure the ratio of the number of successes (finds) to the
number of trials (total number of cracks). This ratio
multiplied by 100% yields an estimate of the reliability of an
inspection process and is termed the point estimate. A point
estimate is independent of sample size and may or may not
constitute a statistically significant measurement. A
statistically significant analysis must take into account both
the sample size and the success of the observations in the
sample.

If we assume a totally successful inspection process (no
failures) we may use standard reliability tables to select a
sample size. A 95% confidence level was selected for
processing the individual Inconel 718 and Haynes 188 inspection
results. For data analysis at a 90% reliability level, 30
successful inspection trials with no failures are required to
establish a valid sampling and hence a statistically
significant data point. For large crack sizes where detection
reliability would be expected to be high, this criteria would
be reasonable. For smaller crack sizes where detection
reliability would be expected to be lower, the required sample
size to meet the 90% reliability / 95% confidence level would
be very large if not infinite.

E.   Calculation of Confidence Limits

To establish a reasonable sample size and to maintain some
continuity of data, the sample size was held constant at 30 NDT
trials for all crack lengths. Confidence limits were then
applied to the data generated to provide a basis for comparison
and analysis of detection successes, and to provide an estimate
of the true proportion of cracks of a particular size range
that can be detected.

Confidence limits are statistical determinat.. ⅃ based on
sampling theory and are boundaries within which we expect the
true reliability value to be if an infinitely large sample were
to be taken.

The method that is used to determine confidence limits is
dependent upon the distribution of whatever characteristic that
is being evaluated. Data based upon discrete success/failure
criteria such as fluorescent inspection results are best
described statistically by applying the binomial distribution
(Ref. 5). The normal, Chi-square and Poisson distributions are
sometimes used as approximations to the binomial distribution
and are selected on the basis of available sample size.

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The data available from the Inconel 718 and Haynes 188 panel inspections were suitable for application of the binomial distribution as described by Yee et al (Ref. 6) in an independent NASA program, to find the lower or one-sided confidence limit based on the proportion of successes in each sample group (point estimate). The lower confidence level, P was obtained by solving the equation:

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

Where G is the confidence level desired,
N is the number of tests performed,
n is the number of successes in N tests,
And P is the lower confidence level.

F.   Data Plotting

Probability of Detection (POD) curves were plotted for the individual inspection results and for the combined inspection data. The statistics and plotting routine software utilized were developed on previous reliability programs (Ref. 7). The plots were generated by referring to the tables of ordered values of actual flaw dimensions. Starting at the longest crack length (deepest crack depth), we counted down 30 inspection observations and calculated a point estimate of detection probability (successes divided by trials). A single data point was plotted as an "x" at the largest crack length (depth) in the group of 30. This plotting technique biases the data in the conservative direction. The lower confidence limit at a 95% confidence level (G=0.95) was calculated for this data group of 30 cracks and plotted as a "▫" at the largest crack length (depth) in the group.

The process is then repeated by eliminating the largest
crack in the group and counting down the next 30 observations,
calculating the point estimate and confidence limit and
plotting at the largest crack length in this next data group.
The process is repeated until there are no longer 30
observations remaining to make up the required number of
trials. This overlapping sampling method is applicable since
all observations are independent and hence may be included in
any data sampling group. An added advantage is the "smoothing
of the curve" that results from such a plotting technique.

Plots of detection probabilities for the three Inconel 718
panel inspections and the three Haynes 188 inspections are
shown in Figures 10-21. The data has been plotted by both
crack length and by estimated crack depth for each inspection.
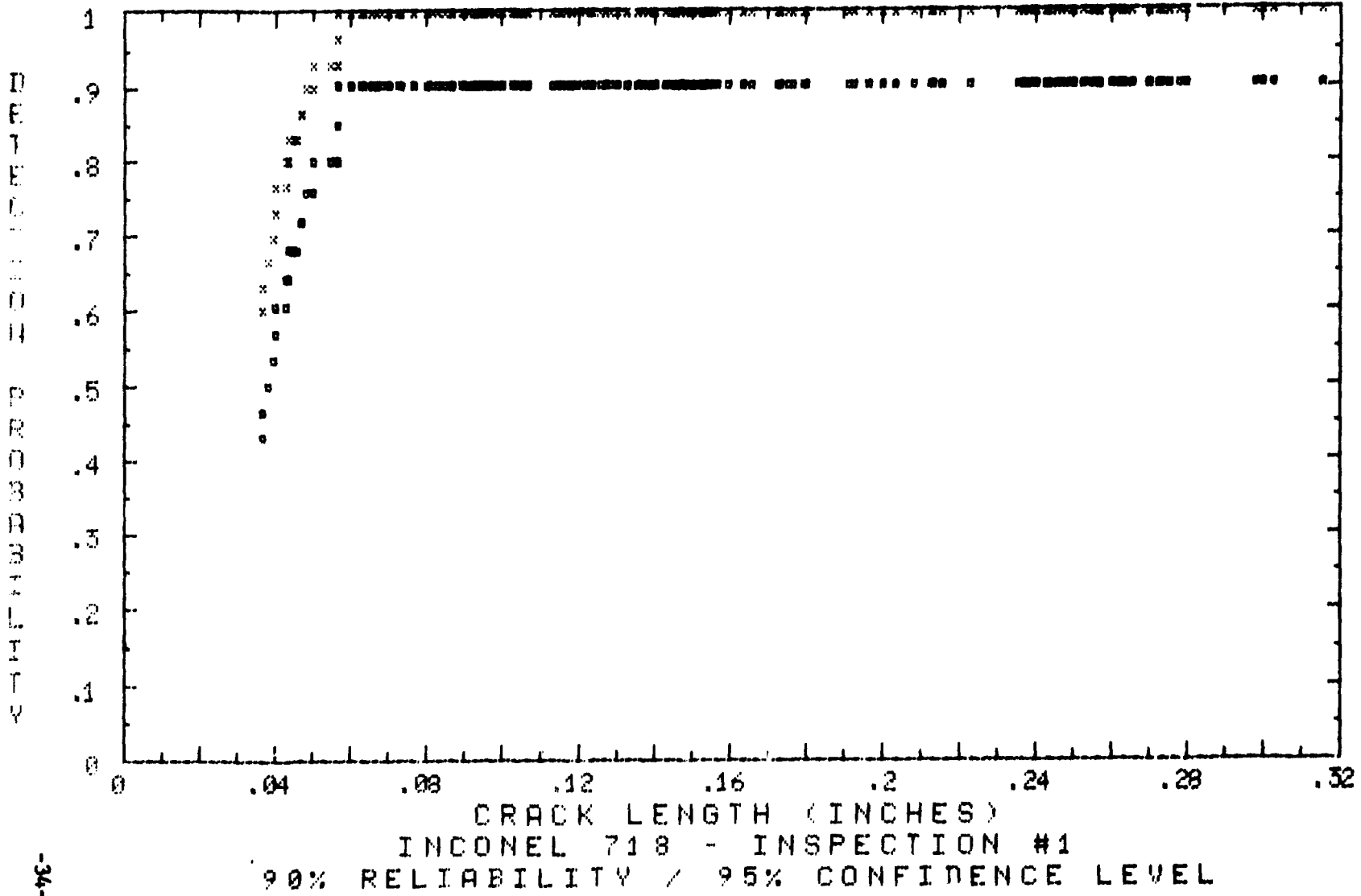
Figure 10 - Crack Detection Probability of Inconel 718 Penetrant Inspection #1.

EST. CRACK DEPTH (IN.)
INCONEL 718 - INSPECTION #1
90% RELIABILITY / 95% CONFIDENCE LEVEL
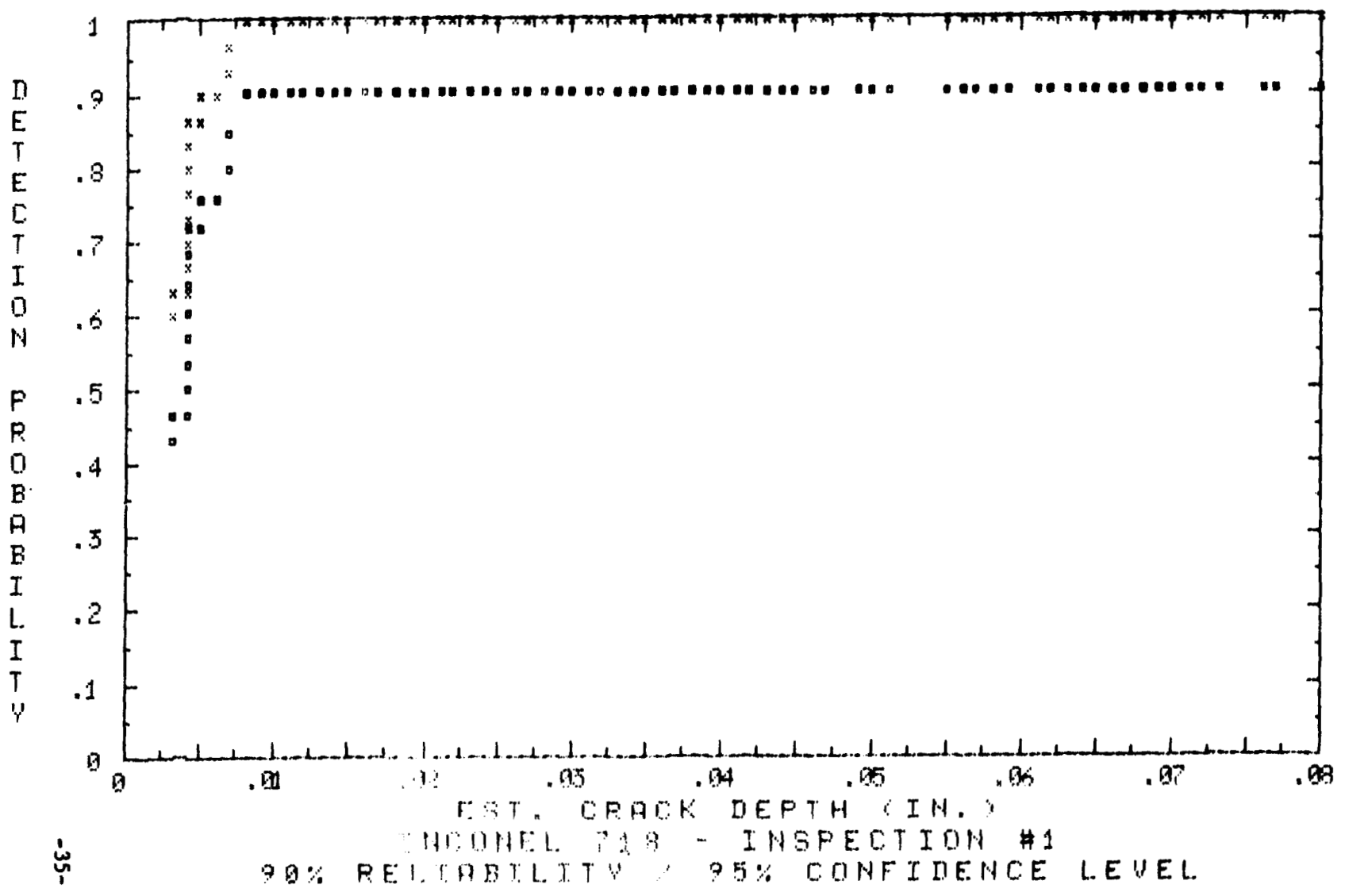
Figure 11 - Crack Detection Probability of Inconel 718 Penetrant Inspection #1.
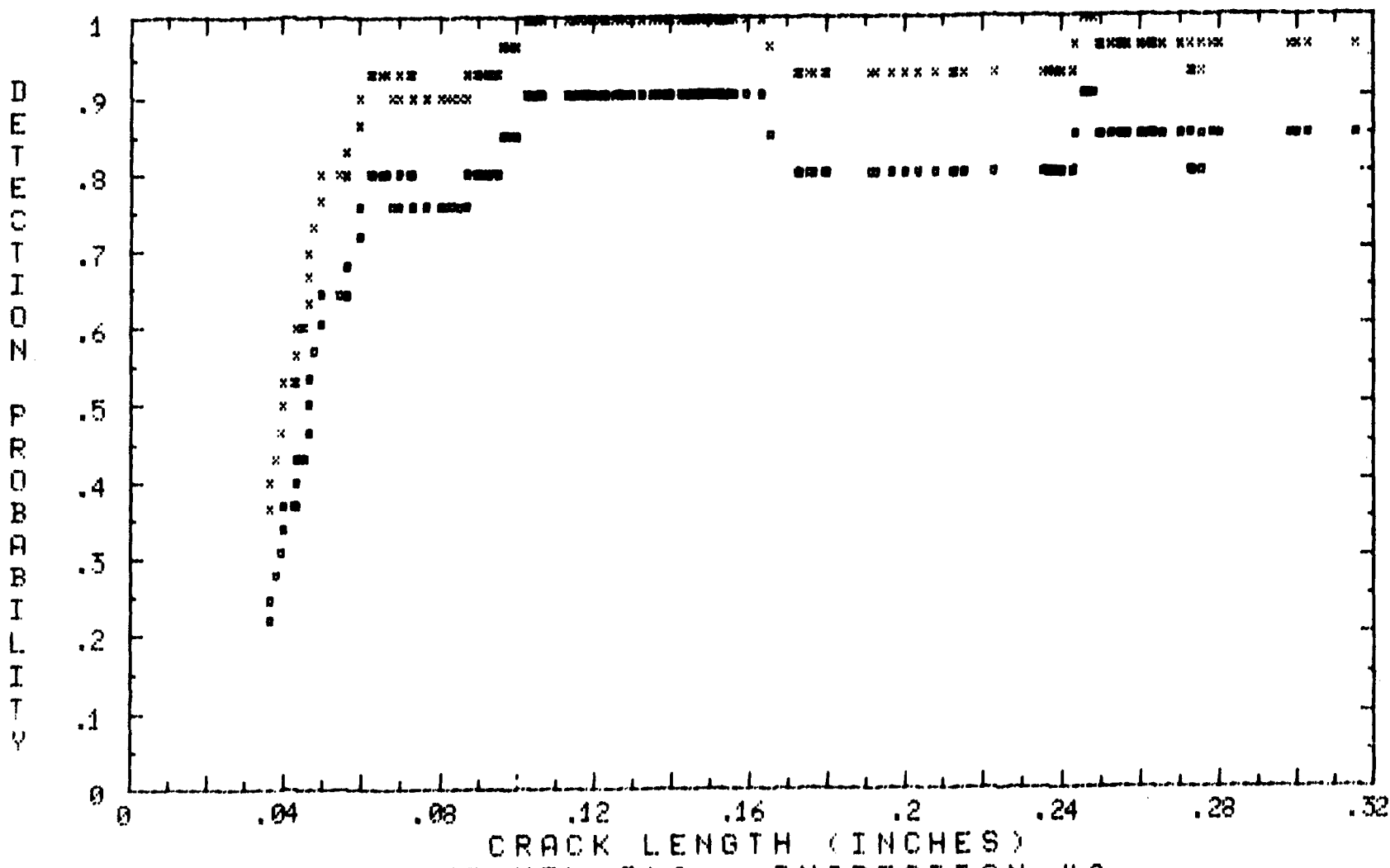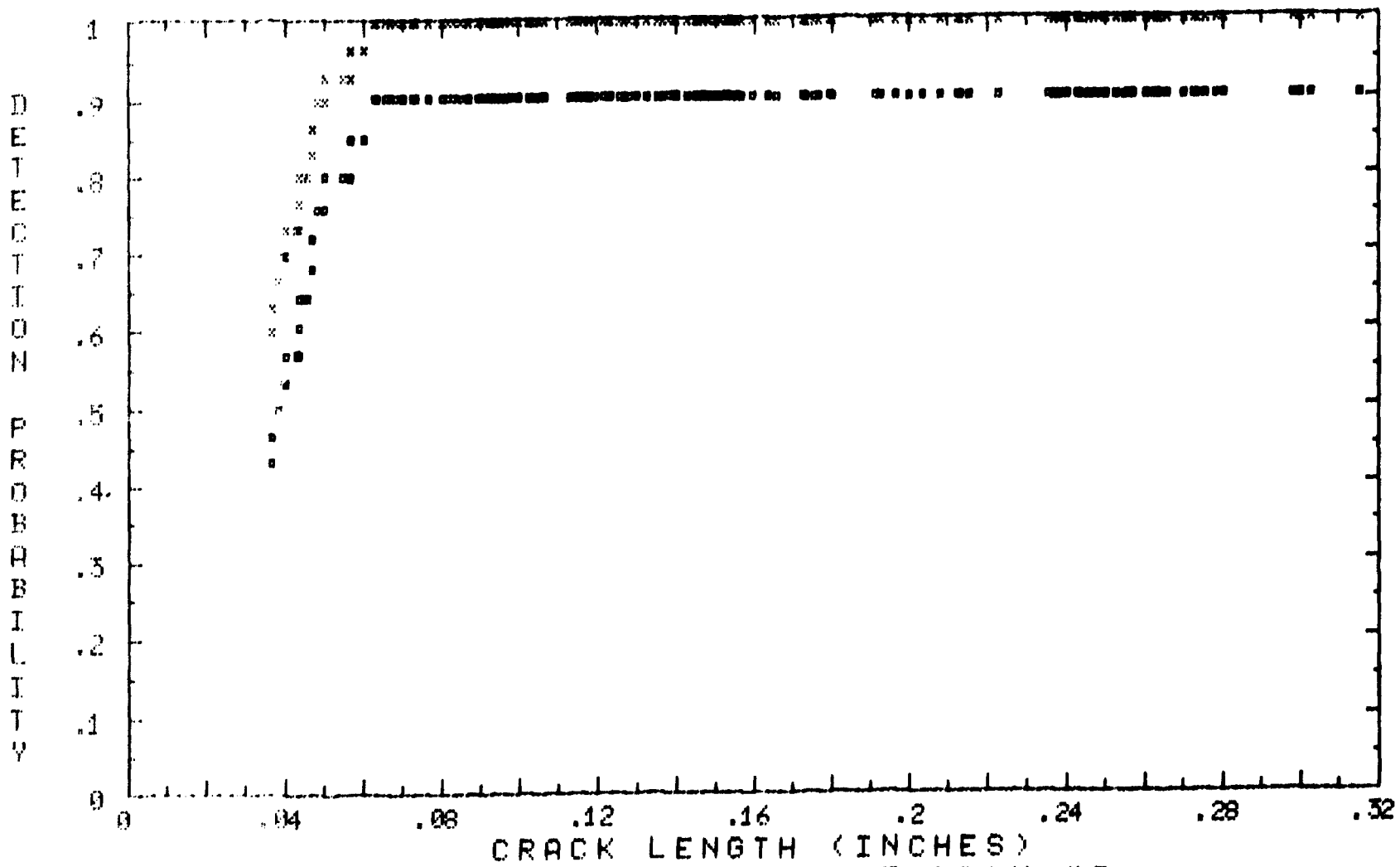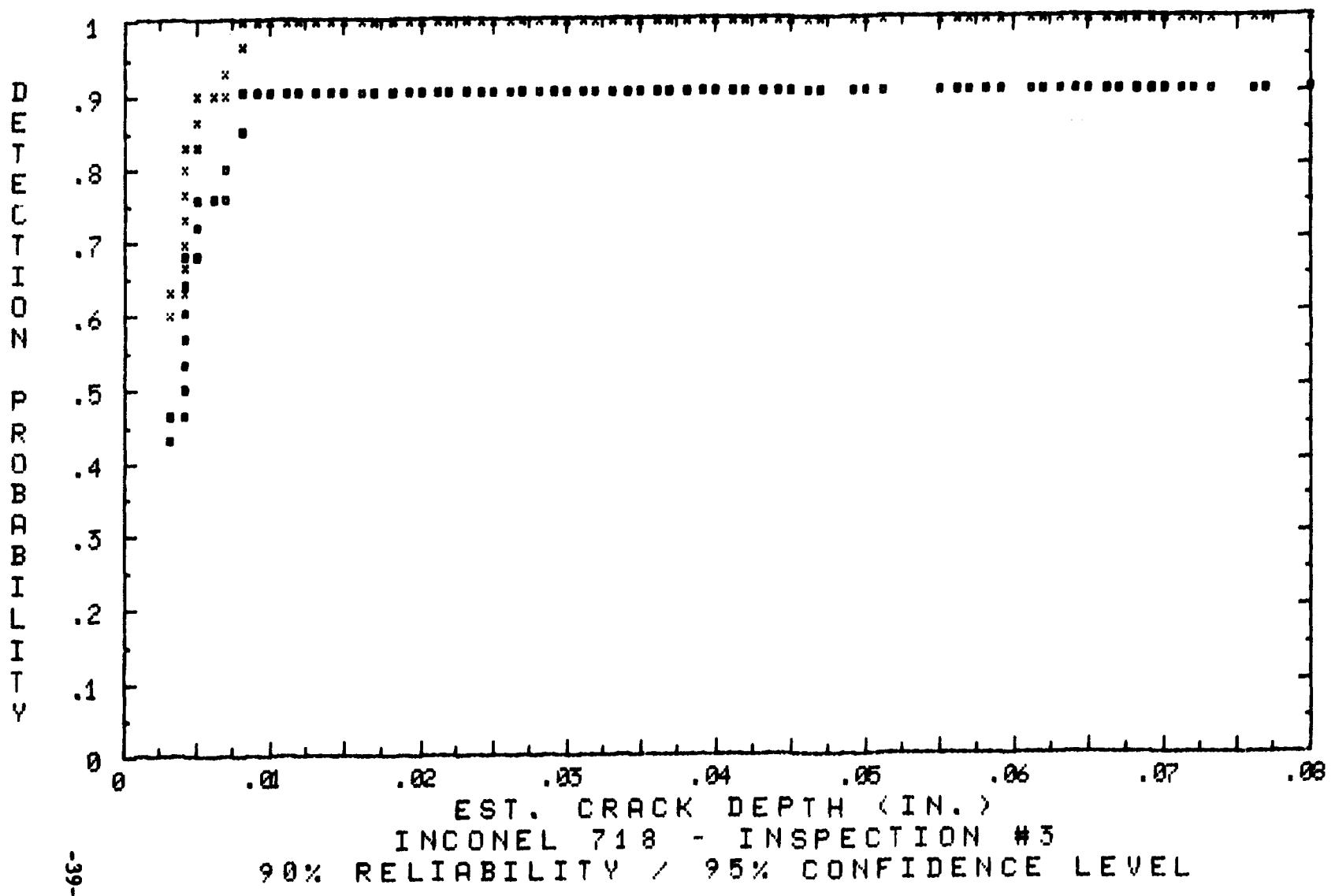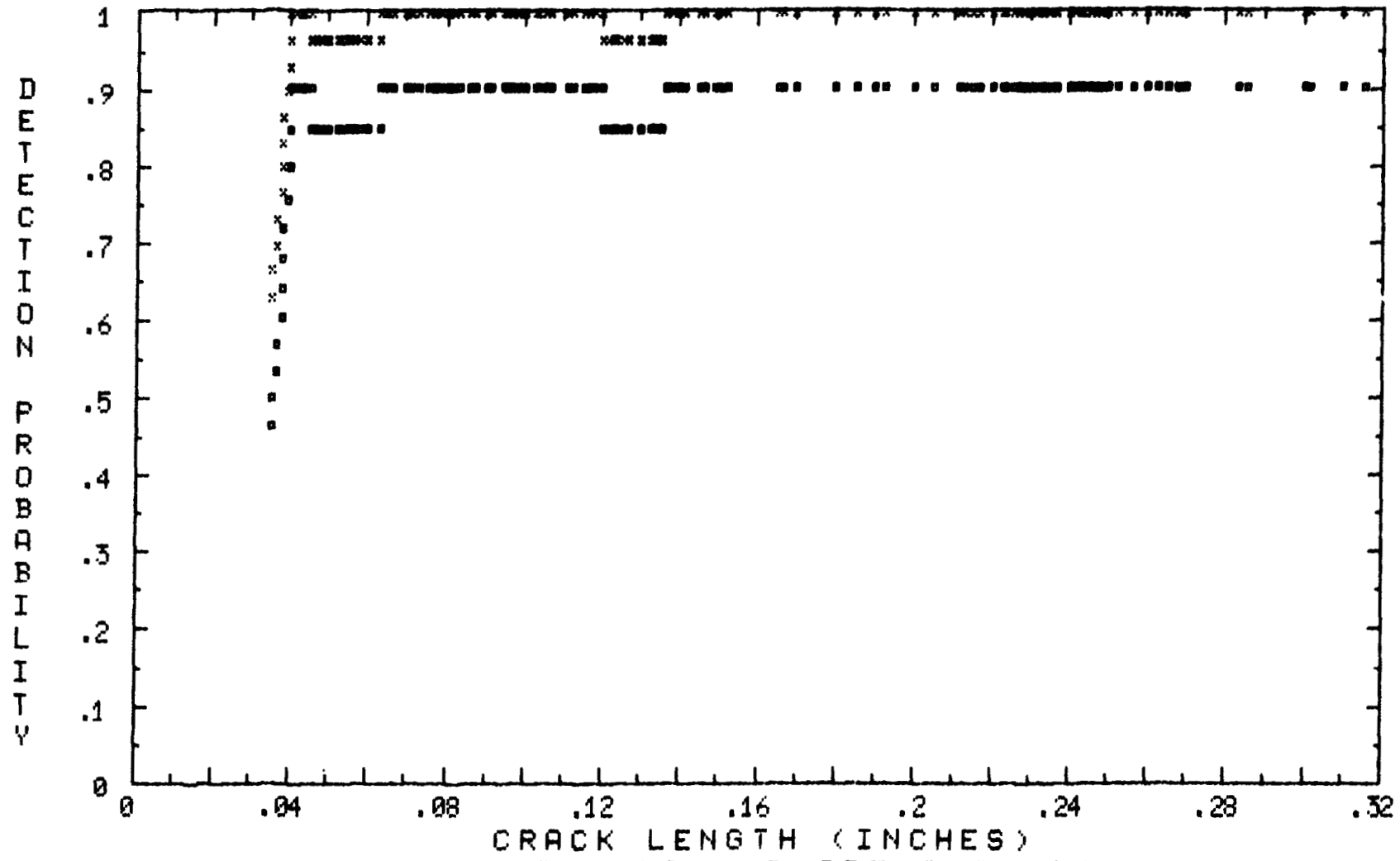
CRACK LENGTH (INCHES)
INCONEL 718 - INSPECTION #2
90% RELIABILITY / 95% CONFIDENCE LEVEL

Figure 12 - Crack Detection Probability of Inconel 718 Penetrant Inspection #2.

Figure 13 - Crack Detection Probability of Inconel 718 Penetrant Inspection #2.

Figure 14 - Crack Detection Probability of Inconel 718 Penetrant Inspection #3.

EST. CRACK DEPTH (IN.)
INCONEL 718 - INSPECTION #3
90% RELIABILITY / 95% CONFIDENCE LEVEL

Figure 15 - Crack Detection Probability of Inconel 718 Penetrant Inspection #3.

Figure 16 - Crack Detection Probability of Haynes 188 Penetrant Inspection #1.

-40-
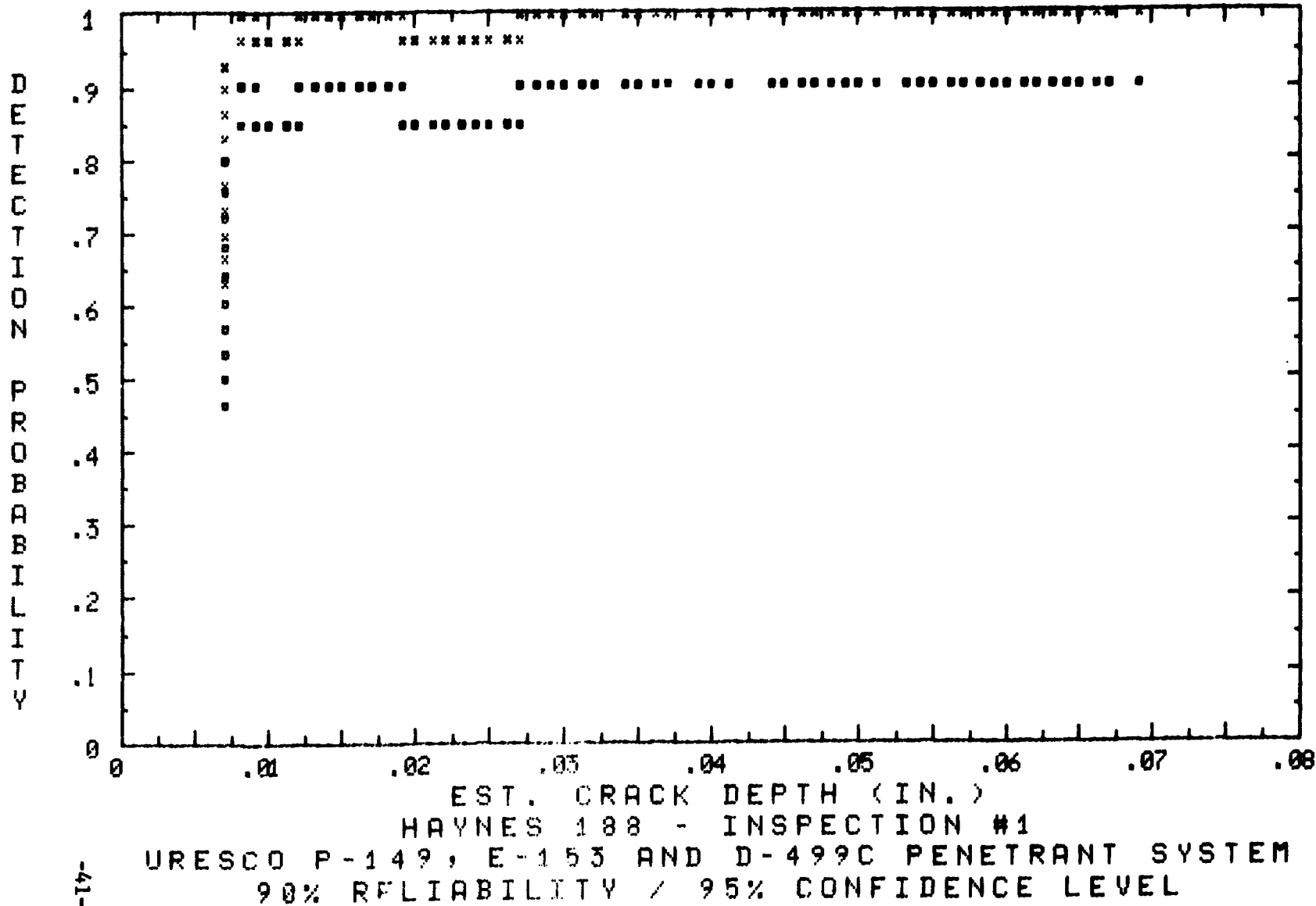
Figure 17 - Crack Detection Probability of Haynes 188 Penetrant Inspection #1.
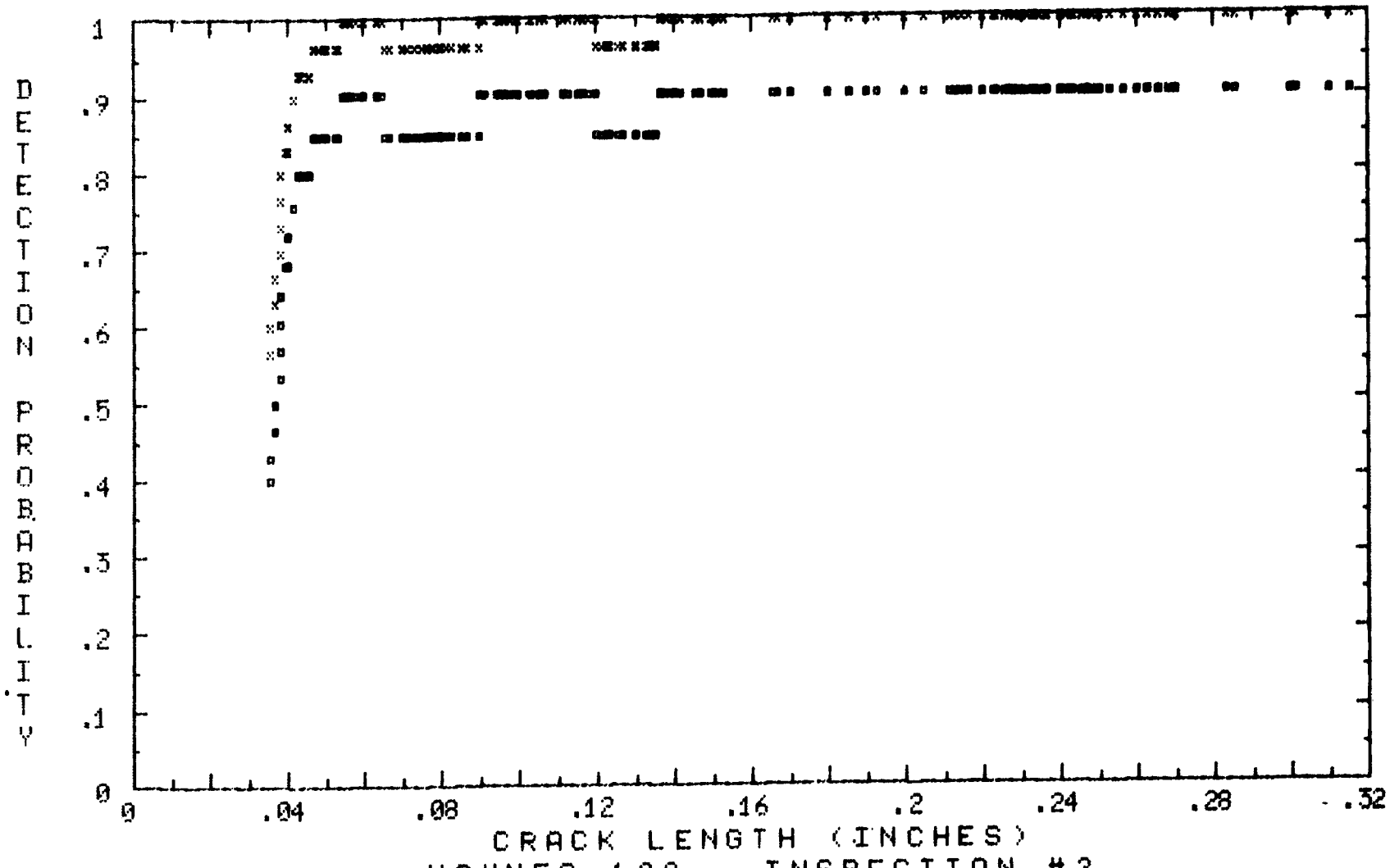
-41-

Figure 18 - Crack Detection Probability of Haynes 188 Penetrant Inspection #2.
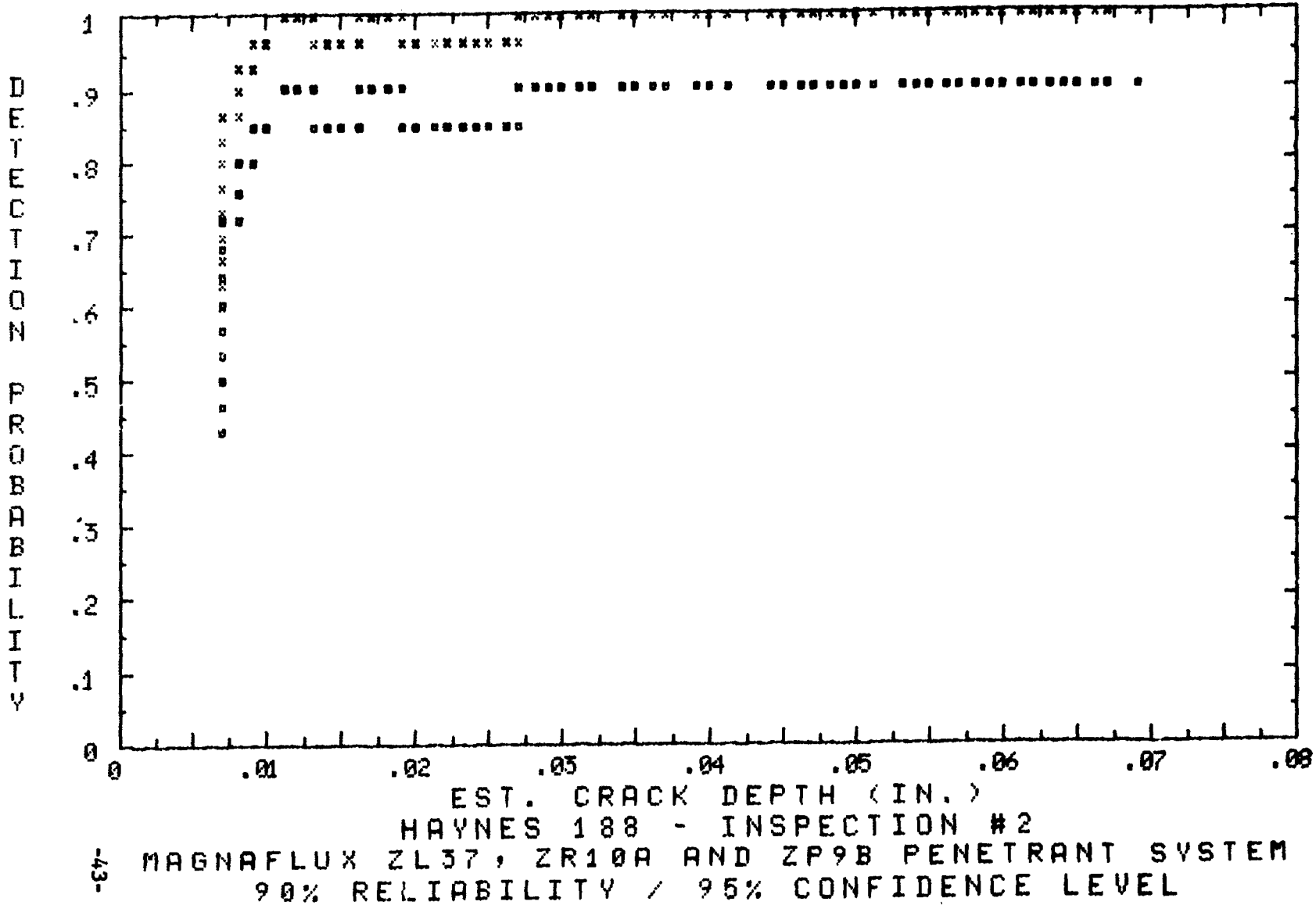
Figure 19 - Crack Detection Probability of Haynes 188 Penetrant Inspection #2.
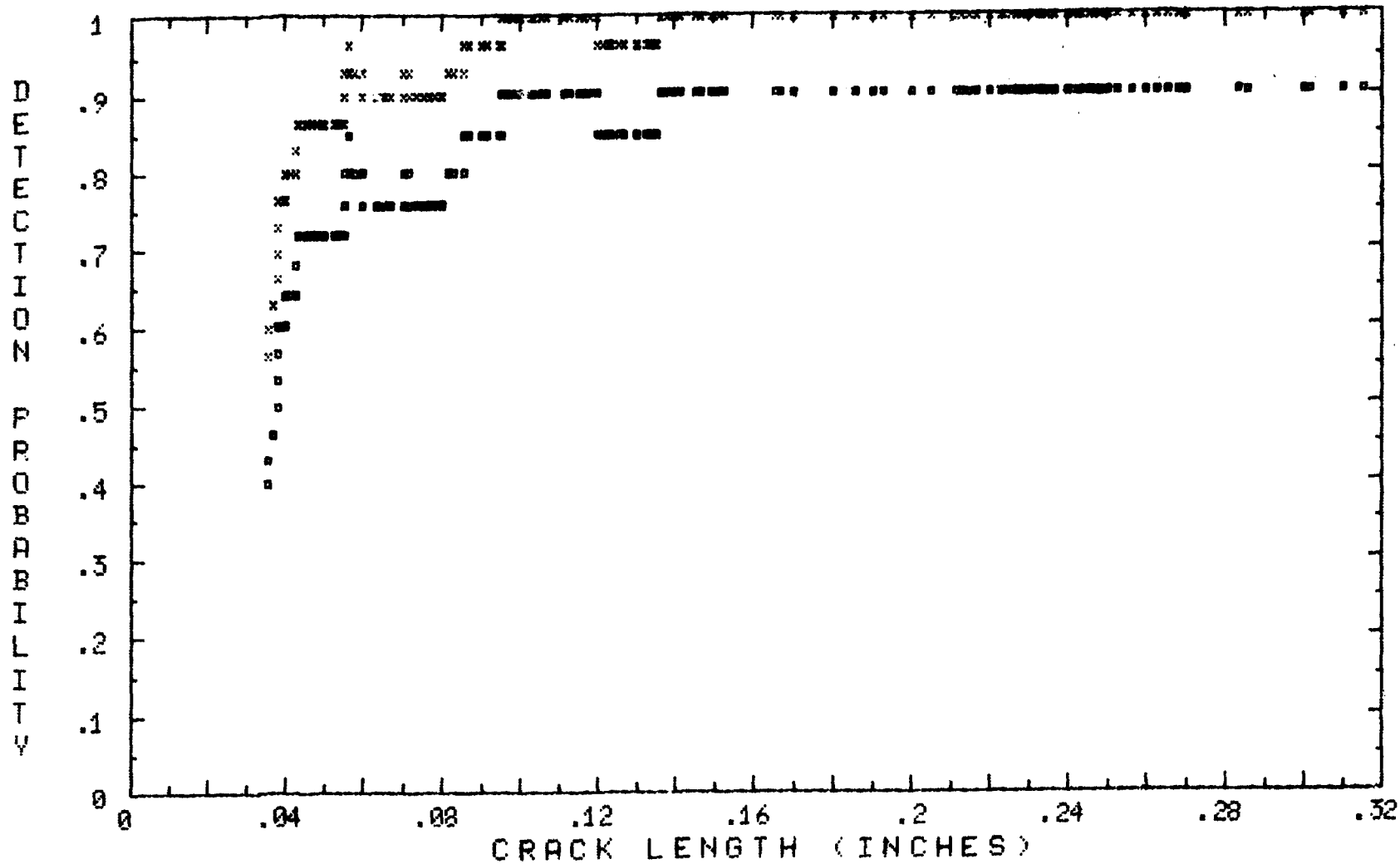
Figure 20 - Crack Detection Probability of Haynes 188 Penetrant Inspection #3.
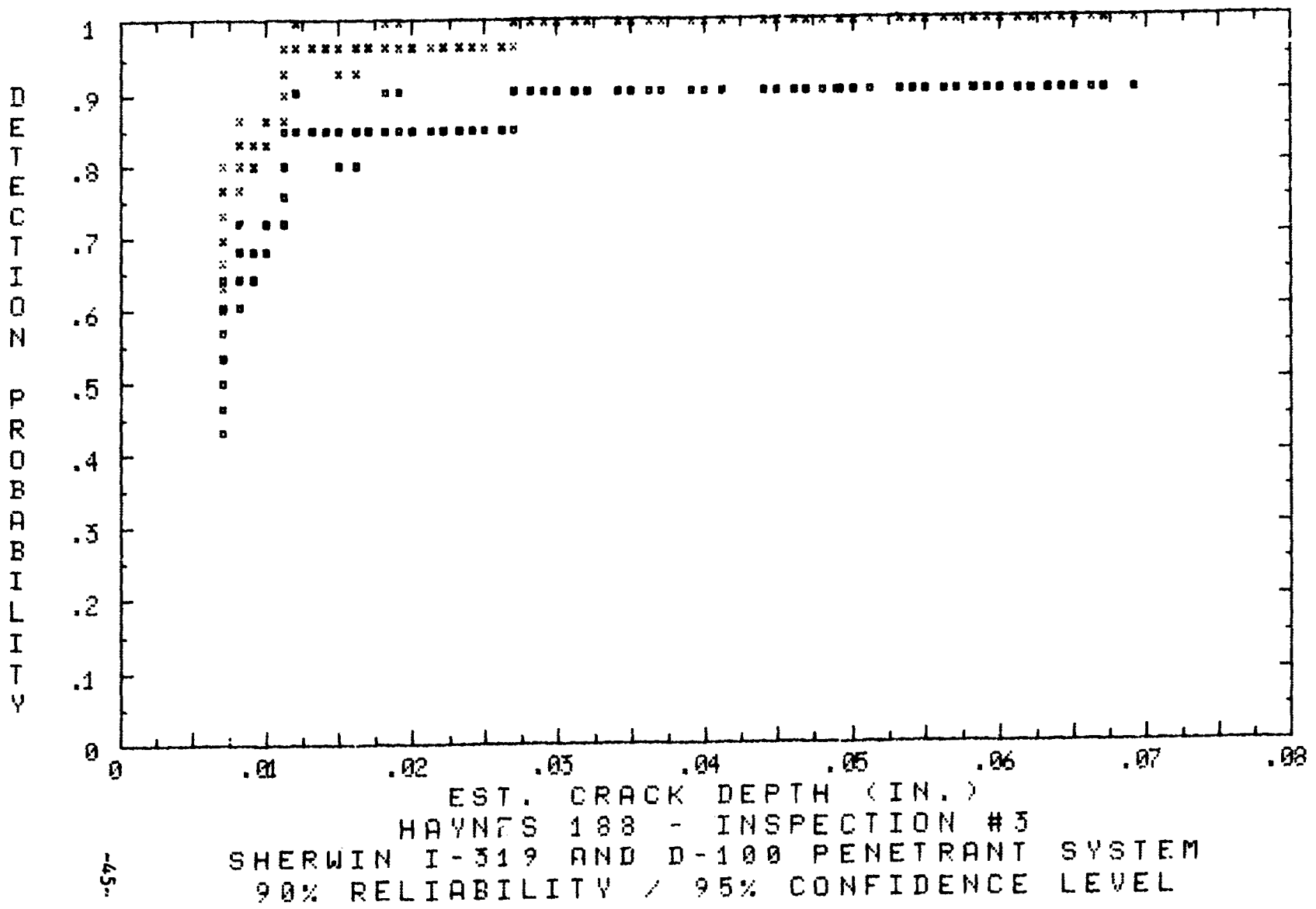
Figure 21 - Crack Detection Probability of Haynes 188 Penetrant Inspection #3.

VII. FLAW LOCATION MAPPING

The actual flaw lists tabulating the flaw dimensional data were utilized to provide the necessary information for producing flaw location maps for both the Inconel 718 and Haynes 188 panels. The flaw lists were loaded into the computer from disc and a basic language program using a dot matrix printer was used to draw the specimen maps. The maps show the flaw location and relative flaw size graphically on a panel drawing. The maps also provide in tabular form, the x-y coordinates of the flaw location, the flaw length the estimated flaw depth, and the approximate flaw aspect ratio. Information is also provided as to the panel grain orientation. On panels with the flaws located on the rear side, the flaws are shown looking through the panel. In all cases the x-y coordinates are measured from the corner with the panel serial number. The maps of the Inconel 718 panels are located in Appendix G and Appendix H contains the maps of the Haynes 188 panels. A hardcopy listing of the Basic program used to generate the flaw maps is located in Appendix I.

VII. DISCUSSION OF RESULTS

A.   Derivation of Specimens for
      Flaw Detection Reliability Assessment

The inspection results and data analysis obtained on the Inconel 718 and Haynes 188 specimens demonstrate the suitability of the specimens and the control mechanisms utilized for repeated flaw detection reliability studies using fluorescent penetrant inspection. The specimens were produced to contain sufficient fatigue cracks ranging in length from 0.010 inches to 0.250 inches and having an aspect ratio ranging from 0.12 to 0.27 evenly distributed to accommodate a 95% reliability / 95% confidence level statistical assessment of NDI flaw detection reliability. The cleaning procedure development performed as an integral part of this program demonstrated that complete removal of penetrant from fatigue type cracks is possible utilizing several different cleaning solvents. A detailed cleaning procedure was developed from the results utilizing the most effective materials tested.

B.   Flaw Detection Reliability

The Inconel 718 specimens were inspected utilizing a single inspection method with three independent operators. The haynes 188 specimens were processed by a single operator using three different fluorescent penetrant systems. The results demonstrated that the reliability of fluorescent penetrant inspections is dependent on both human factors and material variations.

Two analysis methods were applied to determine the flaw detection reliability of the penetrant inspection sequences performed using the Inconel 718 and Haynes 188 specimens. The first method applied was determination of the least group of thirty consecutive flaws successfully detected. This constitutes a simple method for determining the 90% reliability / 95% confidence level capability for a given inspection method. The second, more rigorous method applied to the inspection data was the traditional method of plotting the probability of detection (P.O.D.) point estimate and confidence limit versus flaw length (deptn). The two methods are similar in that a 30 flaw data grouping and countdown technique is utilized to plot the P.O.D. curves. This method produces the "knee" of the P.O.D. curve at the upper bound of the least group of thirty flaws successfully detected in a controlled inspection process. The P.O.D. method of data analysis provides the added benefit of graphical presentation of the probability of detection for all flaw lengths. The method of analysis using the least group of thirty consecutive flaws successfully detected could be misleading if used alone when there are a few flaws missed at all flaw lengths due to processing errors or human factors or for inspections that are out of control.

VIII. CONCLUSIONS AND RECOMMENDATIONS

A.   Conclusions

Fatigue cracked test specimens of Inconel 718 and Haynes 188 materials suitable for use in assessing NDE reliability capabilities were successfully derived during this program. The specimens were designed and produced to contain flaws ranging in size from 0.010 inches to 0.250 inch in sufficient numbers and size distribution (see Table 5) to accomodate a 95% reliability / 95% confidence level statistical analysis of flaw detection capability. Flaw numbers and locations on each specimen were varied to afford random inspection opportunities for flaw detection.

Since fluorescent penetrant inspection was deemed to be the NDE technique most likely to effect the reusability and durability of the test specimens, a cleaning technique which would assure removal of typical fluorescent type penetrants was derived. This technique was demonstrated to completely remove fluorescent penetrants from fatigue cracks by the opening of test flaws and examining for traces of flourescence. This cleaning technique and appropriate handling should assure valid results through repeated inspections and longer-term reliability studies.

A study of "typical" aerospace program fluorescent penetrant inspection capabilities was conducted utilizing the test specimens produced to demonstrate the suitability of the test panels and the control mechanisms applied by Martin Marietta Aerospace in conducting NDE reliability assessments. The study also provided a data base from which correlative comparisons can be made with results similarly derived via earlier studies of fluorescent penetrant inspection of fatigue flawed aluminum, titanium and steel test specimens. The inspection results were analyzed and the detection reliability was determined at a 90% reliability / 95% confidence level using the least group of thirty consecutive flaws successfully detected and a more rigorous technique plotting the detection reliability and confidence limit versus the flaw dimensions.

B.   Recommendations

The test specimens produced during this program were demonstrated to be suitable for repetitive fluorescent penetrant inspection reliability assessment. It is recommended that specimens of this type not be used for assessing visible penetrant systems due to the extreme difficulty in cleaning penetrant materials of this type from tightly closed flaws. No problems are anticipated with the application of other nondestructive inspection techniques to the specimens for the purpose of assessing NDE reliability.

REFERENCES

1. Robert W. Neuschafer and James B. Beal: "Assessment of and
   Standardization for Quantitative Nondestructive Testing,"
   NASA TM-X-64706, September 30, 1972.

2. Ward D. Rummel, Paul H. Todd, Jr., Sandor A. Frecska, and
   Richard A. Rathke: "The Detection of Fatigue Cracks by
   Nondestructive Testing Methods". NASA CR-2369, February
   1974.

3. Ward D. Rummel, Richard A. Rathke, Paul H. Todd, Jr.,
   Thomas L. Tedrow, and Steve J. Mullen: " Detection of
   Tightly Closed Flaws by Nondestructive Testing (NDT)
   Methods in Steel and Titanium". NASA CR-15098,
   September, 1976.

4. Larry G. Headrick, Steve J. Mullen, and Ward D. Rummel:
   "Fluid Vaporization Testing for the Detection of Surface
   Connected Flaws". American Society for Nondestructive
   Testing. Presented at QualTest-1 Conference and
   Exposition, Pittsburg, Pennsylvania, October 6, 1982.

5. Irwin Miller and John E. Freund: "Probability and
   Statistics for Engineers". Prentice-Hall, Inc.,
   1965, pp. 39-44.

6. Yee, B.G.W., F.H. Chang, J.C. Couchman, G.H. Lemon, and
   P.F. Packman, "Assessment of NDE Reliability Data," NASA
   CR-134991, 1976.

7. W.D. Rummel, S.J. Mullen, F.B. Ross, and J.J. Jezek,
   "Reliability of Nondestructive Inspection (NDI) of
   Aircraft Engine Components, Phase III Report".
   SA-ALC/MM-7617, June, 1982.

APPENDIX A

DEVELOPMENT FLAW DIMENSIONAL

DATA

INCONEL 718
DEVELOPMENT CRACKS
CASE I - CRACK LENGTHS 0.010" - 0.050"

****

CASE	PANEL/ CRACK #	NOTCH LENGTH INCHES	NOTCH DEPTH INCHES	CRACK LENGTH INCHES	CRACK DEPTH INCHES	FINAL LENGTH INCHES	FINAL DEPTH INCHES	FINAL a/2c
I	1LC/1	.031	.014	.067	.034	.036	.004	.11
	1LC/4	.032	.012	.062	.029	.000	.000	.00
	2LA/1	.034	.011	.057	.028	.000	.000	.00
	2LA/2	.056	.011	.080	.033	.025	.003	.12
	2LB/1	.041	.012	.065	.023	.000	.000	.00
	2LC/1	.040	.017	.069	.031	.018	.001	.06
	1LA/1	.023	.017	.060	.028	.000	.000	.00
	1LA/2	.024	.017	.062	.022	.000	.000	.00
	1LA/3	.028	.020	.062	.029	.000	.000	.00
	1LA/4	.030	.023	.059	.029	.000	.000	.00
	1LA/5	.031	.024	.066	.031	.007	.001	.14
	1TA/1	.041	.019	.082	.033	.051	.003	.06
	1TA/2	.040	.019	.086	.039	.054	.009	.17

****

A-1

INCONEL 718
DEVELOPMENT CRACKS
CASE II - CRACK LENGTHS 0.051" - 0.100"

****

CASE	PANEL/ CRACK #	NOTCH LENGTH INCHES	NOTCH DEPTH INCHES	CRACK LENGTH INCHES	CRACK DEPTH INCHES	FINAL LENGTH INCHES	FINAL DEPTH INCHES	FINAL a/2c
IIA	1LC/2	.051	.012	.109	.049	.087	.019	.22
	1LC/5	.060	.013	.094	.041	.078	.011	.14
	1TB/1	.048	.010	.128	.050	.110	.020	.18
	1TB/2	.062	.010	.081	.021	.000	.000	.00
IIB	1LC/3	.030	.010	.088	.040	.063	.010	.16
	2LA/3	.035	.005	.078	.024	.000	.000	.00
	2LA/5	.040	.010	.113	.041	*	.011	---
	2LB/2	.040	.012	.106	.050	.095	.020	.21
	2LC/2	.040	.014	.095	.049	.081	.019	.23
	1TA/3	.043	.012	.103	.040	.084	.010	.12

****

* Entire flaw was not exposed after fracturing specimen so final flaw length
could not be determined.

INCONEL 718
DEVELOPMENT CRACKS
CASE III - CRACK LENGTHS 0.101" - 0.150"

CASE	PANEL/ CRACK #	NOTCH LENGTH INCHES	NOTCH DEPTH INCHES	CRACK LENGTH INCHES	CRACK DEPTH INCHES	FINAL LENGTH INCHES	FINAL DEPTH INCHES	FINAL a/2c
IIIA	2LA/4	.054	.010	.120	.054	.100	.024	.24
	2LC/3	.066	.012	.126	.057	.113	.027	.24
	2LD/1	.097	.013	.185	.074	.193	.044	.24
	1TB/3	.090	.011	.141	.053	.125	.023	.18
	1TB/4	.068	.012	.120	.049	.105	.019	.18
IIIB	2LB/3	.059	.012	.134	.082	.182	.052	.28
	2LB/4	.039	.012	.129	.059	.120	.029	.24
	1TA/4	.044	.017	.166	.065	.156	.035	.22

INCONEL 718
DEVELOPMENT CRACKS
CASE IV - CRACK LENGTHS 0.151" - 0.250"

CASE	PANEL/ CRACK #	NOTCH LENGTH INCHES	NOTCH DEPTH INCHES	CRACK LENGTH INCHES	CRACK DEPTH INCHES	FINAL LENGTH INCHES	FINAL DEPTH INCHES	FINAL a/2c
IVA	2LB/5	.092	.012	.168	.072	.157	.042	.27
	2LD/2	.068	.012	.164	.070	.162	.040	.25
	2LD/3	.102	.013	.171	.072	.166	.042	.25
	2LD/4	.156	.013	.261	.100	.257	.070	.27
	1TB/5	.160	.011	.255	.086	.248	.056	.23
IVB	2LC/4	.040	.014	.160	.074	.156	.044	.28
	2LC/5	.090	.012	.178	.080	.175	.050	.29
	2LD/5	.042	.014	.239	.100	.237	.070	.30
	1TA/5	.043	.015	.233	.086	.231	.056	.24

HAYNES 188
DEVELOPMENT CRACKS
CASE I - CRACK LENGTHS 0.010" - 0.050"

CASE	PANEL/ CRACK #	NOTCH LENGTH INCHES	NOTCH DEPTH INCHES	CRACK LENGTH INCHES	CRACK DEPTH INCHES	FINAL LENGTH INCHES	FINAL DEPTH INCHES	FINAL a/2c
I	AL/1	.030	.025	.056	.030	.000	.000	0
	BL/1	.046	.025	.080	.040	.042	.010	.24
	BL/2	.046	.025	.082	.044	.057	.014	.25
	CL/2	.025	.024	.068	.035	.031	.005	.16
	CT/1	.034	.025	.055	.031	.012	.001	.08
	CT/2	.032	.025	.062	.032	.016	.002	.12
	DT/1	.035	.026	.051	.036	.023	.006	.26
	DT/2	.035	.025	.059	.036	.024	.006	.25
	DT/3	.037	.025	.071	.038	.046	.008	.17
	DT/4	.036	.025	.071	.034	.032	.004	.12
	DL/1	.036	.025	.078	.035	.023	.005	.23
	DL/2	.035	.025	.064	.034	.020	.004	.22
	GT/2	.030	.026	.064	.037	.033	.007	.21
	FL/3	.033	.027	.060	.034	.023	.004	.17

HAYNES 188
DEVELOPMENT CRACKS
CASE II - CRACK LENGTHS 0.051" - 0.100"

CASE	PANEL/ CRACK #	NOTCH LENGTH INCHES	NOTCH DEPTH INCHES	CRACK LENGTH INCHES	CRACK DEPTH INCHES	FINAL LENGTH INCHES	FINAL DEPTH INCHES	FINAL a/2c
IIA	ET/3	.084	.015	.107	.037	.071	.007	.10
	CT/3	.092	.016	.110	.035	.075	.005	.07
	CT/4	.101	.016	.116	.034	.108	.004	.04
	CL/4	.053*	.014	.128	.057	.111	.027	.25
	ET/3	.054	.017	.105	.048	.087	.018	.20
	EL/4	.054	.017	.101	.044	.085	.014	.16
IIB	AL/3	.030	.025	.117	.057	.108	.027	.25
	CT/5	.038	.025	.120	.058	.105	.028	.27
	CL/1	.034	.025	.089	.045	.071	.015	.21
	DL/3	.036	.025	.135	.053	.105	.023	.22
	FL/2	.030	.025	.094	.043	.075	.013	.17

* Starter notches for Case IIA flaws less than .054 inch in length were not utilized on the deliverable Haynes 188 panels. Those development flaws grown with starter notches less than .054 inch in length were not included in the data base from which the flaw depths were estimated.

HAYNES 188
DEVELOPMENT CRACKS
CASE III - CRACK LENGTHS 0.101" - 0.150"

CASE	PANEL/ CRACK #	NOTCH LENGTH INCHES	NOTCH DEPTH INCHES	CRACK LENGTH INCHES	CRACK DEPTH INCHES	FINAL LENGTH INCHES	FINAL DEPTH INCHES	FINAL a/2c
IIIA	BL/3	.064*	.015	.148	.063	.137	.033	.24
	CL/5	.057*	.016	.139	.063	.129	.033	.26
	ET/2	.100	.017	.146	.052	.133	.022	.17
	FL/1	.098	.017	.146	.054	.130	.024	.18
	FT/1	.083	.015	.142	.056	.131	.026	.20
IIIB	AT/1	.046	.023	.116	.049	.115	.019	.17
	AT/2	.046	.023	.124	.057	.114	.027	.24
	AL/2	.030	.025	.115	.048	.112	.018	.11
	ET/4	.030	.025	.139	.061	.132	.031	.23

* Starter notches for Case IIIA flaws less than .070 inch in length were not utilized on the deliverable Haynes 188 panels. Those development flaws grown with starter notches less than .070 inch were not included in the data base from which the crack depths were estimated.

HAYNES 188
DEVELOPMENT CRACKS
CASE IV - CRACK LENGTHS 0.151" - 0.250"
CASE A FLAWS

CASE	PANEL/ CRACK #	NOTCH LENGTH INCHES	NOTCH DEPTH INCHES	CRACK LENGTH INCHES	CRACK DEPTH INCHES	FINAL LENGTH INCHES	FINAL DEPTH INCHES	FINAL a/2c
IVA	BT/1	.110*	.015	.192	.072	.189	.042	.22
	BT/2	.140*	.015	.286	.110	.285	.080	.28
	BT/4	.078*	.015	.214	.084	.210	.054	.26
	BT/5	.088*	.015	.271	.097	.266	.067	.25
	BL/4	.124*	.015	.234	.092	.231	.062	.27
	BL/5	.150*	.016	.230	.086	.227	.056	.25
	DL/4	.219	.015	.327	.093	.327	.063	.19
	DL/5	.204	.015	.247	.072	.239	.042	.18
	DT/5	.217	.015	.233	.062	.210	.032	.15
	ET/1	.187	.014	.241	.074	.235	.044	.19
	EL/1	.100	.013	.240	.078	.236	.048	.20
	FT/2	.205	.016	.282	.094	.269	.064	.24
	GT/1	.197	.016	.267	.088	.261	.058	.22
	GL/1	.211	.015	.287	.095	.281	.065	.23
	GL/2*	.096	.015	.169	.067	.159	.037	.23

A-8

* Starter notches for Case IVA flaws less than .160 inch in length were not
  utilized on the delivable Haynes 188 panels. Those development flaws grown
  with starter notches less than .160 inch in length were not included in the
  data base from which the crack depths were estimated.

HAYNES 188
DEVELOPMENT CRACKS
CASE IV - CRACK LENGTHS 0.151" - 0.250"
CASE B FLAWS

CASE	PANEL/ CRACK #	NOTCH LENGTH INCHES	NOTCH DEPTH INCHES	CRACK LENGTH INCHES	CRACK DEPTH INCHES	FINAL LENGTH INCHES	FINAL DEPTH INCHES	FINAL a/2c
IVB	AT/3	.046	.023	.183	.077	.183	.047	.26
	AT/4	.046	.023	.223	.087	.220	.057	.26
	AT/5	.046	.023	.325	.108	.320	.078	.24
	AL/4	.030	.025	.178	.073	.177	.043	.24
	AL/5	.030	.025	.241	.090	.240	.060	.25

APPENDIX B

SPECIMEN CLEANING PROCEDURES

APPENDIX B

Specimen Cleaning Procedures

1.0 SCOPE

1.1 This document describes the procedure for
cleaning the Inconel 718 and Haynes 188 fatigue
crack test specimens following penetrant inspection
and otherwise to remove contamination.

2.0 REFERENCES

2.1 Allied Chemical Product Safety Data Sheet C 2021

2.2 Allied Chemical Genesolv DA Technical Data #526-314

2.3 Allied Chemical Product Specification #196-00257-B

3.0 EQUIPMENT AND MATERIALS

3.1 Ultrasonic Cleaner.

3.2 Specimen Cleaning Racks.

3.3 Vapor Degreaser.

3.4 Allied Chemical Genesolv DA solvent.

4.0 PERSONNEL

4.1 Specimen cleaning shall be performed by personnel
familiar with this procedure.

5.0 PROCEDURE

5.1 Remove all developer from specimen surfaces by
flushing with water and mechanically wiping as
necessary.

5.2 Dry specimens and place in specimen cleaning racks.

5.3 Place cleaning racks in vapor degreaser and degrease for 10 minutes using Genesolv DA as the degreasing agent. 1,1,1 trichloroethane may be substituted for Genesolv DA. Do not exceed 10 minutes or specimens will become overheated and drying of the penetrant will occur. Degreasing may be eliminated if degreasing equipment is unavailable.

5.4 Remove specimens from degreaser and ultrasonically clean specimens in Genesolv DA for a minimum of 6 hours. Specimens should be placed in cleaning racks to provide a minimum of 1/8 inch space between specimens. The number of panels placed in the cleaner should be limited to 5 panels per gallon of solvent.

   5.4.1 Trichloroethane may be substituted for Genesolv DA with an increase in minimum cleaning time to 8 hours.

APPENDIX C

LIQUID PENETRANT INSPECTION PROCEDURE

FOR FATIGUE CRACK DETECTION

APPENDIX C

Liquid Penetrant Inspection Procedure For
Fatigue Crack Detection

1.0 SCOPE

    1.1 This procedure describes liquid penetrant inspection of Inconel 718 and Haynes 188 plate for detecting fatigue cracks.

2.0 REFERENCES

    2.1 Uresco Corporation Data Sheet No. PN-100.

    2.2 Nondestructive Testing Training Handbooks P1-4-2, Liquid Penetrant Testing, General Dynamics Corporation, 1967.

    2.3 Nondestructive Testing Handbook, McMasters Ronald Press, 1959, Volume I, Sections 6, 7 and 8.

    2.4 ASNT Nondestructive Testing Handbook, American Society for Nondestructive Testing, 1982, Volume 2, Liquid Penetrant Tests.

3.0 EQUIPMENT AND MATERIALS

    3.1 Uresco P-149 High Sensitivity Fluorescent Penetrant.
        Magnaflux ZL37 High Sensitivity fluorescent Penetrant
        Sherwin I-319 Water Wash Penetrant.

    3.2 Uresco E-153 Lipophilic Emulsifier.
        Magnaflux ZR10A Hydrophilic Remover.

    3.3 Uresco D-499C Nonaqueous Spray Developer.
        Magnaflux ZP9B Nonaqueous Spray Developer.
        Sherwin D-100 Nonaqueous Spray Developer.

    3.4 Ultraviolet light source (Magnaflux Black-Ray B-100).

    3.5 Uresco Tri-Con Spray Gun

3.6 Paint brush (1-1/2 inch).

3.7 Isopropyl alcohol.

3.8 Custom made specimen racks.

3.9 Magnifier, 10x.

3.10 Forced air drying oven.

3.11 Ultra-Violet Products, Inc. UVX Digital Radiometer.

4.0 PERSONNEL

4.1 The liquid penetrant inspection shall be performed by technically qualified personnel.

5.0 PROCEDURE

5.1 Apply P-149 penetrant to panels surfaces using a brush to the areas to be inspected. Place panels in specimen racks and allow a dwell time of 30 - 40 minutes.

5.2 Turn on ultraviolet light and allow a warm up of 15 minutes.

5.2.1 Measure intensity of the ultraviolet light and assure a minimum reading of 1020 micro watts per sq.cm. at 15" from the filter.

5.3 After the 30 minute penetrant dwell time, immerse the specimen racks containing the panels into the E-153 emulsifier bath. Remove racks from the bath and allow panels to drain. Total emulsification time for panels is 90 seconds.

5.4 After 90 second emulsification time, remove emulsifier with a water wash in a darkened room under black light. Spray panels in racks with water spray at 80 F and 30 psi until emulsifier has been completely removed.

5.5 Place specimen racks containing panels in drying oven at 160 F for a period of 10 minutes or until panels are dry.

5.6 Remove panels from rack and apply D-499C developer by spraying from the pressurized container. Hold the container 6 to 12 inches from the area to be inspected and apply a light coat of developer sufficient to provide a continuous, thin film on the surfaces to be inspected.

5.7 Allow a 30 minute bleed out time and inspect panels for cracks under black light. Inspection is to be performed in a dark room with no more than two foot candles of white ambient ligh .

5.8 Using the acetate grids, locate and record the flaw location coordinates.

5.9 Follow above procedures when using ZL37 penetrant with following exceptions:

    5.9.1 Prewash panels in racks prior to emulsification.

    5.9.2 Substitute ZR10A for E-153. Allow panels to remain in remover bath for entire emulsification period.

    5.93 Substitiute ZP9B for D-499C.

5.10 Follow above procedures when using I-319 penetrant with following exceptions:

    5.10.1 Eliminate step 5.3. Wash immediately following completion of penetrant dwell time.

    5.10.2 Substitute D-100 for D-499C.

MCR-83-568
NDE DETECTABILITY OF FATIGUE TYPE CRACKS
IN HIGH STRENGTH ALLOYS

APPENDIX D

INSPECTION DATA DOCUMENTATION

This appendix has been withheld from publication at
this time. The presented data represents the flawed specimens
which will be utilized in upcoming studies of the detectability
of NDE being applied by space program contractors. Release
of this data at this time could bias the study results. The
data of this appendix will be included in the final study report.

APPENDIX E

INCONEL 718 SPECIMEN FLAW

DOCUMENTATION

This appendix has been withheld from publication at
this time. The presented data represents the flawed specimens
which will be utilized in upcoming studies of the detectability
of NDE being applied by space program contractors. Release
of this data at this time could bias the study results. The
data of this appendix will be included in the final study report.

THE DETECTABILITY OF FATIGUE TYPE CRACKS
IN HIGH STRENGTH ALLOYS

APPENDIX F

HAYNES 188 SPECIMEN FLAW

DOCUMENTATION

This appendix has been withheld from publication at
this time. The presented data represents the flaw l specimens
which will be utilized in upcoming studies of the detectability
of NDE being applied by space program contractors. Release
of this data at this time could bias the study results. The
data of this appendix will be included in the final study report.

APPENDIX G

INCONEL 718 FLAW LOCATION

MAPS

This appendix has been withheld from publication at
this time. The presented data represents the flawed specimens
which will be utilized in upcoming studies of the detectability
of NDE being applied by space program contr ors. Release
of this data at this time could bias the study results. The
data of this appendix will be included in the final study report.

MCR-83-568
NDE DETECTABILITY OF FATIGUE TYPE CRACKS
IN HIGH STRENGTH ALLOYS

APPENDIX H

HAYNES 188 FLAW LOCATION

MAPS

This appendix has been withheld from publication at
this time. The presented data represents the flawed specimens
which will be utilized in upcoming studies of the detectability
of NDE being applied by ace program contractors. Release
of this data at this time could bias the study results. The
data of this appendix will be included in the final study report.

MCR-83-568
NDE DETECTABILITY OF FATIGUE TYPE CRACKS
IN HIGH STRENGTH ALLOYS

APPENDIX I

MAP GENERATION PROGRAM

LISTING

APPENDIX I

BASIC LANGUAGE
SPECIMEN MAP GENERATION PROGRAM

```
1 DEFUSR=-578:X=USR(4700):IF X<>0 THEN STOP

5 CLEAR10000

10 DEFSTR E:DEFINT I-O:DIM EX(291,5),M(12), B(5,12),
   C(5),BY(5,12),BL(5,12)

20 L=1:Z=249:N8=0:N7=1

30 CMD"D:1

40 INPUT"ENTER FILE NAME ";FI$

42 CLS:INPUT"IS MATERIAL <H>AYNES 188 OR <I>NCONEL 718";
   FM$

43 IF FM$="H" THEN ET="H1" ELSE ET="I7"

50 GOSUB 6000

60 P$="       ###            #       #.##  ##.##     #.###
   #.###       #.##"

70 IF EX(1,1)="1" THEN N8=0 ELSE N8=1

500 Q=13:LK=0:N=5:NP=0:NQ=0:NZ=0:FOR I=1 TO 5:M(I)=0:NEXT I:
    IF N8=1 THEN READ A$,C$:B$="NONE":N7=N7+1:GOTO 540

510 A$=EX(L,1):B$=LEFT$(EX(L,3),1)

520 C$=RIGHT$(EX(L,3),1)

530 IF B$="1" THEN B$="FRONT" ELSE B$="REAR"

540 IF C$="T" THEN C$="TRANSVERSE" ELSE C$="LONGITUDINAL"

546 IF N8=1 THEN GOTO 990

850 FOR J=L TO L+12

860 FOR K=1 TO 5

870 IF VAL(EX(J,2))=K THEN M(K)=M(K)+1:B(K,M(K))=VAL(EX(J,5)):
    BY(K,M(K))=VAL(MID$(EX(J,5),6,4)):BL(K,M(K))=VAL(EX(J,4))
```

```
880 NEXT K

890 IF EX(J,1)<>EX(J+1,1)THEN GOTO 990

895 NQ=NQ+1

900 NEXT J

990 LPRINT CHR$(10)CHR$(10):F1=25:OUT Z,3:GOSUB 5040:GOSUB 5040

1000 FOR K=1 TO 48:OUT Z,0:NEXT K:OUT Z,4:OUT Z,2:OUT Z,57:OUT
     Z,2:OUT Z,4:FOR K=1 TO 34:OUT Z,0:NEXT K

1005 GOSUB 5010:GOSUB5040

1010 GOSUB 5000:GOSUB 5020:GOSUB 5040

1020 GOSUB 5000:GOSUB 5020:FOR K=1 TO 42:OUT Z,0:NEXT K

1030 FOR K=1 TO 7:OUT Z,4:NEXT K:OUT Z,3:OUT Z,2:LPRINT"  =
     CRACK LOCATIONS"

1040 OUT Z,3:GOSUB 5040

1050 GOSUB 5000:GOSUB 5020:GOSUB 5040

1060 GOSUB 5000:GOSUB 5020:FOR K=1 TO 49:CUT Z,0:NEXT K

1070 OUT Z,3:OUT Z,2:LPRINT"    FRONT VIEW"

1080 OUT Z,3:GOSUB 5040

1090 FOR I=1 TO 8:GOSUB 5000:GOSUB 5020:GOSUB 5040:NEXT I

1100 GOSUB 5000:GOSUB 5020

1110 IZ=0

1115 IZ=IZ+1:IF IZ=8 GOTO 1145

1117 IF IZ=5 THEN GOSUB 5070

1120 GOSUB 5040

1125 Q=0-.285714

1130 IF N=3 AND IZ=3 GOSUB 5080:GOTO 1115

1131 IF N=3 AND IZ=5 GOSUB 5080:GOTO 1115

1135 IF M(N)<>0 AND BY(N,M(N))>Q THEN GOSUB 5080:GOTO 1115
```

```
1140 GOSUB 5000:GOSUB 5020: GOTO 1115

1145 GOSUB 5040

1160 GOSUB 5000:GOSUB 5029

1170 IF N=1 GOTO 1185

1180 N=N-1:GOTO 1110

1185 GOSUB 5040

1190 FOR I=1 TO 7:GOSUB 5000:GOSUB 5020:GOSUB 5040:NEXT I

1200 GOSUB 5000:GOSUB 5020

1230 FOR K=1 TO 32:OUT Z,0:NEXT K:OUT Z,3:OUT Z,2

1240 LPRINT"SIDE:   ";B$:OUT Z,3:GOSUB 5040

1250 GOSUB 5000:GOSUB 5020:GOSUB 5040

1252 GOSUB 5000:GOSUB 5020:FOR K=1 TO 32:OUT Z,0:NEXT K:OUTZ,3:
     OUT Z,2:LPRINT"GRAIN ORIENTATION:   ";C$:OUT Z,3:GOSUB 5040

1254 GOSUB 5000:GOSUB 5020:GOSUB 5040

1255 EA=ET+RIGHT$("000"+A$,3)

1256 GOSUB 5000:OUT Z,63:FOR K=1 TO 4:OUT Z,0:NEXT K:OUT Z,3:
     OUT Z,2:LPRINTEA;:OUT Z,3:FOR K=1 TO 44:OUT Z,0:NEXT K:OUT
     Z,63:GOSUB 5040

1258 GOSUB 5000:GOSUB 5.20:GOSUB 5040

1260 FOR K=1 TO 48:OUT Z,0:NEXT K:FOR K=1 TO 6:OUT Z,1:NEXT K:
     FOR K=1 TO 33:OUT Z,0:NEXT K:FOR K=1 TO 77:OUT Z,1:NEXT K:
     FOR K=1 TO 32:OUT Z,0:NEXT K

1280 GOSUB 5040

1290 FOR K=1 TO 5:GOSUB 5040:NEXT K

1300 FOR K=1 TO 87:OUT Z,0:NEXT K:OUT Z,31

1310 FOR K=1 TO 29:OUT Z,4:NEXT K:OUT Z,3:OUT Z,2

1320 LPRINT" X ";:OUT Z,3

1330 FOR K=1 TO 27:OUT Z,4:NEXT K:OUT Z,17:OUT Z,10:OUT Z,4:
     GOSUB 5040
```

```
1340 OUT Z,3:OUT Z,2

2000 LPRINT CHR$(10)CHR$(10)CHR$(10)CHR$(10)

2040 LPRINT TAB(27)"LOCATION";TAB(52)"EST."CHR$(10)

2050 LPRINT TAB(28)"INCHES";TAB(41)"LENGTH";TAB(52)"DEPTH";
     TAB(63)"EST."CHR$(10)

2060 LPRINT"        CRACK #";TAB(18)"AREA";TAB(27)"X";TAB(34)"Y";
     TAB(41)"INCHES";TAB(52)"INCHES";TAB(63)"a/2c"CHR$(10)

2070 LPRINT"        ---------  ------   ----   ----   --------
     --------   ------"CHR$(10)CHR$(10)

3400 IF N8=1 THEN LPRINT"          NONE":GOTO3475

3405 IF NZ=1 THEN GOTO 3430

3410 IF NQ>5 AND NP=5 THEN OUT Z,3:OUT Z,3:OUT Z,12:OUT Z,3:OUT
     Z,2:LPRINT"CRACK DATA FOR PANEL NUMBER ";EA;"CONTINUED"
     CHR$(10)CHR$(10):NZ=1:GOTO2040

3430 F=VAL(EX(L,4))

3440 D=VAL(RIGHT$(EX(L,4),4)):D1=D/F

3450 LPRINT USING P$;VAL(EX(L,0)), VAL(EX(L,2)), VAL(EX(L,5)),
     VAL(MID$(EX(L,5),6,5)),F,D,D1

3451 LPRINT CHR$(10)

3453 NP=NP+1

3455 IF L=IL THEN END

3460 L=L+1

3470 IF EX(L-1,1)=EX(L,1) THEN 3410

3475 IF VAL(EX(L-1,1))+N7<>VAL(EX(L,1)) THEN N8=1:GOTO 3480

3476 N8=0:N7=1

3480 OUT Z,3:OUT Z,3:OUT Z,12:OUT Z,3:OUT Z,2:GOTO 500
```

```
5000 IF N=3 AND IZ=4 THEN Fl=46 ELSE Fl=50

5001 FOR K=1 TO Fl:OUT Z,0:NEXT K

5002 IF Fl=50 THEN OUT Z,63 ELSE OUT Z,3:OUT Z,2:LPRINT"Y";:OUT
     Z,3

5005 FOR K=1 TO INT(24+(Fl-25)/2):OUT Z,0:NEXT:RETURN

5010 OUT Z,63:FOR K=1 TO 75:OUT Z,1:NEXT K:OUT Z,63:RETURN

5020 OUT Z,63:FOR K=1 TO 75:OUT Z,0:NEXT K:OUT Z,63:RETURN

5029 LK=LK+1:IF LK=1 OR LK=6 THEN GOTO 5035

5030 OUT Z,63:FOR K=1 TO 7:FOR J=1 TO 5:OUT Z,8:NEXT J

5031 FOR J=1 TO 5:OUT Z,0:NEXT J:NEXT K

5032 FOR J=1 TO 5:OUT Z,8:NEXT J:OUT Z,63:RETURN

5035 OUT Z,63:FOR K=1 TO 75:OUT Z,8:NEXT K:OUT Z,63:RETURN

5040 OUT Z,3:OUT Z,13:OUT Z,3:OUT Z,11:RETURN

5048 FOR I=1 TO 2:GOSUB 5000:GOSUB 5020:GOSUB 5040:NEXT I

5049 FOR K=1 TO 87:OUT Z,0:NEXT K:RETURN

5060 OUT Z,3:OUT Z,10:RETURN

5070 FOR K=1 TO 32:OUT Z,0:NEXT K

5072 OUT Z,3:OUT Z,2:LPRINT"AREA ";N

5074 OUT Z,3:RETURN

5080 GOSUB 5049:IF BY(N,M(N))>Q THEN OUT Z,63:GOSUB5102:RETURN

5082 GOSUB 5020:RETURN

5100 GOSUB5000:OUT Z,63

5102 IF BL(N,M(N))<.051 THEN KQ=3:GOTO5106

5103 IF BL(N,M(N))<.101 THEN KQ=5:GOTO5106

5104 IF BL(N,M(N))<.151 THEN KQ=7:GOTO5106
```

```
5105 IF BL(N,M(N))>.150 THEN KQ=9:GOTO 5106

5106 MP=5:YY=0

5107 YY=YY+.047619

5108 IF BY(N,M(N))>(Q+YY) THEN MP=MP-1:GOTO 5107

5109 W=2[MP

5110 K1=INT(B(N,M(N))/4*75+.49)-KQ/2:J=75-K1-KQ:IF
     B(N,M(N))>3.95 THEN K1=75-KQ:J=0

5111 IF B(N,M(N))<.050 THEN J=75-KQ:GOTO5120

5115 FOR I=1 TO K1:OUT Z,0:NEXT I

5120 FOR I=1TOKQ:OUT Z,W:NEXT I

5130 M(N)-M(N)-1:IF BY(N,M(N))>Q GOTO 5140

5131 IF J=0 THEN OUT Z,63:RETURN

5133 FOR I=1 TO J:OUT Z,0:NEXT I:OUT Z,63:RETURN

5140 OUT Z,3:OUT Z,13:FOR I=1 TO 88:OUT Z,0:NEXT I:GOTO 5102

6000 OPEN"I",1,FI$:CLS:PRINT"GETTING FILE   ";FI$

6010 INPUT#1,IL,JK

6020 FOR K=1 TO IL:FOR J=0 TO JK

6030 INPUT#1,EX(K,J)

6040 NEXT J,K:RETURN

6999 'DATA FOR UNFLAWED HAYNES 188 PANELS

7000 DATA 4,T,6,L,7,T,13,L,17,L,24,L,27,L,39,T,43,T,47,L,
     54,L, 63,T,69,T,78,L,85,L,93,T,100,L
```

NOTE: This program was written for use with an Integral Data
        Systems, Model 440 dot matrix printer. Graphics codes
        vary from printer to printer so the program will have
        to modified accordingly when used with other printers.