Review of Demonstration Efforts for Model Assisted POD

MAPOD Working Group meeting

20 April 2007

Palm Springs, CA

Outline

- Intergraph program
- NIAR program
- etc.

Intergraph Program

- Review and categorization of inspections in C-130 Technical Orders (TO's).

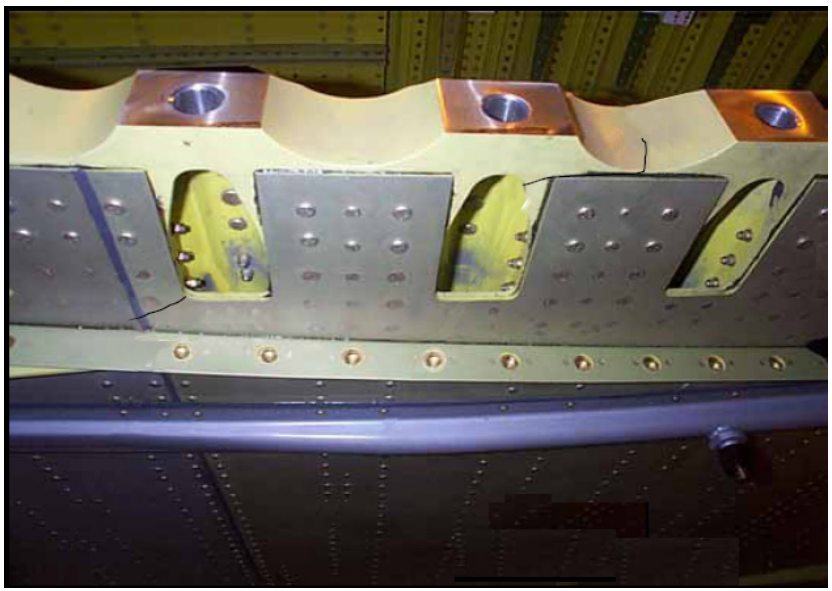
- Work with depot to obtain service-retired parts of interest.

C-130 Rainbow Fitting

C-130 Rainbow Fitting

Rainbow Fitting

- A C-130 aircraft rainbow fitting was sent to AFRL in December 2006



Rainbow Fitting

C-5 Horizontal Stabilizer

Horizontal Tie Box Fitting

Data Collection for Model Creation

- Reviewed aircraft specific Nondestructive Inspection Tech Orders
  - Found no 2nd layer eddy current inspections for the C-5, C-130 or F-15 aircraft
  - Created matrix to establish groupings for eddy current inspections
    - Based on physical access to the inspection area
    - Based on whether inspection is routinely accomplished
    - Based on availability of aircraft parts

Groupings met from these 2 parts

GROUPINGS
Coil Sideways
Above Head
Radius
Eye Level
Around Obstacles
Stooping/Kneeling
Coil Towards Inspector
Flush Fastener
Blind Scan
Long Reach
Inside Wing

TRI/Austin Work

- Basic assumption:

$\ln(\text{signal}) = \beta_0 + \beta_1 \ln(\text{crack size}) + \varepsilon$

- What is ε?
  - all the variabilities
    - instrumentation
    - human factors
    - crack to crack
    - etc...

Residuals

- Assumption of method is that ε is a random variable, zero mean, normally distributed
- We often assume that the components of ε are independent variables
  - This is important, just ask Chuck.
- We believe that these are hardest to deal with.

In a perfect world...

- If there was no ε, we would not need 60 samples to define a linear relationship!
- If we could easily model nefarious concepts like $\varepsilon_{humanfactors}$, wouldn't need POD studies.
- … but we aren't there yet.

XFN

- Transfer from EDM to cracks, from POD specimens to service materials, requires the transfer in ε.
  - I can change the slope of the linear fit with instrumentation gain and offset.
  - Underestimate ε = unconservative POD.

- FOR EXAMPLE Good hole quality in machined POD specimens likely to be unrepresentative of holes that are inspected in service.

- (see DSTO work presented this week)

FMA

- Clear value of model is ability to simulate variations in parameters without extreme numbers of test specimens.
  - FOR EXAMPLE: probe tilt, conductivity, crack location/orientation
- Thus could theoretically model many components of ε.
- (see AFRL work)

Efforts underway on ε

- Review available historical data that contains estimates of ε, experimental designs that allow breakdown of this.

- GOAL instead of tables of NDT detection threshold values, tables of ε.

NIAR Efforts

- Bolt Hole Eddy Current reliability
  - directed towards A-10

Factors - Discontinuity variables - Notches

factor	***type***	***note***
wire diameter	controlled	do not study, fix a single diameter
heat affected zone	uncontrolled	hold constant by manufacturing in a controlled procedure
tool condition	uncontrolled	hold constant by manufacturing in a controlled procedure
process variables - wire feed, speed	uncontrolled	hold constant by manufacturing in a controlled procedure
notch shape	controlled	based on expected crack shape
tool materials and dimensions	uncontrolled	hold constant by manufacturing in a controlled procedure

Factors - Discontinuity variables - Cracks

factor	***type***	***note***
load spectrum	fixed	constant amplitude, amplitude to be defined from A-10 spectrum (lower wing skin)
closure	fixed	this is a function of loads used to grow crack
contact asperities, roughness	fixed	this is a function of material, loads used to grow crack
morphology (shape, orientation, depth, length)	controlled	this is a function of loads used to grow crack
nucleation feature	fixed	not feasible to replicate fretting / corrosion / fatigue nucleation mechanisms, use EDM starter
mode - I, II, III,	fixed	this is a function of loads used to grow crack
growth mechanism – fatigue – corrosion/fatigue – corrosion	fixed	only fatigue

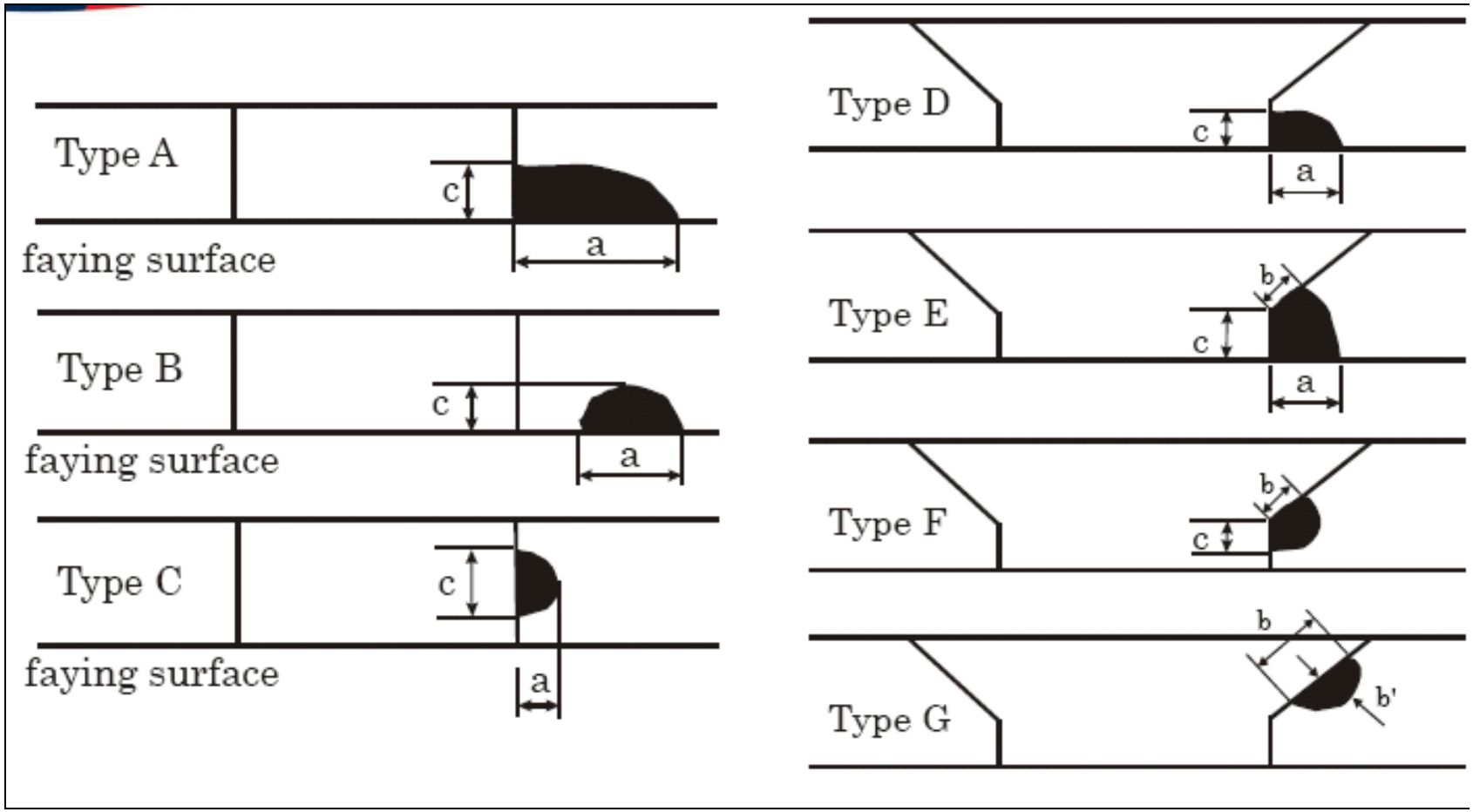
Factors - Material

factor	***type***	***note***
materials properties	fixed	all cracks to be in 0.250” thick Al 7075-T6

Factors - Geometry

factor	***type***	***note***
hole shape	fixed	– all holes to be 0.500” diameter, as machined quality 1. fixed for baseline set, vary for separate study
hole quality – cleanliness – machining damage – fretting, corrosion damage	fixed	– as machined – fixed for baseline set, vary for separate study
crack location in stackup	controlled	• vary as desired 1st layer vs 2nd layer vs …
crack location in hole	controlled	– separate specimens sets with origins at bore and at faying surface (see figure below, Type C and Type A)

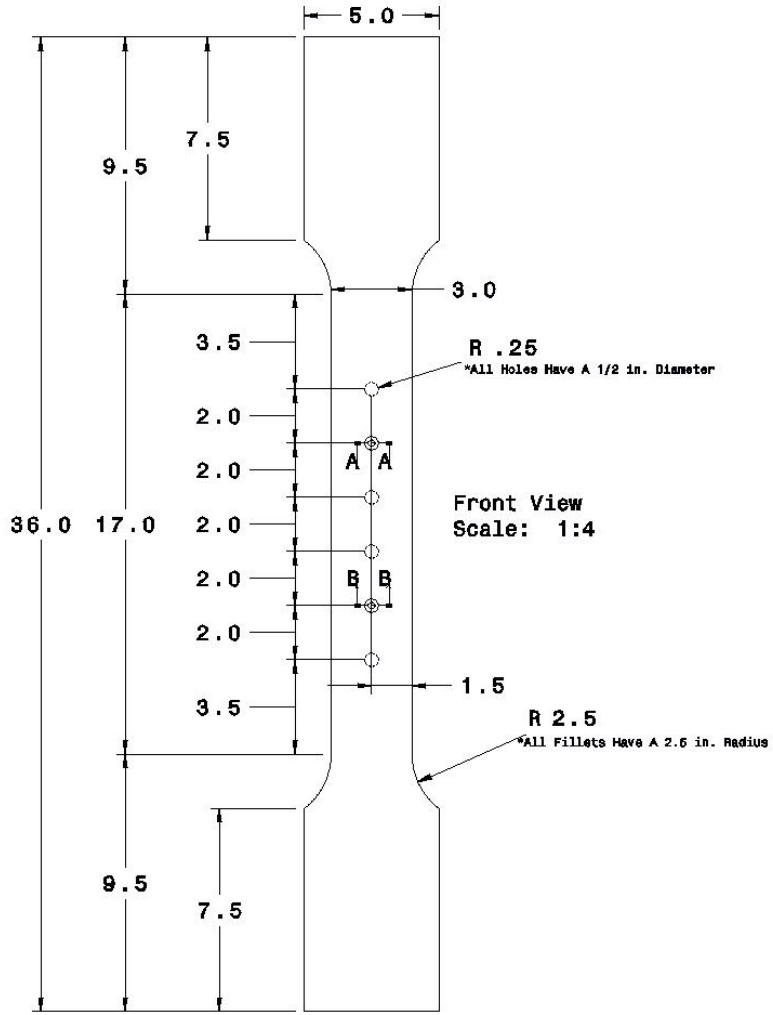
Factors - Geometry



Factors - System/Operator Issues

- Generic set of specimens to be used for multiple trials

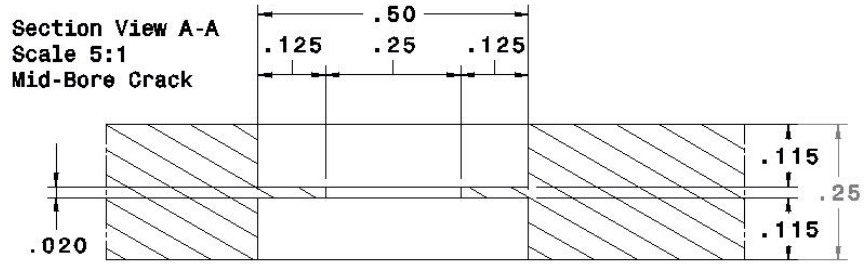
factor	***type***	***note***
NDI equipment	fixed	- as defined in T.O., must control through calibration
NDI technique – scan plan – decision threshold	fixed	- as defined in T.O., must control through calibration - record signal magnitudes



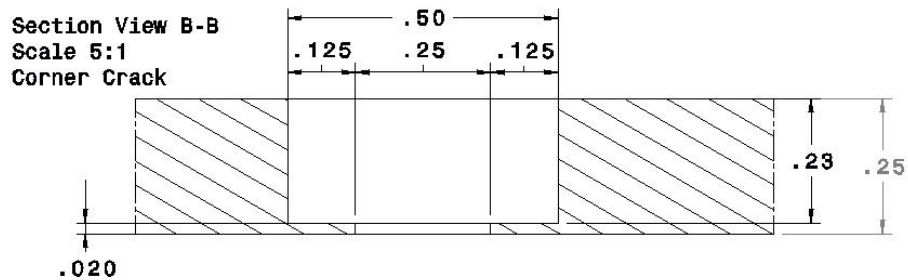
Front View
Scale: 1:4

Test Specimen Has Thickness of 1/4 in.

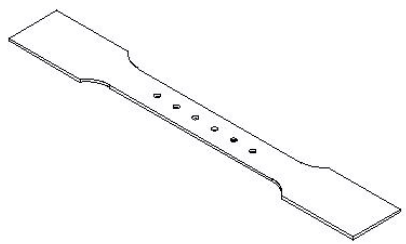
MACHINE DOTTED-LINE HOLES AFTER THE COMPLETION OF FATIGUE TEST OF CORNER AND MID BORE CRACKS



*All Pilot Holes Have A 1/4 in. Diameter



Cracks Propagate Parrallel To 3.0 in. Width Of The Test Specimen



Isometric View
Scale: 1:8

WICHITA STATE UNIVERSITY

NIAR — RESEARCH / DESIGN / TESTING / CERTIFICATION

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AIRCRAFT STRUCTURAL TESTING AND EVALUATION CENTER
FULL SCALE STRUCTURAL TEST LABORATORY
9709 E CENTRAL AVE : WICHITA, KS 67206

PROPRIETARY DATA

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TITLE: A-10 BHEC Fatigue Test Specimen

DWG NO.

DATE: 02/16/07
BY:

SCALE: AS NOTED

SHT X OF X

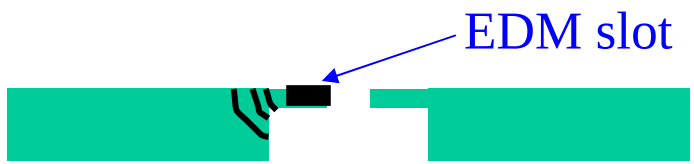
RUN -

CATIA DRAWING

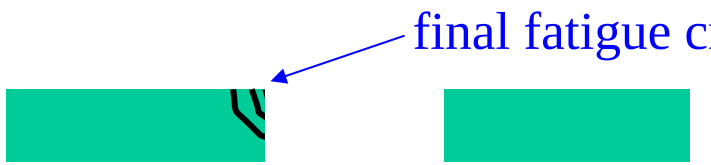
Specimen With Corner Cracks - Conceptual Drawing

Hole X-Section Details for Corner Crack

Machine undersized pilot holes and create thin lips using end mill / flat bottom drill



EDM slots using minimum diameter wire. Generate fatigue cracks of “appropriate size”.

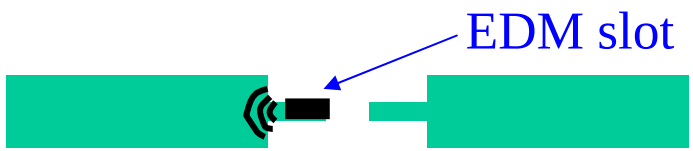


Drill / ream holes to final size. Measure crack sizes.

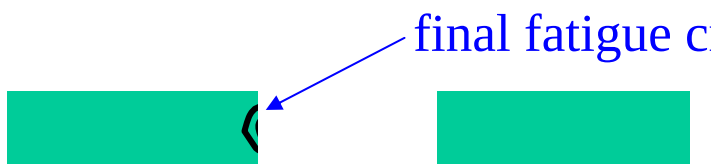
Specimen With Mid-Bore Crack - Conceptual Drawing

Hole X-Section Details for Mid-Bore Crack

Machine undersized pilot holes and create thin lips using end mill / flat bottom drill



EDM slots using minimum diameter wire. Generate fatigue cracks of “appropriate size”.



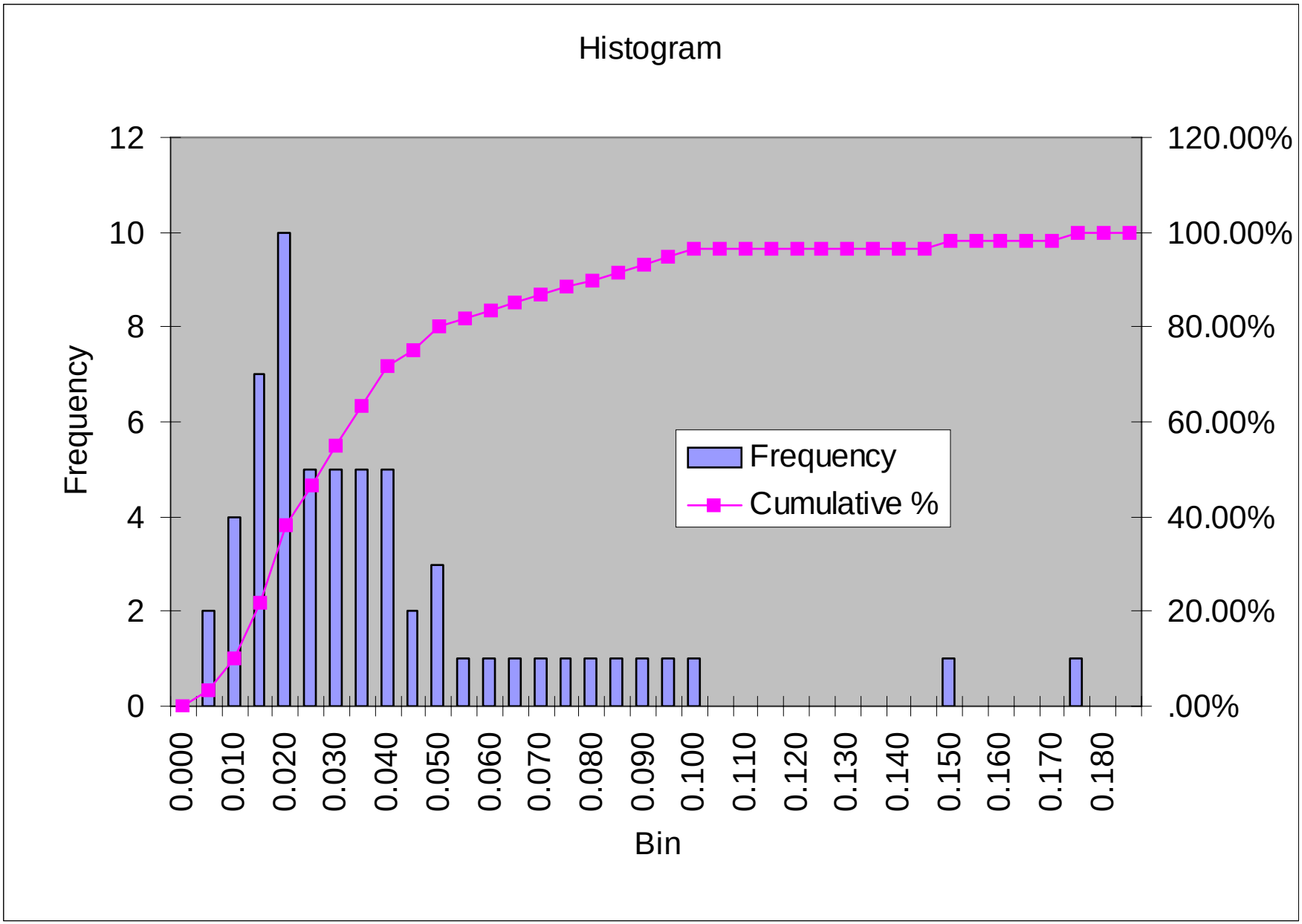
Drill / ream holes to final size. Measure crack sizes.

Summary of A-10 specimens

- Four layer specimen (3 aluminum, 1 steel) of 0.25-in plate with 0.090-in to 0.125-in aluminum shim
- Six 0.50-in diameter holes per specimen
- Maximum of two cracks per hole (fore and aft)

Summary of A-10 specimens

- Crack Population
  - Two to three cracks per specimen with no cracks in some specimens
  - distribute sizes assuming 90/95 crack size of 0.030-in
  - Sixty corner cracks, Sixty midbore cracks in aluminum plates


Histogram
Frequency
12
10
8
6
4
2
0
120.00%
100.00%
80.00%
60.00%
40.00%
20.00%
.00%
Frequency
Cumulative %
0.000
0.010
0.020
0.030
0.040
0.050
0.060
0.070
0.080
0.090
0.100
0.110
0.120
0.130
0.140
0.150
0.160
0.170
0.180
Bin

Summary of A-10 specimens

- Manufacture of Specimen
  - Only drill the holes with cracks before fatiguing
  - Drill the uncracked holes after fatiguing
  - Machine matching holes in each layer of the specimen
  - Gives ability to move cracks in depth, change the stackup
- Number of Specimens
  - Fifty total specimens with cracks - 20 with 3 cracks, 30 with 2 cracks
  - Three additional specimens with EDM defects
  - Additional cracked specimens for fractographic analysis of crack shape and size