PROBABILITY OF DETECTION OF SECOND LAYER CRACKS AT FERROUS FASTENERS IN AIRCRAFT LAP-JOINT STRUCTURES FOR PULSED EDDY CURRENT

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BLIND CALIBRATON-LESS DETECTION OF DEFECTS USING EDDY CURRENT

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OUTLINE

- Motivation
- Approach (and challenges)
- Robust Statistics
- Application
- Conclusions

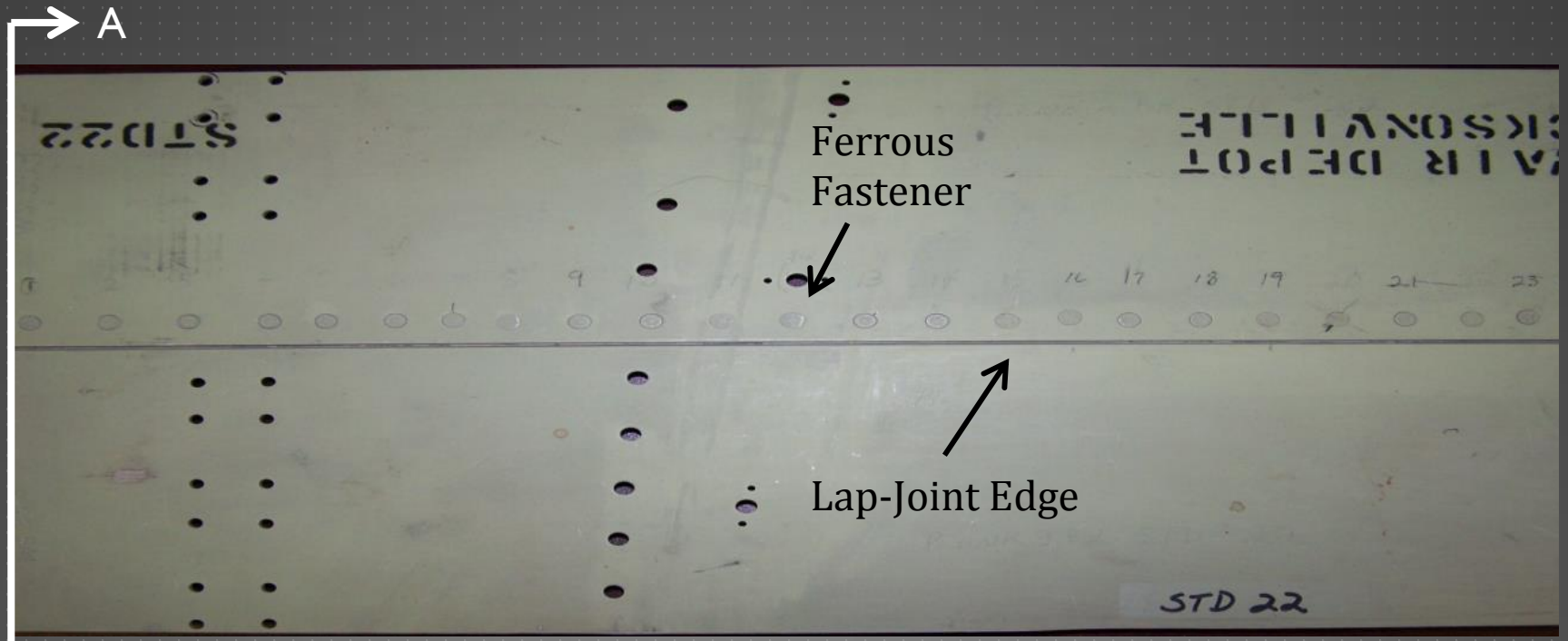
MOTIVATION

Find cracks around ferrous fasteners (Aurora (P-3 Orion) aircraft)

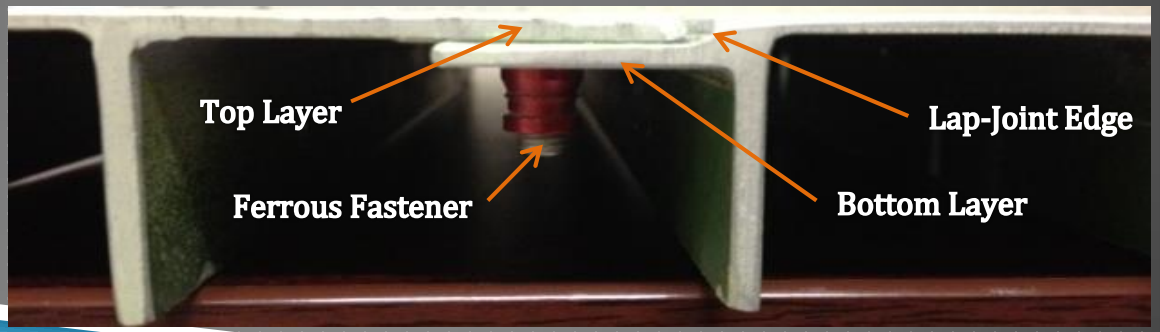
MOTIVATION

- Currently uses bolt hole eddy current
- Requires fastener removal
  - Tedious and time-consuming
  - Large down-time
  - High Cost
  - Possible damage to structure
- Want a method to screen fasteners
  - False call rate vs $a_{90/95}$

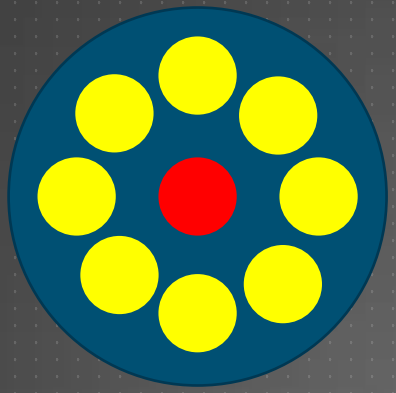
MOTIVATION



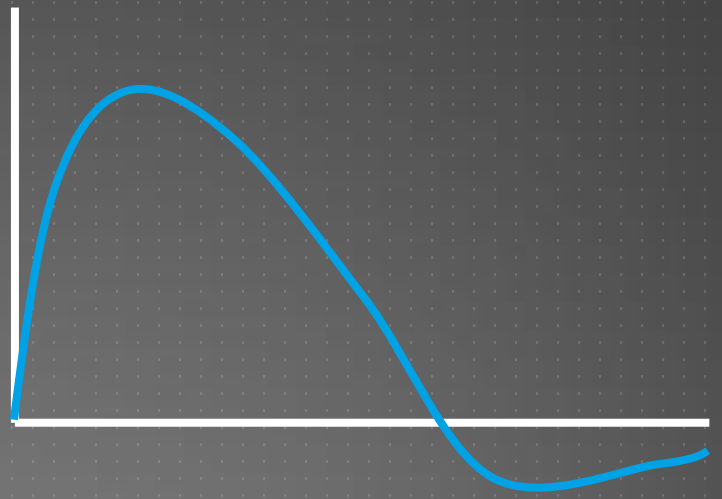
Section AA



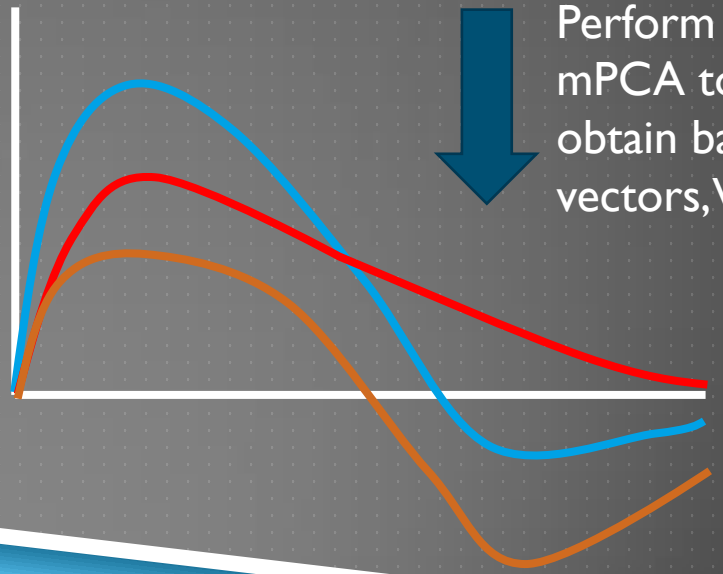
APPROACH



obtain data



Perform mPCA to obtain basis vectors, V_{ij}

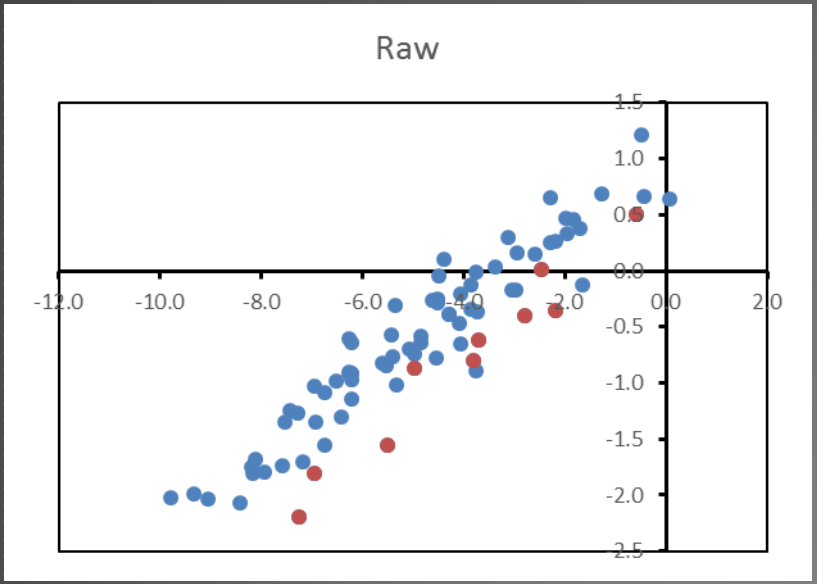


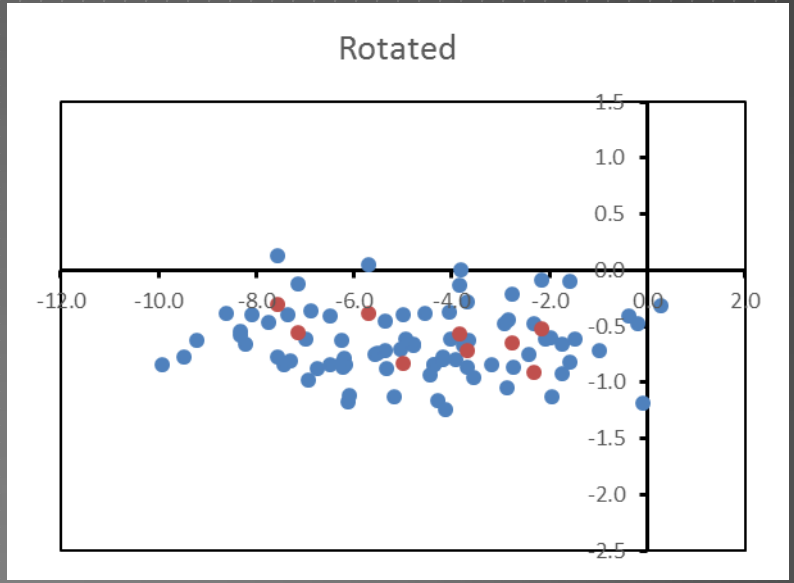
obtain scores, S_{ij}

$$s_j = S_{1j}V_{1j} + S_{2j}V_{2j}$$

Use mPCA to convert time domain signal to scores

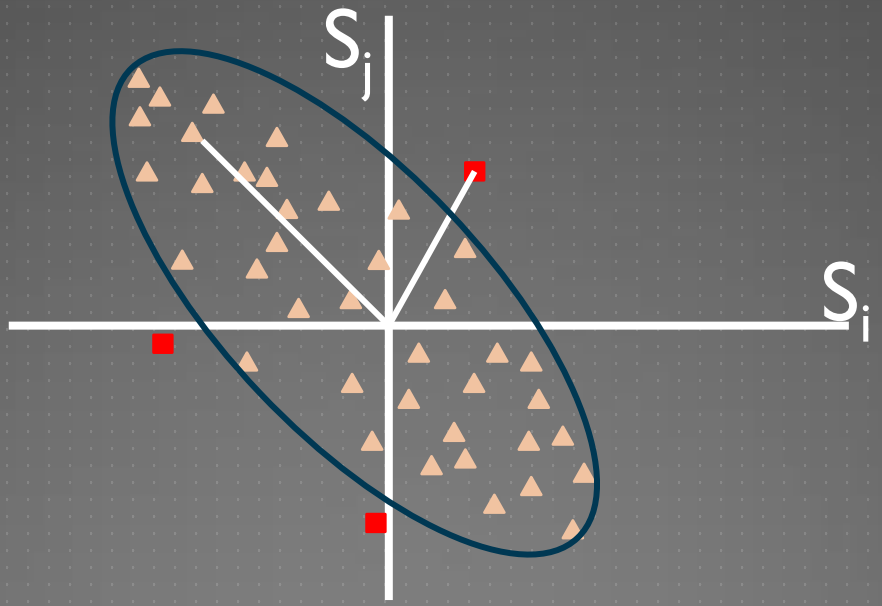
APPROACH


Raw
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-12.0
-10.0
-8.0
-6.0
-4.0
-2.0
0.0
2.0


Rotated
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-12.0
-10.0
-8.0
-6.0
-4.0
-2.0
0.0
2.0

APPROACH

Scores are clustered in PCA space

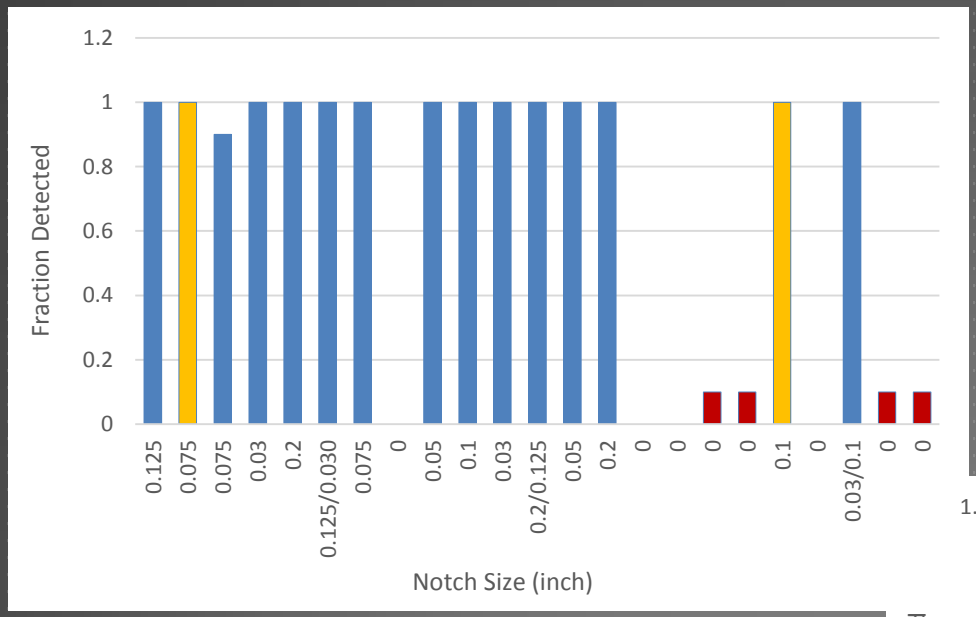


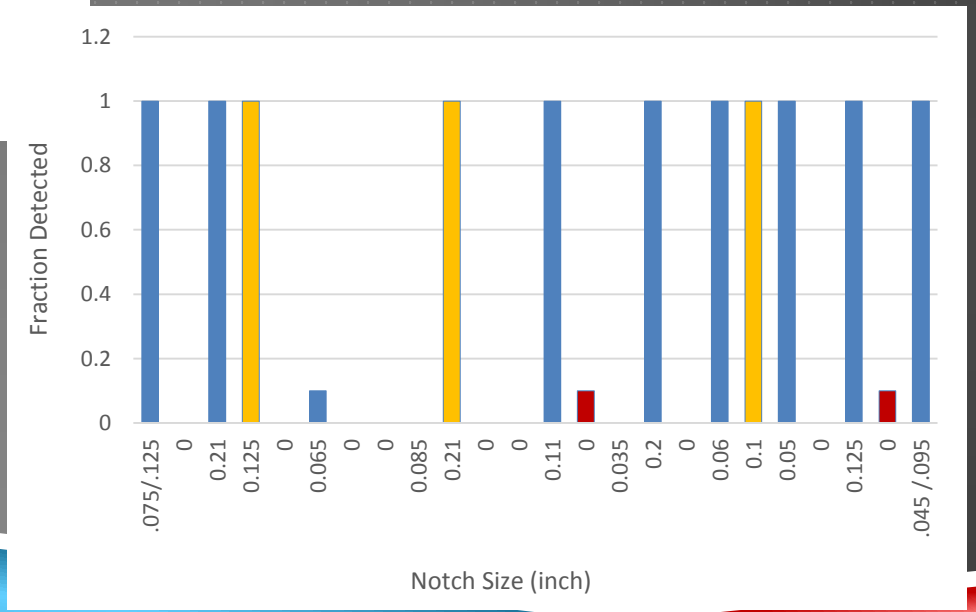
Mahalanobis distance compensates for covariance of data and can be thought of as the distance in standard deviations. Outliers (■) are actually further from centroid (in standard deviations) than pink (blank) points

MAHALANOBIS DISTANCE

- Measure of distance of a point from the mean in standard deviations.
- Accounts for different variances/covariances
- Needs the covariance matrix, C, and mean vector for the blanks
- If C and the mean vector are contaminated with crack data, data for all cracks will be masked, $d < d_{true}$

RESULTS


1.2
1
0.8
0.6
0.4
0.2
0
Fraction Detected
0.125
0.075
0.075
0.03
0.2
0.125/0.030
0.075
0
0.05
0.1
0.03
0.2/0.125
0.05
0.2
0
0
0
0
0.1
0
0.03/0.1
0
0
Notch Size (inch)


1.2
1
0.8
0.6
0.4
0.2
0
Fraction Detected
.075/.125
0
0.21
0.125
0
0.065
0
0
0.085
0.21
0
0
0.11
0
0.035
0.2
0
0.06
0.1
0.05
0
0.125
0
.045 /.095
Notch Size (inch)

ISSUES

- How to obtain an uncontaminated covariance matrix? Robust Statistics
- Lab samples are defect rich. How to generate large numbers of blanks like the real case? Bootstrap Method

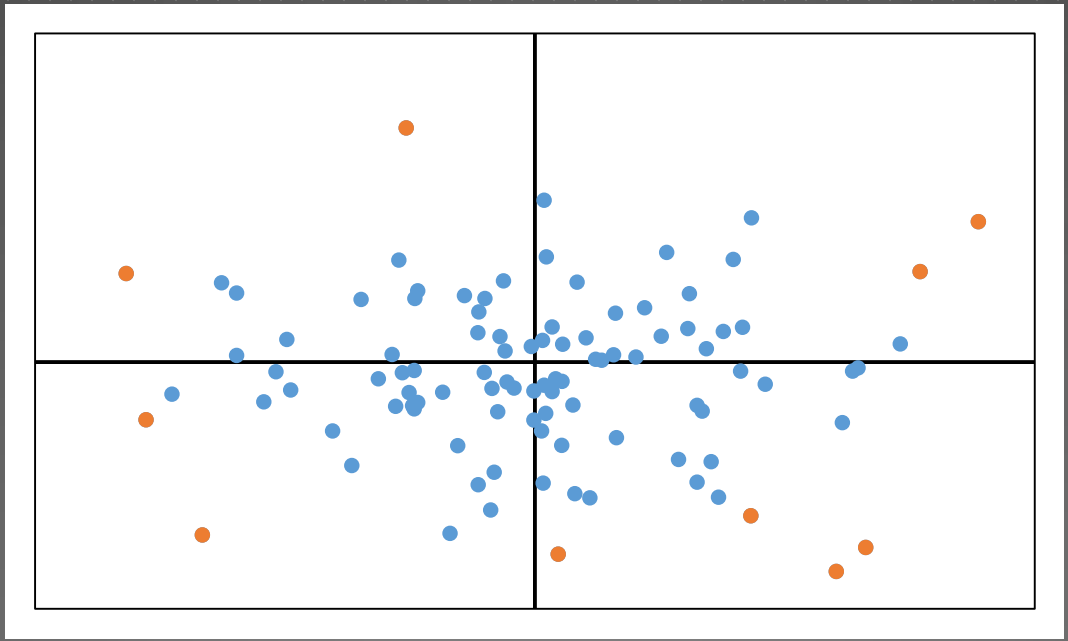
ROBUST STATISTICS

Find an uncontaminated kernel and calculate mean, covariance matrix

- Minimum Covariance Determinant
- Smallest Half Volume

Find the tightest data group that encloses a certain fraction, D, of the data
Want D to be as large as possible without capturing any outliers so estimate of C will be good

ROBUST STATISTICS



Only Use a certain data fraction (DF), ignoring most distant points

Use median instead of mean

Mean absolute deviation instead of standard deviation

BOOTSTRAP METHOD

Blanks

S1	S2	S3	S4	S5
2.35E+00	-1.58E+00	-3.29E-02	1.62E-02	-1.48E-02
4.52E+00	-8.96E-01	7.29E-02	-1.98E-02	1.66E-02
6.13E+00	-6.10E-02	-1.18E-02	1.61E-02	1.43E-02
6.16E+00	2.53E-01	-3.63E-03	-4.45E-02	-7.12E-03
6.68E+00	-9.94E-02	-1.83E-02	-4.91E-02	7.98E-03
6.71E+00	6.47E-01	3.22E-02	4.88E-02	1.43E-02

Cracks

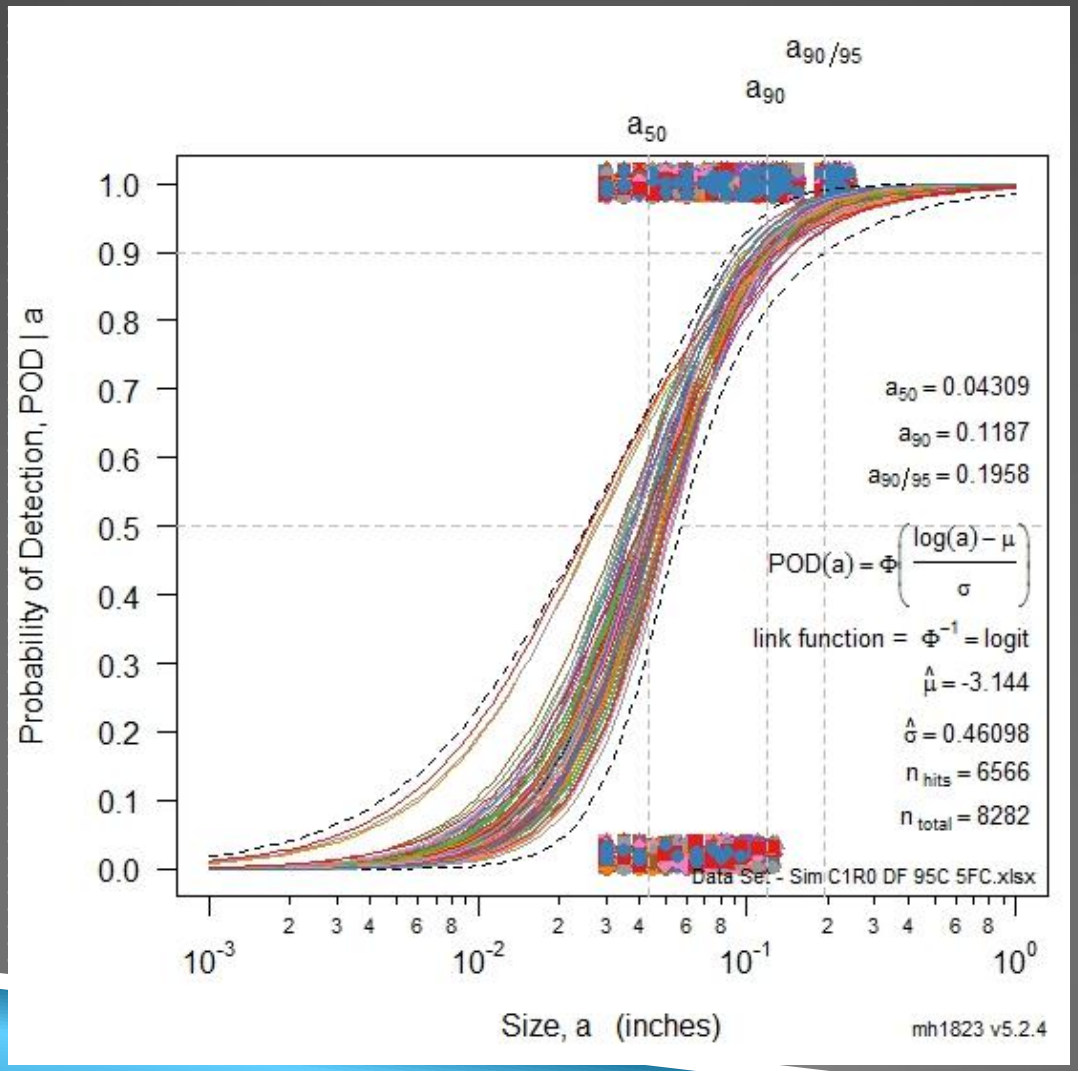
S1	S2	S3	S4	S5
8.19E+00	1.15E+00	-2.98E-02	1.55E-02	1.48E-04
4.33E+00	-4.63E-01	5.22E-03	9.47E-03	-4.60E-03
5.95E+00	4.28E-01	2.23E-02	3.48E-02	-6.60E-03
6.72E+00	3.91E-01	2.86E-01	-4.69E-02	-2.40E-03
4.52E+00	-4.66E-01	7.27E-02	8.54E-03	3.23E-03
5.96E+00	3.40E-01	3.78E-01	-3.34E-02	8.33E-04
7.46E+00	7.10E-01	-7.51E-03	-2.23E-03	1.53E-03

S1	S2	S3	S4	S5
8.19E+00	1.15E+00	-2.98E-02	1.55E-02	1.48E-04
4.33E+00	-4.63E-01	5.22E-03	9.47E-03	-4.60E-03
5.95E+00	4.28E-01	2.23E-02	3.48E-02	-6.60E-03
6.72E+00	3.91E-01	2.86E-01	-4.69E-02	-2.40E-03
4.52E+00	-4.66E-01	7.27E-02	8.54E-03	3.23E-03
5.96E+00	3.40E-01	3.78E-01	-3.34E-02	8.33E-04
7.46E+00	7.10E-01	-7.51E-03	-2.23E-03	1.53E-03
5.57E+00	8.44E-03	-2.27E-02	3.37E-02	5.07E-03
1.09E+01	1.42E+00	-2.38E-01	-2.93E-02	-1.76E-03
3.48E+00	-1.50E+00	-6.33E-02	-4.75E-02	-7.08E-03
9.64E+00	6.05E-01	-2.32E-01	-3.04E-02	-1.29E-02
8.25E+00	1.10E+00	-4.08E-02	1.55E-02	-4.24E-03
8.73E+00	1.23E+00	2.84E-02	-4.83E-03	4.00E-03
7.68E+00	1.16E+00	6.51E-02	3.76E-02	-5.10E-03
7.54E+00	7.60E-01	2.79E-01	-2.16E-02	-5.66E-03
5.02E+00	-3.61E-01	3.48E-02	4.17E-03	-9.05E-04
4.70E+00	-4.20E-02	3.67E-01	-1.01E-02	-4.55E-03
6.46E+00	3.24E-01	-2.02E-02	1.65E-02	-4.98E-03
4.67E+00	-4.43E-01	-6.56E-02	3.72E-02	-1.84E-03

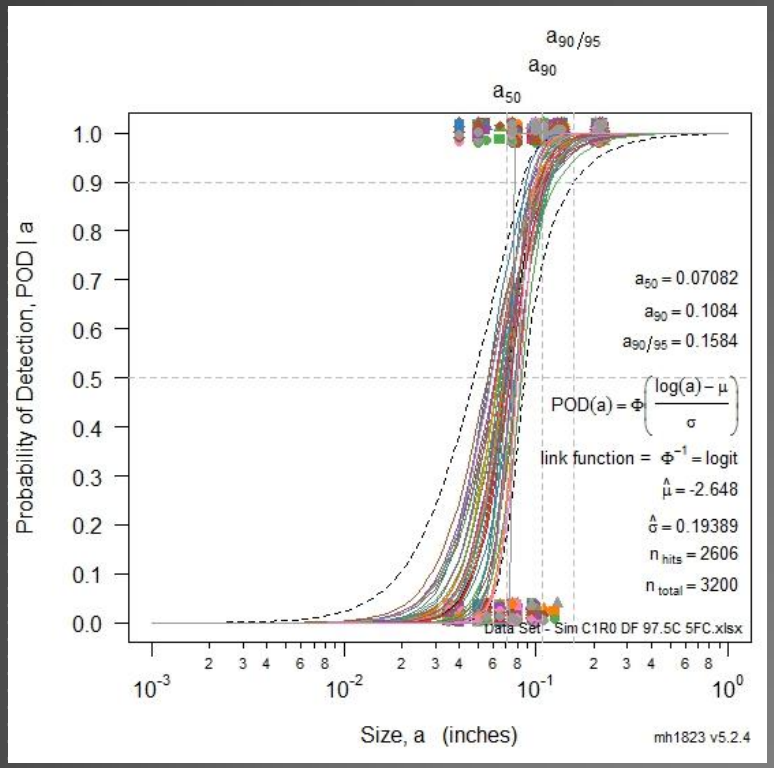
PRELIMINARY RESULTS

- Need at least 40 fasteners in group
- Want data fraction, D, to be as large as possible

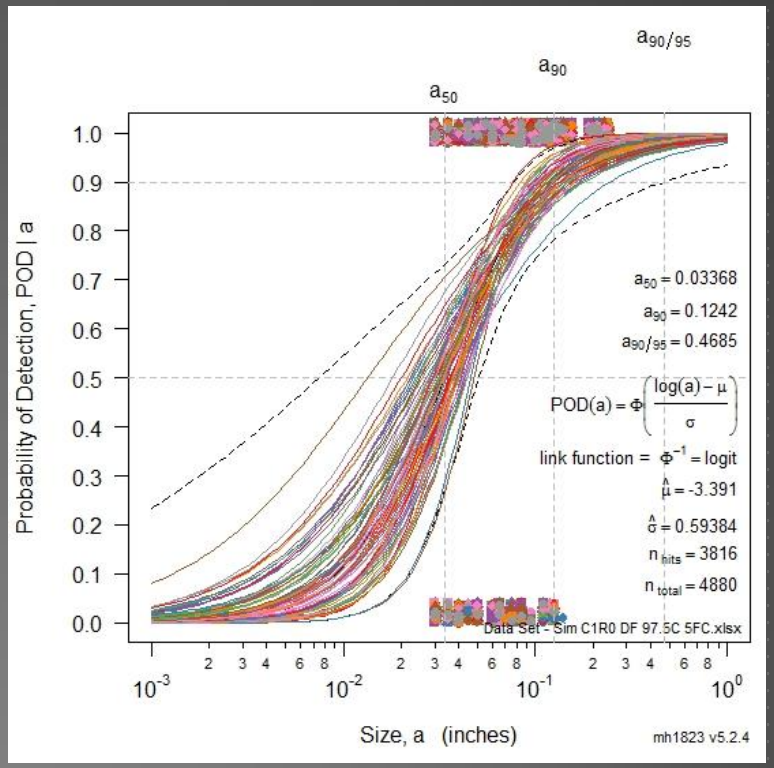
POD


$a_{90/95}$
a_{90}
a_{50}
Probability of Detection, POD | a
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
$a_{50} = 0.04309$
$a_{90} = 0.1187$
$a_{90/95} = 0.1958$
$POD(a) = \Phi\left(\frac{\log(a) - \mu}{\sigma}\right)$
link function = Φ^{-1} = logit
$\hat{\mu} = -3.144$
$\hat{\sigma} = 0.46098$
$n_{hits} = 6566$
$n_{total} = 8282$
Data Set: - Sim C1R0 DF 95C 5FC.xlsx
10^{-3}
10^{-2}
10^{-1}
10^{0}
Size, a (inches)
mh1823 v5.2.4

POD



Top (40)



Bottom (60)

POD

FC/DF	95%	97.5%	100%
5%	0.139	0.148	0.149
10%	0.124	0.115	0.115

Bolt hole (unfinished) 0.050

SUMMARY

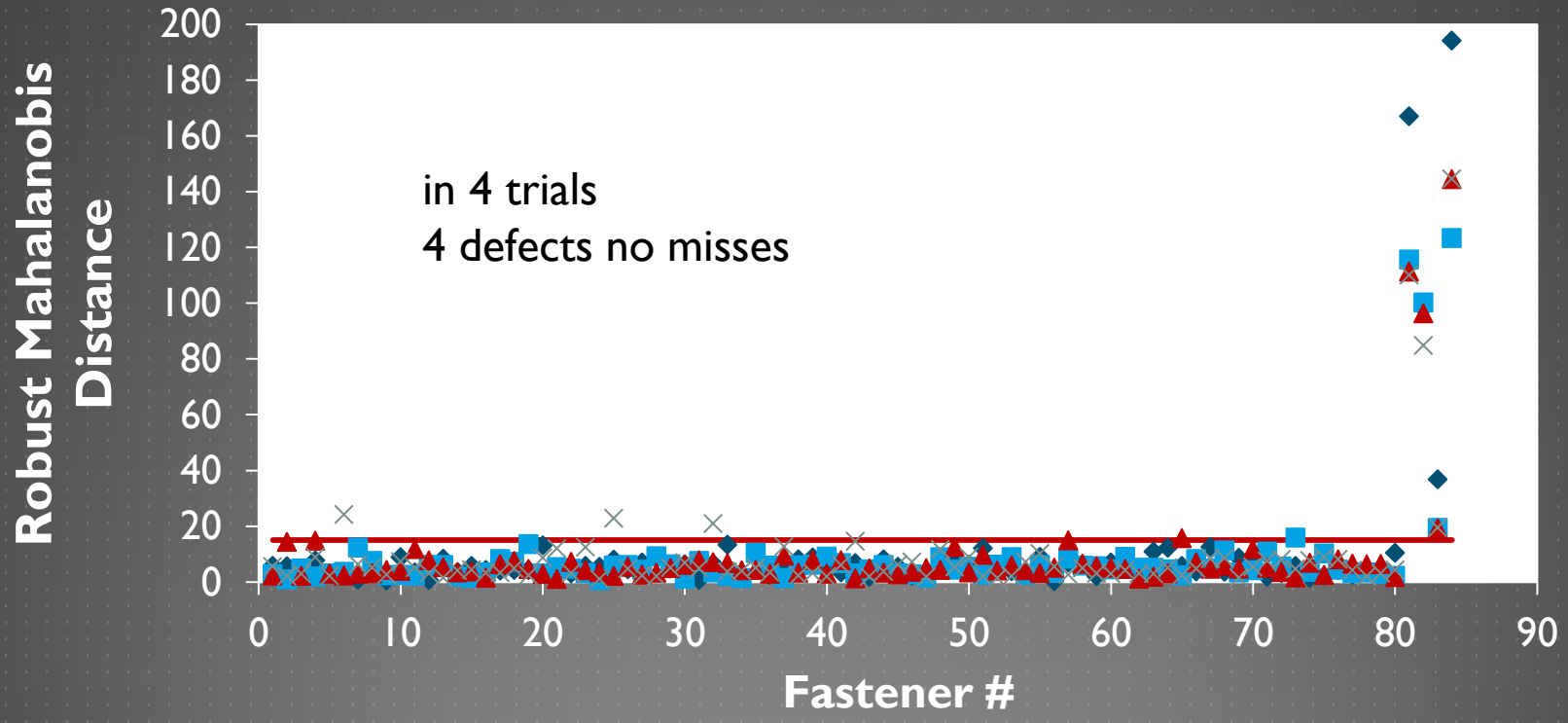
- Cluster approach can detect defects without calibration
- Robust statistics allow the technique to be used blind when defect density is low.
  - What is the cost of a "miss" or false call
- Need to run blind detection on higher defect densities to determine how this affects POD
- Can we use a second criterion to reduce misses?

ACKNOWLEDGEMENTS

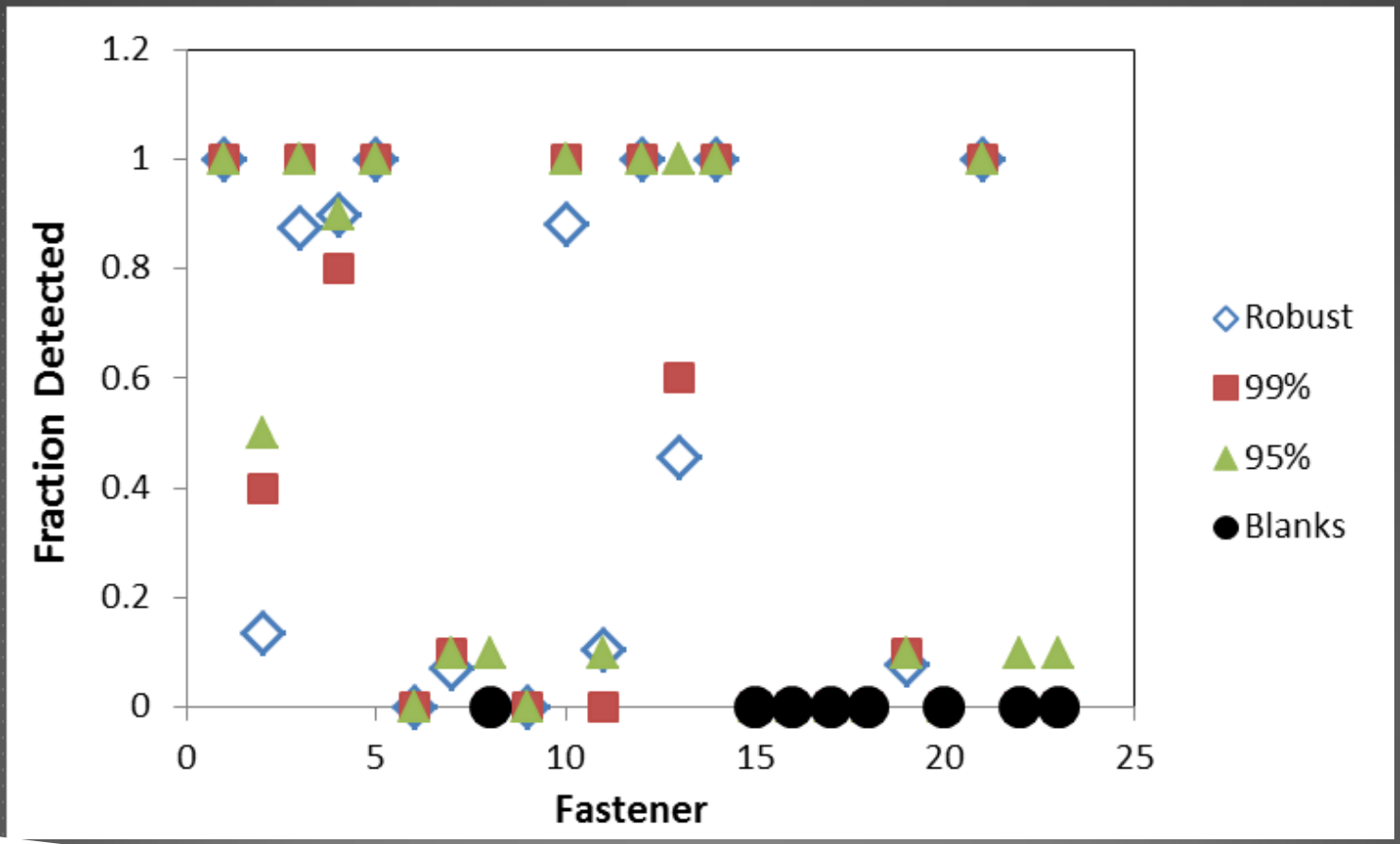
- DTA AERAC Committee

QUESTIONS ?

ROBUST STATS WITH DEFECT



NAVAIR DATA


1.2
1
0.8
0.6
0.4
0.2
0
Fraction Detected
0
5
10
15
20
25
Fastener
Robust
99%
95%
Blanks