An Eddy Current Case Study using NASA's Transfer Function and Limited-Sample Probability of Detection Guidebooks

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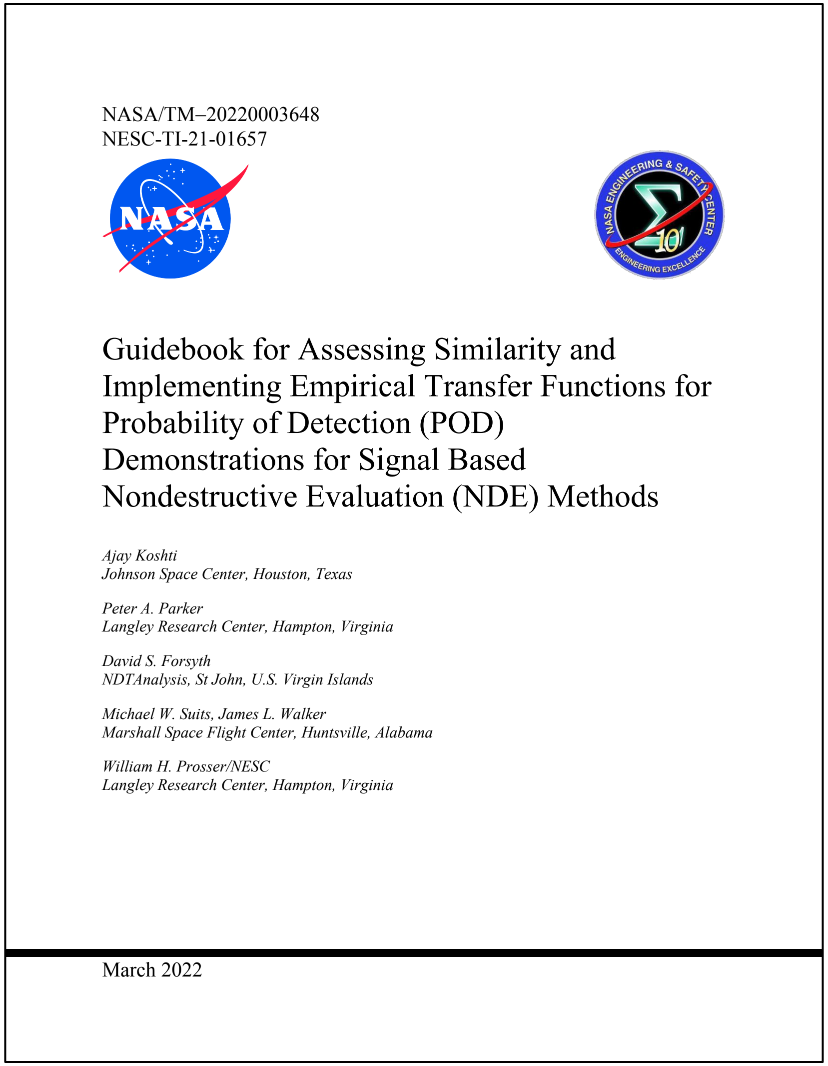
Standard and Special NDE - Background

- Probability of detection (POD) requirements for NASA fracture-critical human-rated systems can be met by either
  1. Similarity to Standard Nondestructive Evaluation (NDE) flaw sizes
  2. Inspector-specific POD demonstration, known as Special NDE
- Standard NDE flaw sizes represent the detection capability of most qualified inspectors based on POD studies on fatigue cracks in flat aluminum specimens for the Space Shuttle Program Orbiter fracture control plan.
- To use Standard NDE, similarity rationale between the Standard NDE POD study and flight component conditions is required.
  – Evaluation considers materials, surface finish, component geometry (e.g., curvature, corners, welds), and inspection access.
  – Similarity has been based on a qualitative engineering evaluation.

Transfer Function Motivation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NESC-TI-21-01657

Guidebook for Assessing Similarity and Implementing Empirical Transfer Functions for Probability of Detection (POD) Demonstrations for Signal Based Nondestructive Evaluation (NDE) Methods

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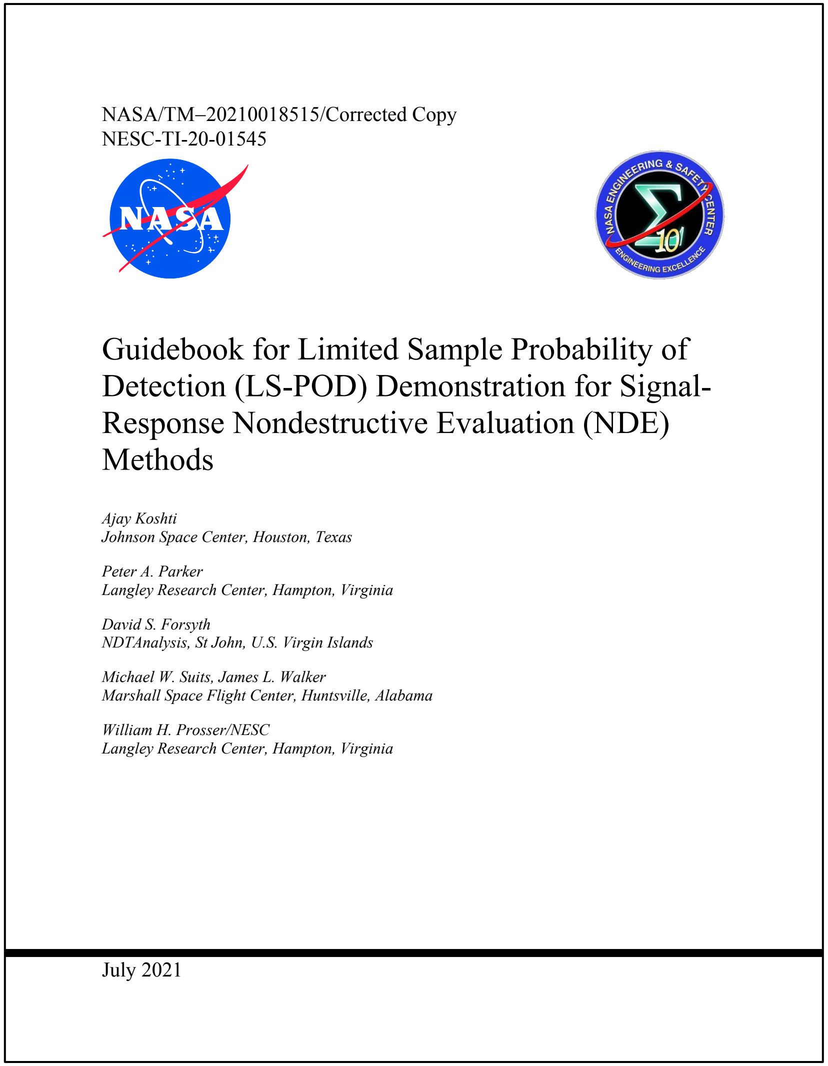
- **NASA recently published a quantitative methodology to evaluate similarity.**
- **If similarity is not supported, the methodology enables the development of a flaw size transfer function**
- **POD demonstration is performed on the "transferred" flaw size**

Limited Sample POD (LS-POD) Demo



NASA/TM–20210018515/Corrected Copy
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Guidebook for Limited Sample Probability of Detection (LS-POD) Demonstration for Signal-Response Nondestructive Evaluation (NDE) Methods

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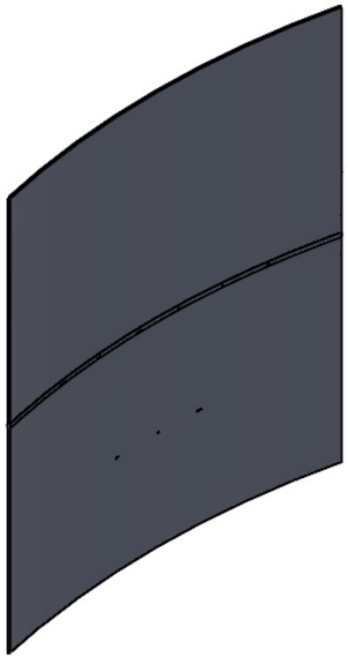
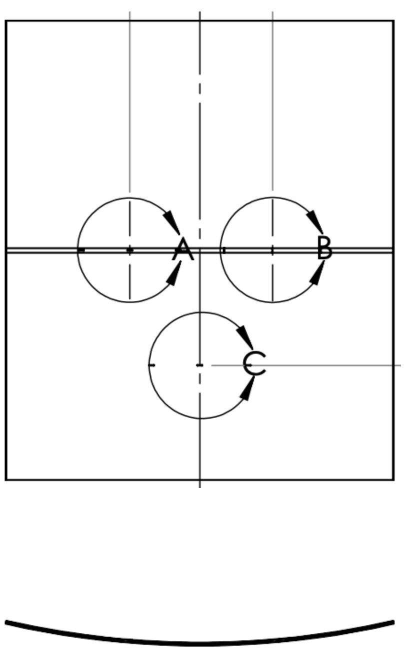
- **To reduce POD demonstration resources, NASA published a new methodology that uses fewer specimens than existing methods.**
  - **Most common is the binomial point-estimate method, known as 29/29.**
  - **LS-POD offers an approach with a minimum of 10 flaws.**
- **LS-POD applies to signal-response NDE methods, e.g., eddy current, not hit/miss methods**

Eddy Current Case Study



Curved metallic panel with a seam welds



Required to demonstrate POD of far-side inspection of flaws in the weld

- **Growing fatigue cracks in a curved flight panel was not desirable (i.e., infeasible).**
- **What size fatigue crack in a flat plate provides representative POD of the critical crack size in a weld of the curved specimen?**

Strategy Overview

- **Place electro-discharge machined (EDM) notches in flight component of varying length, depth, aspect ratio, and orientation.**
- **Compare EC signal (mean and variability) from notches in flight component to notches in flat specimens of identical material.**

Transfer Function Study Notch Sizes

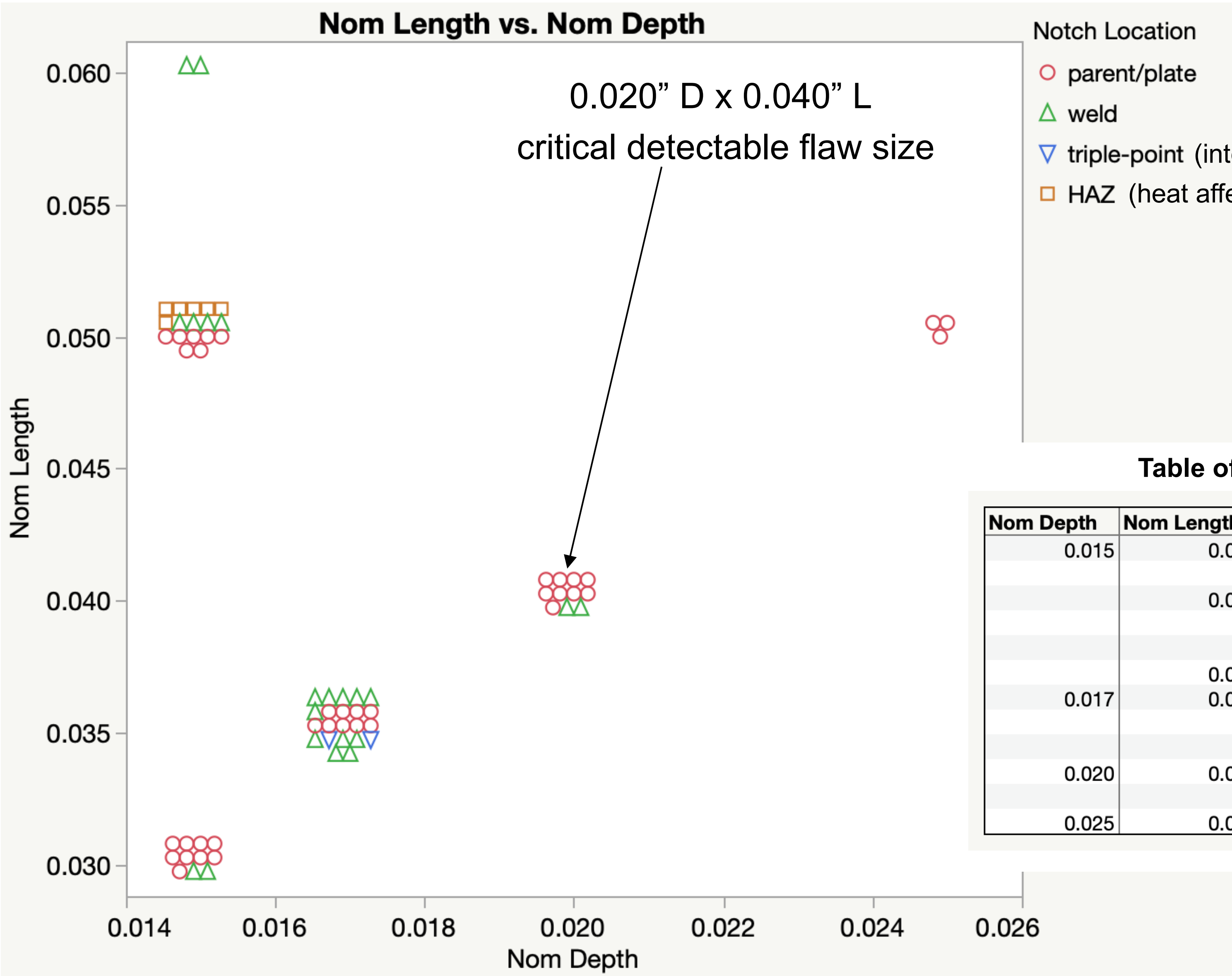


Table of Notches

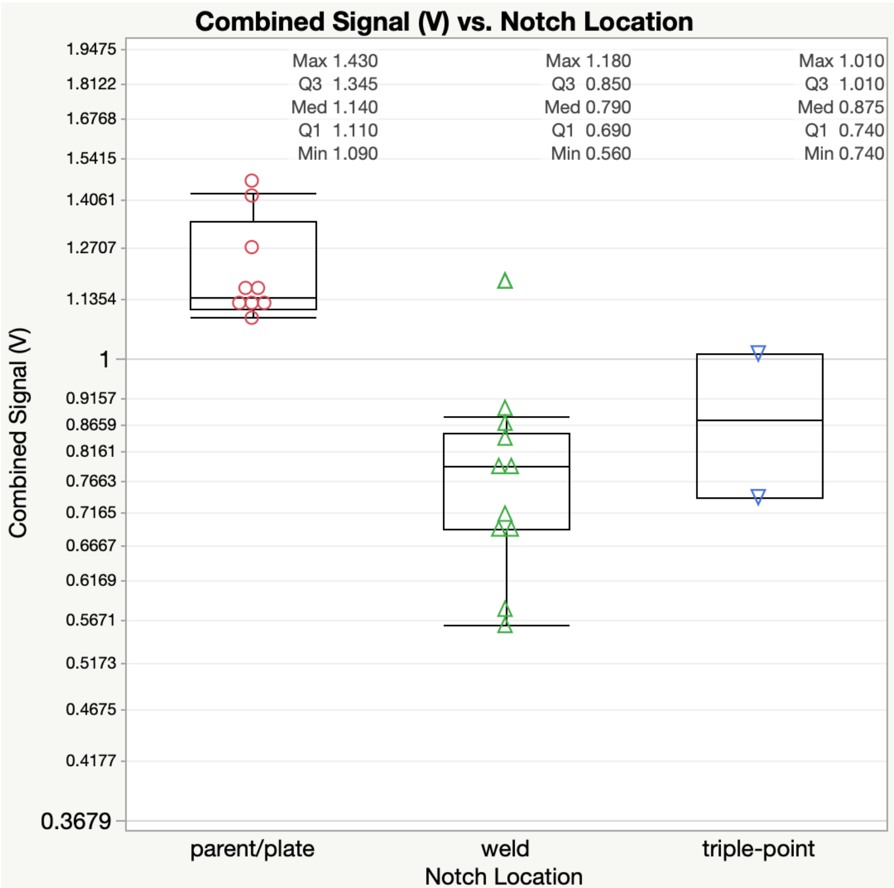
Nom Depth	Nom Length	Notch Location	N
0.015	0.030	parent/plate	5
		weld	2
	0.050	parent/plate	7
		weld	4
		HAZ	6
	0.060	weld	2
0.017	0.035	parent/plate	9
		weld	11
		triple-point	2
0.020	0.040	parent/plate	5
		weld	2
0.025	0.050	parent/plate	2

Possible Outcomes of Transfer Function Study

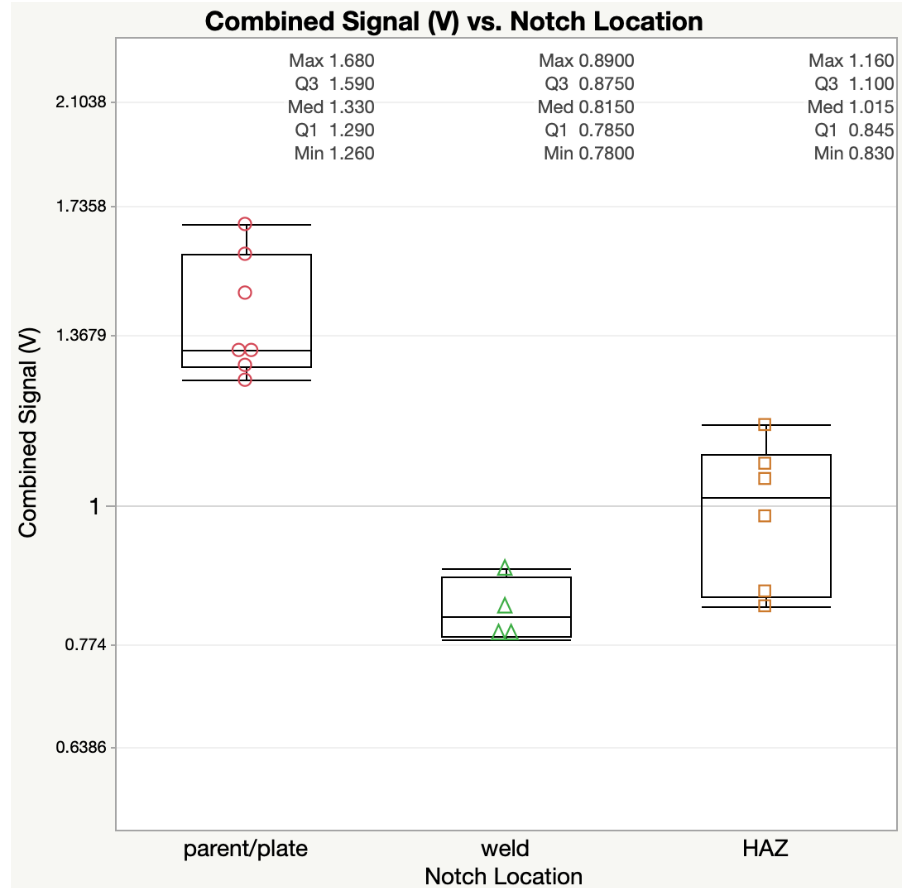
- **If the mean signal level and variability are ‘indistinguishable’ between the notches in the flight component and the flat specimen, then we claim similarity, i.e., there is no geometry transfer function required.**
  - **Similarity is a 1-1 transfer function, and the critical detectable flaw size would be grown in a flat specimen for POD demonstration.**
  - **Guidebook provides the analysis approach and decision criteria to evaluate if the EC signals are ‘indistinguishable.’**
- **If there is a ‘distinguishable’ difference between the mean and/or variability in the EC signal level, then a geometry-based Transfer Function is estimated to predict a representative flaw size (knocked-down size) in a flat panel for POD demonstration.**
- ***Note, this is not a crack-to-notch transfer function, as most commonly pursued. It is a geometry-based transfer function, such that POD is demonstrated on cracks not notches.***

Identifying Bounding Case Location

0.0175” deep x 0.035” long notches



0.015” deep x 0.050” long notches

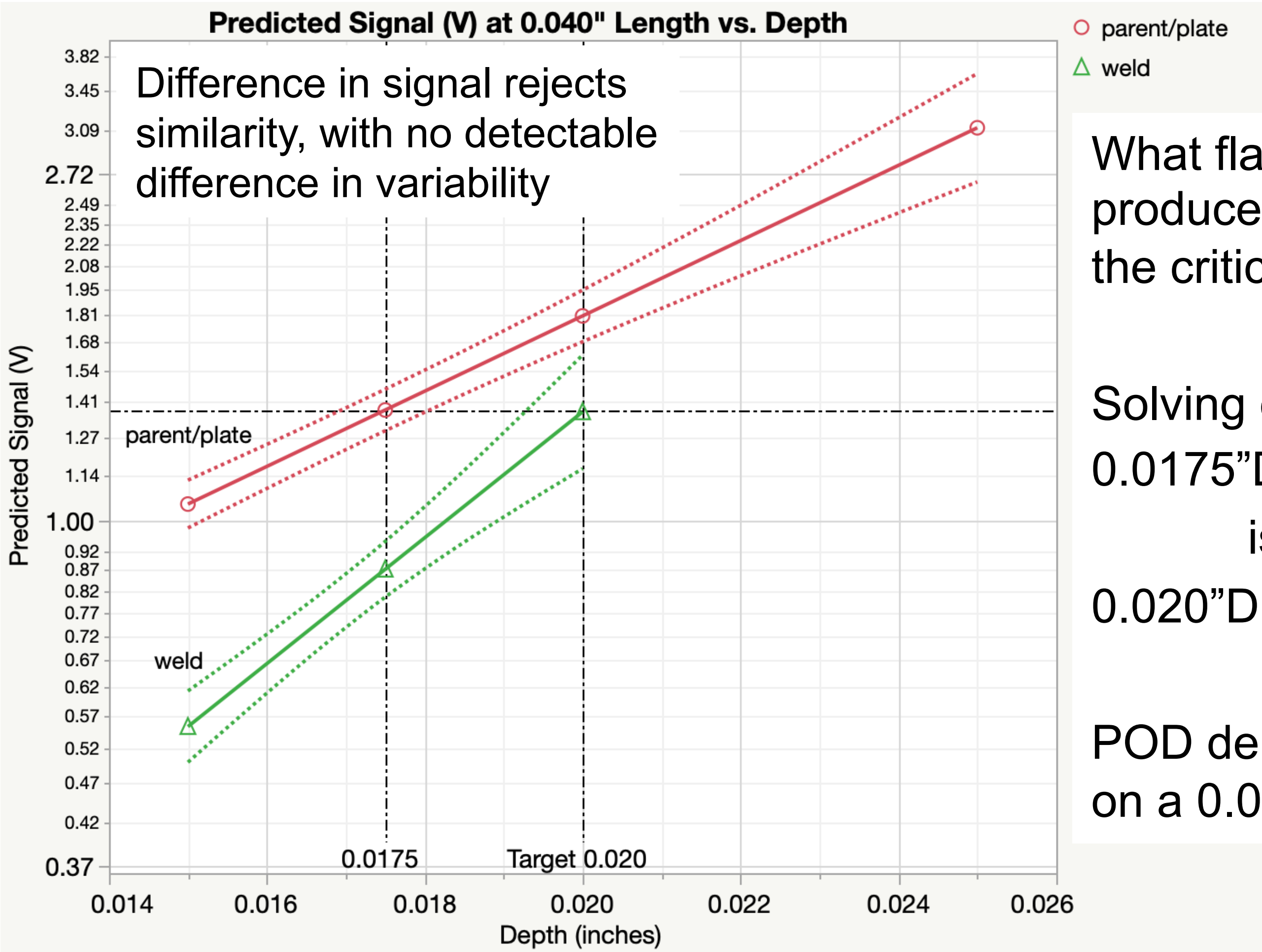


- EC Signal at Weld is lower than Plate
- Weld is lower than Triple-Point

- Weld is lower than Heat Affected Zone

Single seam weld is considered the bounding location, i.e., it will suggest the smallest flaw in the plate for POD demonstration.

Transfer Function and POD Flaw Size



What flaw size in the plate produces the same EC signal as the critical flaw in the weld?

Solving equations (or graphically):
0.0175"D x 0.040"L flaw in a plate
is representative of a
0.020"D x 0.040"L flaw in the weld.

POD demonstration is performed on a 0.0175"D crack in a plate.

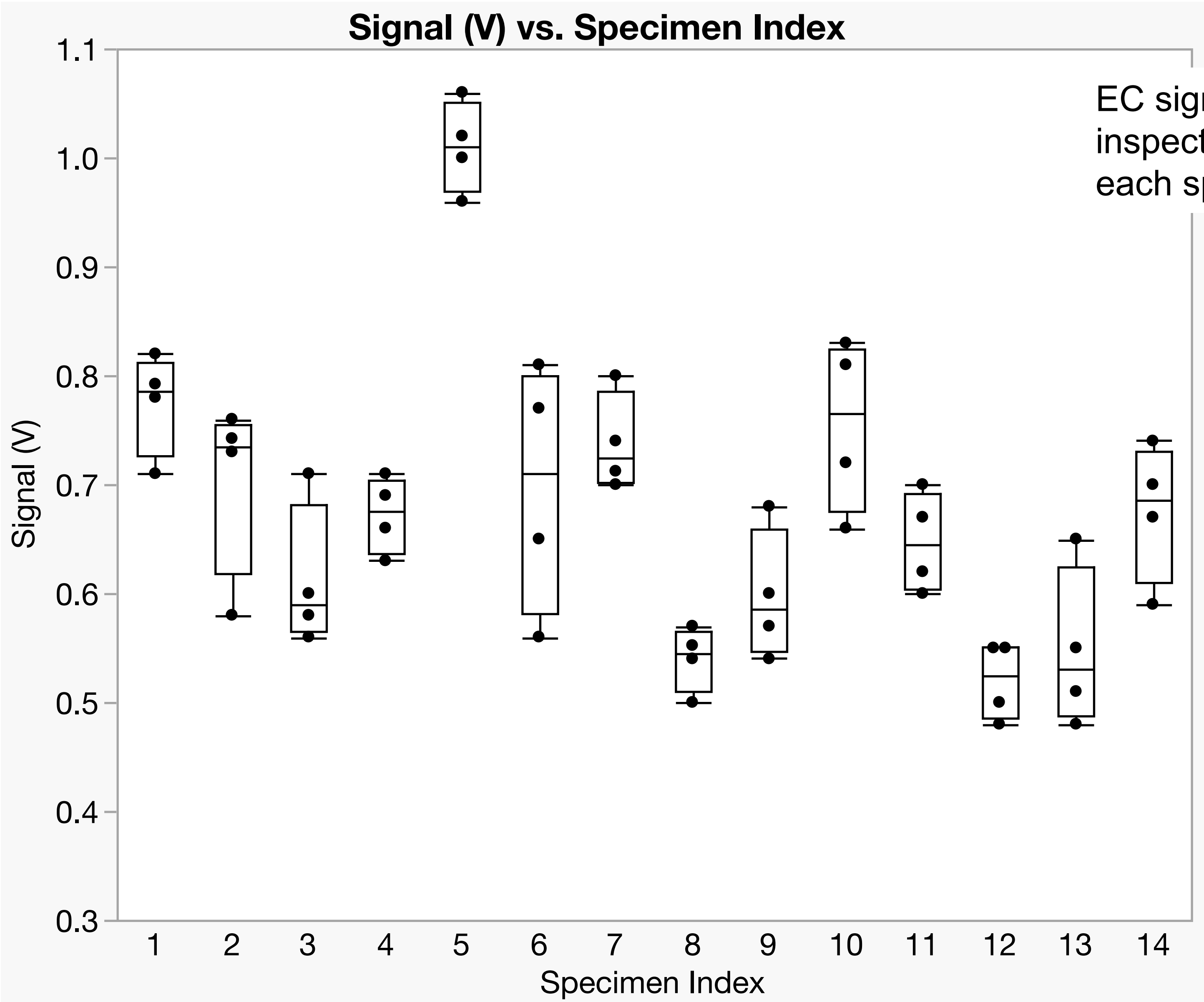
$$y_{\textbf{parent/plate}} = e^{-2.8755 + 108.65*\textbf{Depth} + 32.301*\textbf{Length}}$$

$$y_{\textbf{weld}} = e^{-4.6129 + 181.77*\textbf{Depth} + 32.301*\textbf{Length}}$$

LS-POD Demonstration

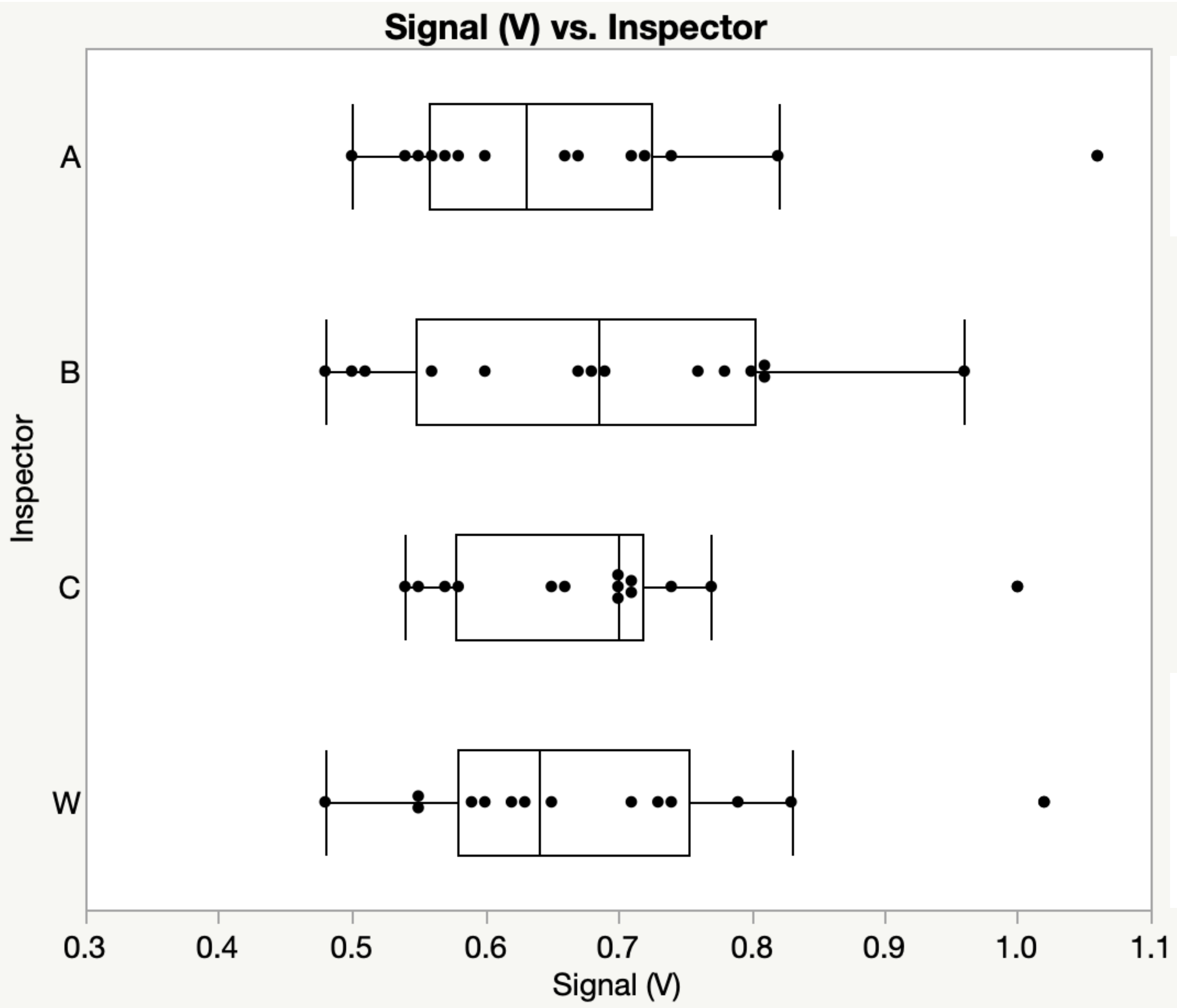
- **A Special NDE demonstration was conducted according to NASA/TM-20210018515, "Guidebook for Limited Sample Probability of Detection (LS-POD) Demonstration for Signal-Response Nondestructive Evaluation (NDE) Methods."**
- **16 plate specimens were fabricated from the flight component material and 1 fatigue crack (0.0175"D x 0.035"L) was grown in each specimen.**
- **2 specimens were broken open to independently characterize crack depth, length, and aspect ratio.**
- **4 inspectors were presented with 14 crack specimens, and they reported their EC signal level from each crack.**
- **4 inspectors performed noise measurements on unflawed areas of the flight component weld regions to assess probability of false calls (POF) at a given decision threshold.**

LS-POD EC Signals by Specimen



EC signals from the 4 inspectors are shown for each specimen.

Distribution of EC Signals by Inspector

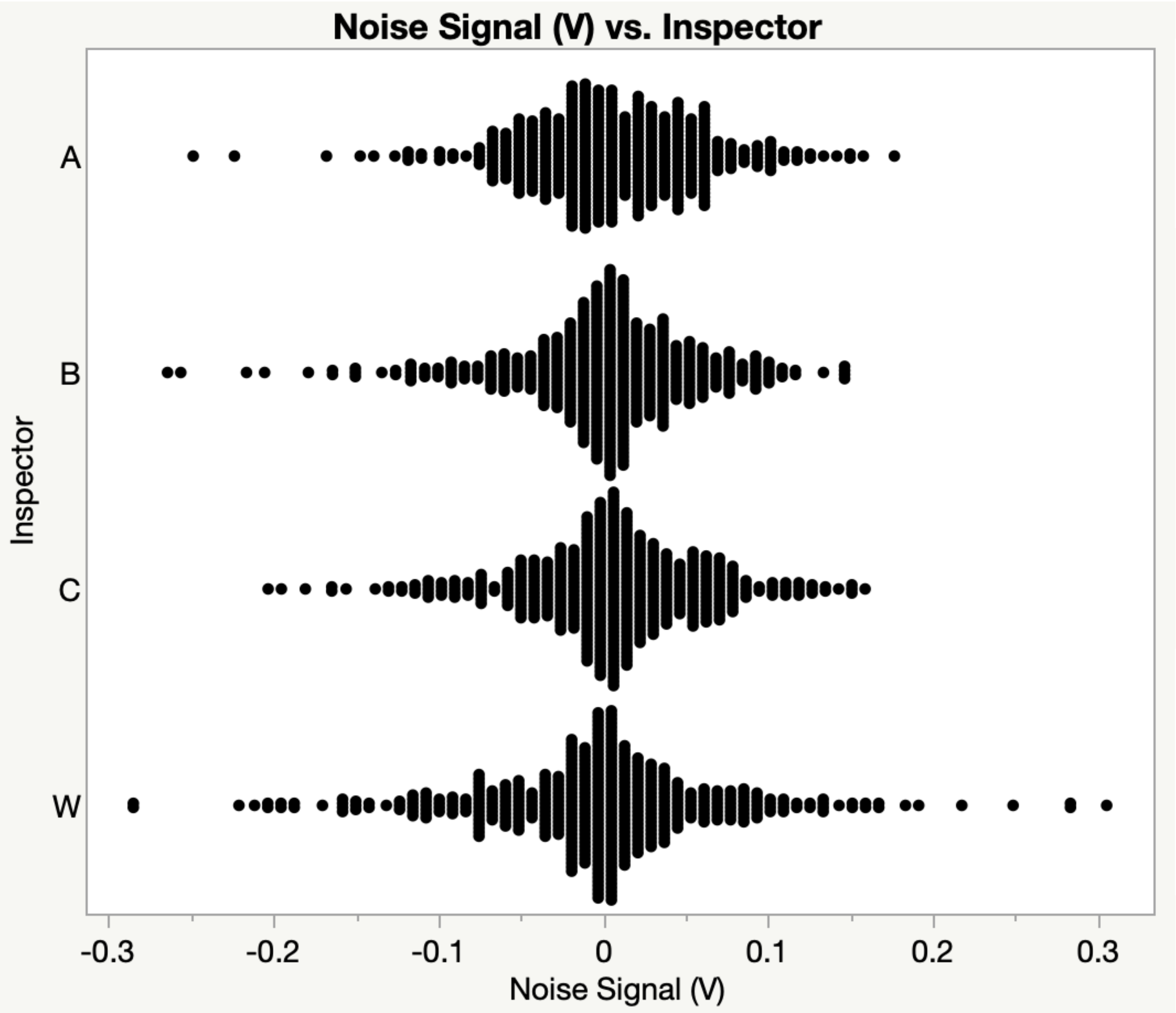


90/95 lower bound signal level is estimated for each inspector, as follows.

Inspector	90/95 Signal (volts)
A	0.44
B	0.44
C	0.49
W	0.45

A decision threshold of 0.44V provides at least 90/95 detection capability for all inspectors

Noise Measurements by Inspector

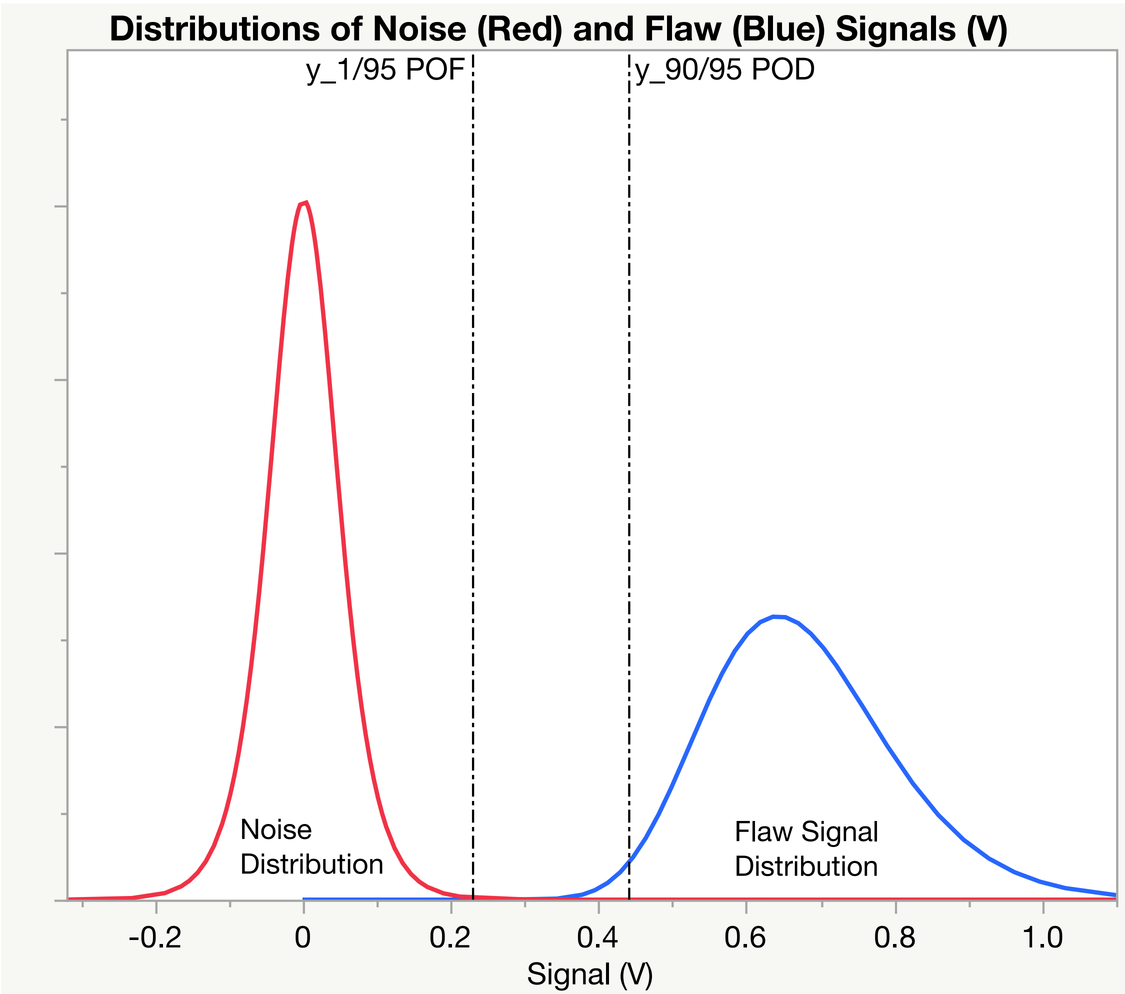


1/95 upper bound on noise signal level is estimated for each inspector, as follows.

Inspector	1/95 Noise (volts)
A	0.147
B	0.144
C	0.149
W	0.234

A decision threshold of 0.44V is sufficient to ensure a maximum of 1/95 POF, i.e., 1% POF.

LS-POD Graphical Summary



The 90/95 lower bound of the flaw signal distribution is greater than the 1/95 upper bound of the noise signal distribution, therefore the POD demonstration was successful.

A decision threshold would be set between the 1/95 noise bound and 90/95 flaw signal bound, preferably toward the 90/95 flaw signal bound.

Concluding Remarks

- **NASA has introduced two new POD methodologies that offer practical benefits to operational inspection demonstrations.**
  1. **Transfer function approach that evaluates similarity.**
  2. **Limited sample POD demonstration reduces resource demands.**
- **Both methodologies were incorporated by reference in NASA's Nondestructive Evaluation Requirements for Fracture-Critical Metallic Components (NASA-STD-5009C)**
- **The methodologies were illustrated with an eddy current detection capability of far-side inspection capability of flaws in welded panels.**
  - **A geometry-based transfer function was developed using EDM notches in flight component and plate geometry to estimate the Special NDE flaw size that is representative of the critical initial flaw size.**
  - **Fatigue cracks of the transferred flaw size in plates were used for a LS-POD Special NDE demonstration.**