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Probability of Detection of Automated Tap Testing for Disbond Detection in Honeycomb Structures

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Background

Adhesive-bonded and composite materials are increasingly used in the aerospace industry;

- ❑ High strength-to-weight ratio
- ❑ Damage tolerance, corrosion resistance and high strength

Structural and flight control components made of composite materials are susceptible to defects

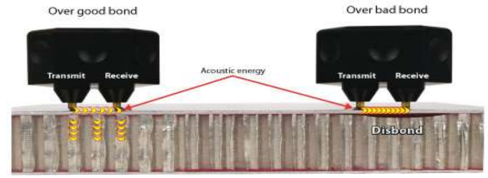
- ❑ Created either during manufacturing
- ❑ Operational life (high loads or foreign object impact damage)

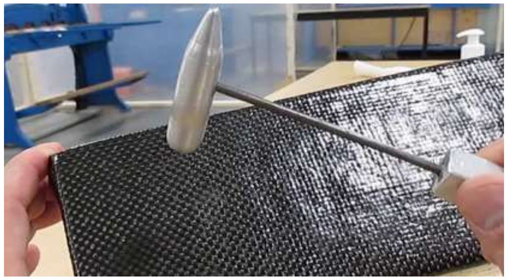
Hidden defect in a critical location has a potential to cause component failure

NDT of Composite

NDT play a major role for evaluation of quality & integrity of composite materials

- ❑ Lack of appropriate NDT method for inspecting composite
- ❑ Increased demand for development of improved NDT
- ❑ More reliable and sensitive method than its predecessor
- ❑ Different types of testing equipment/methods being used
- ❑ Visual inspection, Tap testing, Ultrasonic, Radiography

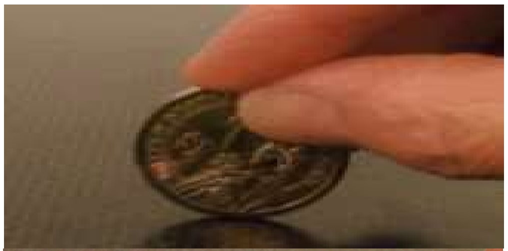


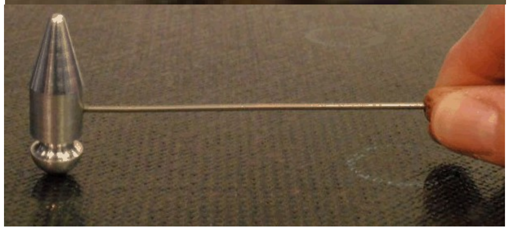


Manual Tap Testing

Tap testing (oldest/simplest)

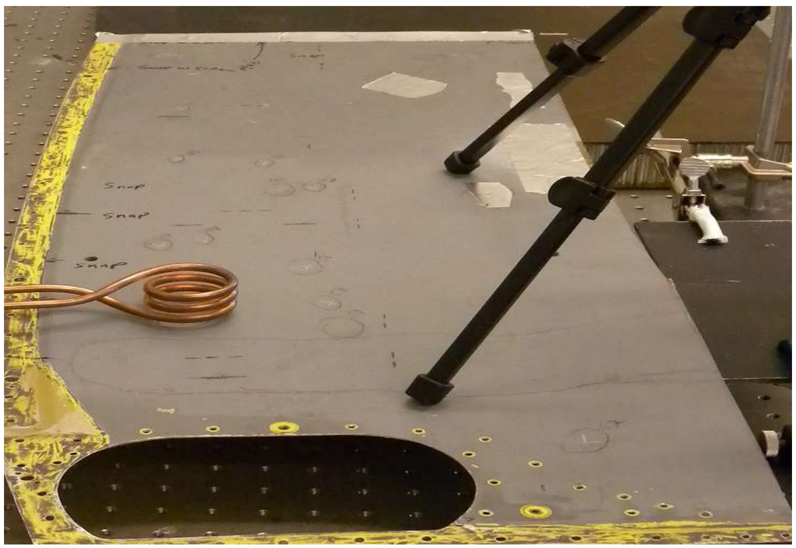
- Primary inspecting method laminated, sandwiched, or bonded honeycomb composite structures)
- Well bonded area → even pitch sound
- Disbonded area → dead or dull sound
- Earliest form of bond testing is coin tap followed hammer or electronic automated method.
- Manual tap performed by non-certified personnel
- Highly dependent on the inspector’s ability to hear and interpret the results





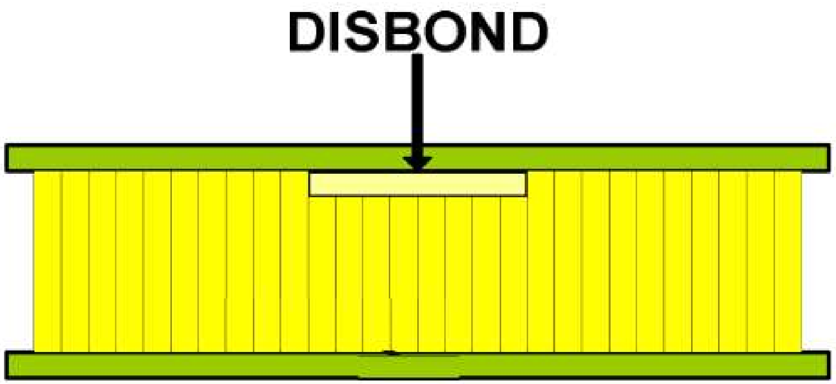
Motivation

The primary inspection method of the targeted honeycomb composite structures is tap testing. It is suspected that current tap testing procedures result in an abundance of false calls that lead to aircraft over-maintenance.



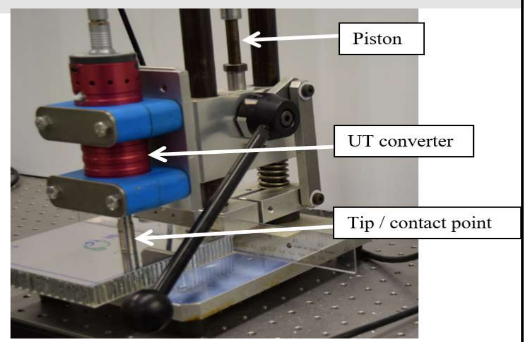
Objective of Study

Investigate & quantify the technical capability of manual vs. automated tap testing procedures on representative honeycomb composite panels to determine if automated tap testing can improve the inspection efficiency and reduce false call rate to detect disbond.

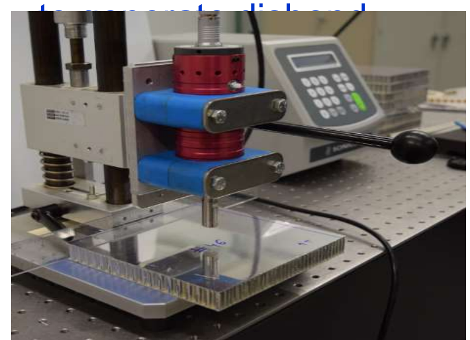


Specimen Setup

- Test articles were modeled as representatives of a helicopter structure
- A set of specimen (12”x12”) manufactured, representative to aluminum-skin aluminum-core honeycomb structures
- New process has been developed to generate controlled disbond without surface dent in honeycomb panels
- **Skin** type / thickness: aluminum 2024-T3, 0.020 inch thick
- **Core**: 0.75 inch thick aluminum alloy 5052.
- **Paint**: All panels were primed and painted with a glossy white finish paint
- **Eight test panels** containing a total of 70 different damage sites that included **dents, disbonds**



Ultrasonic welder and impact drop tower setup

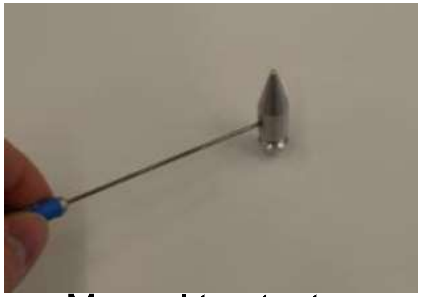


Flaw Size Distribution

- ❑ Flaw distribution was set based around the 12.7 mm (0.5 inch) target flaw size to be detected
- ❑ Typical size of manual Tap testing (inspector guess)
- ❑ 6 to 25 mm (0.25–1.0 inch) diameter flaws divided into five discrete sizes (6, 10, 13, 19, and 25 mm)
- ❑ One large 76 mm (3 inch) diameter flaw
  - ❖ flaw that should be found by all inspector
- ❑ A minimum of 51 mm (2 inch) separation between flaws
  - ❖ to eliminate signal cross-talk
  - ❖ Except closely clustered flaws
- ❑ Few dents to confuse the inspector.
  - ❖ to eliminate signal cross-talk

Inspection by Tap Testing

- ❑ Inspectors (11) were provided with the same experimenter briefing package.
- ❑ Inspector required to mark the flaw size & shape
- ❑ No time constrain to assure all flaws to be found
- ❑ Both manual tap and automated tap tester with the aim to detect 0.25 inch diameter disbond
- ❑ Dents containing disbond were considered as defects
    - ❖ dents without disbond are considered a sound area
- ❑ Automated tap testing inspections, the inspectors were to record the maximum value being displayed

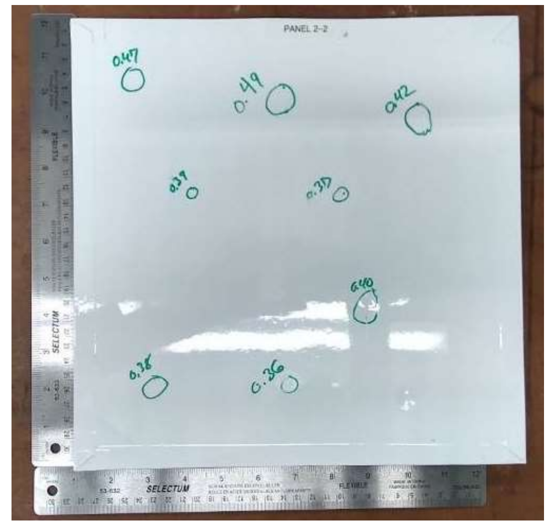


Manual tap tester

Automatic tap tester

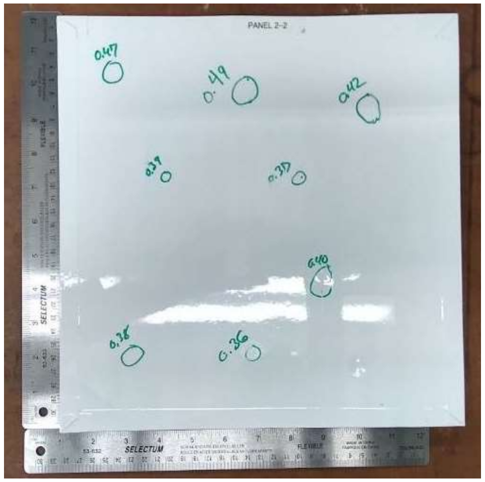
Inspection Data

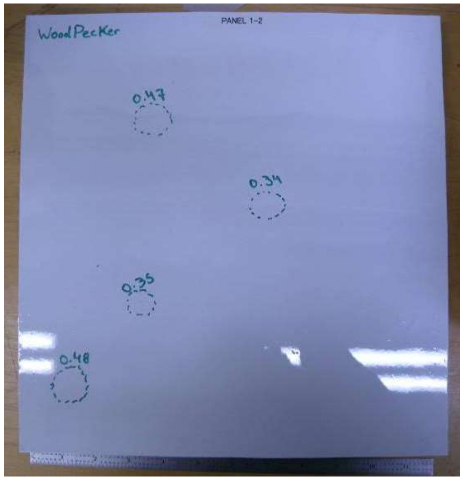
- ❑ Whenever the inspectors found a flaw, they were required to mark the flaw size (diameter) and shape
- ❑ Images taken after the inspections, where the inspectors had marked all the detected defects were analysed
- ❑ Sizing was not taken into consideration for this study
- ❑ From images, various disbond sites were identified along with hit / miss and false calls
    - ❖ defect is detected, hit or 1
    - ❖ defect is not detected, miss or 0
    - ❖ false calls: calling a defect when none is present



Example Inspection Data

- ❑ All the inspector detected defects images data were analysed
- ❑ Compared with the location of the flaws (hit or miss; and false calls data)
- ❑ Inspected data used as in put for POD analysis

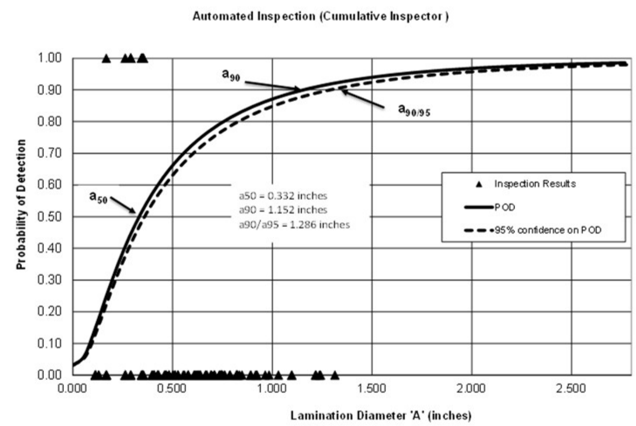




Probability of Detection (POD)

The reliability of a NDT technique is quantified in terms of the probability of detection (POD),

- Evaluate performance of NDT technique, selection and optimization of technique
- Probability of detecting flaw against a characteristic parameter of the flaw (usually its size)
- Expressed as a curve with a specified confidence level
- Estimation relies on large number of realistic defect specimen, followed by practical trials
- Estimated entire curve, focus on a particular point a_{90} and $a_{90/95}$ estimate along the POD curve



Probability of Detection (POD) Data

POD analysis relies on two types of NDT Data related to the presence or absence of a defect

- ❑ **hit/miss inspection data (binary type)**
  - ❖ defect is detected, **hit** or 1, defect is not detected, **miss** or 0, calling a defect when none is present, **false call**
- ❑ **"*â vs a*" inspection data**
  - ❖ ***a*** is the defect size, ***â*** is the measured response of a
- ❑ Two approaches have different requirements.
- ❑ ***â vs a*** analysis, the inspection data has to satisfy four assumptions (linearity of signal, gaussian residual, uniform variance, independence of residuals etc.)
- ❑ Manual and automatic tap testing does not meet ***â vs a*** analysis requirement (inspection data are binary in nature)

Probability of Detection (POD) Models

Various probability distribution models used in deriving equation for constructing POD curve as a function of defect

- ❑ **Log-logistic (logic or log odds) distribution model**

$$POD(a) = \frac{e^{\{\beta_0 + \beta_1 \ln(a)\}}}{1 + e^{\{\beta_0 + \beta_1 \ln(a)\}}} \qquad POD(a) = \frac{1}{1 + e^{-\left[\frac{\pi}{\sqrt{3}}\left(\frac{\ln a - \mu}{\sigma}\right)\right]}}$$

- ❑ **Log-normal distribution model**

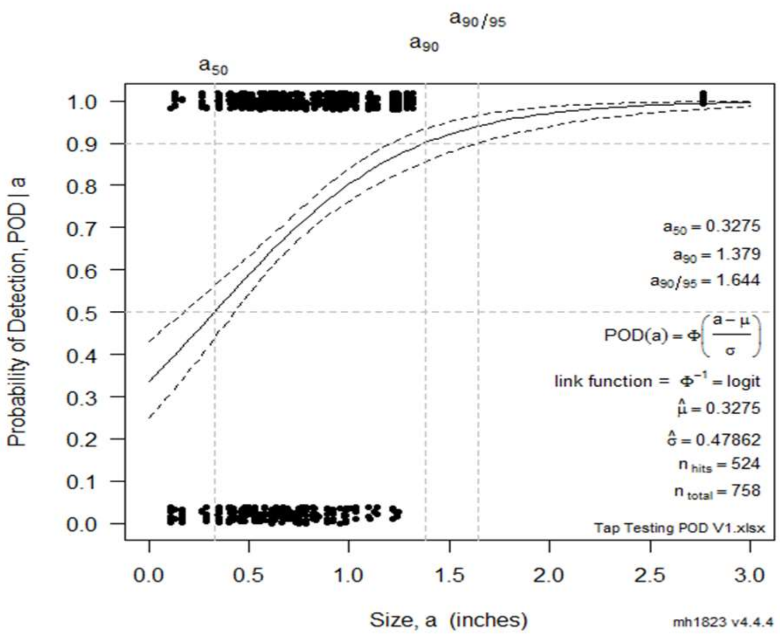
$$POD(a) = \phi\left(\frac{\ln a - \mu}{\sigma}\right)$$

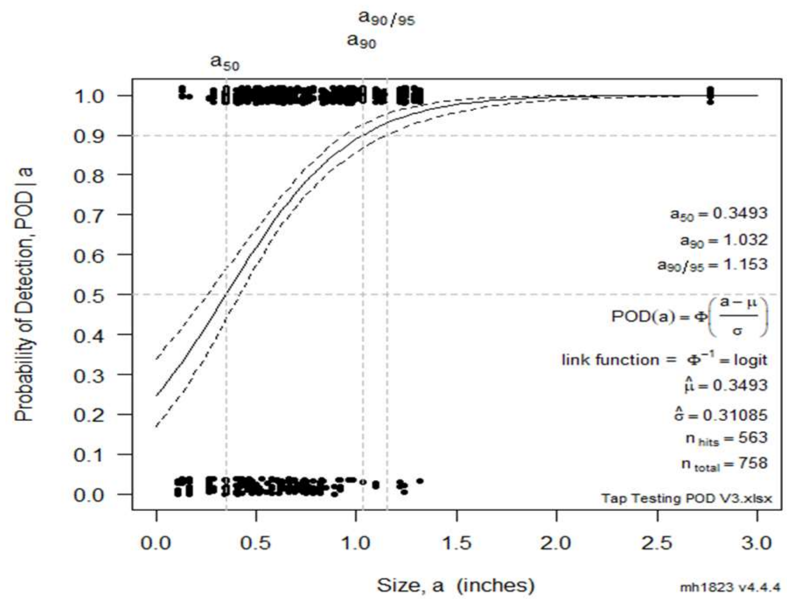
- ❑ **Confidence bound (*Cheng and Else approach*)** to address the statistical uncertainty in estimating the parameters (location parameter μ, scale parameter σ)

Inspection Result

- Manual inspection yielded an average of **48 hits** and **21 misses** per inspector and **43 false calls**
- Automated inspection yielded an average of **51 hits**, **18 misses**, and a total of **30 false calls**
- Increasing threshold in automated testing, the number of false calls was reduced to 13
- Smaller flaws tend to be missed more often than the large ones
- Overall the $\mathbf{a}_{\mathbf{90/95}}$ value decreased by 0.6 inch equivalent diameter using the automated tap test from 1.70 to 1.10 inches
- Inspection carried out in laboratory environment. Automated tap testing may yield even better improvement over manual tap test in noisy environment

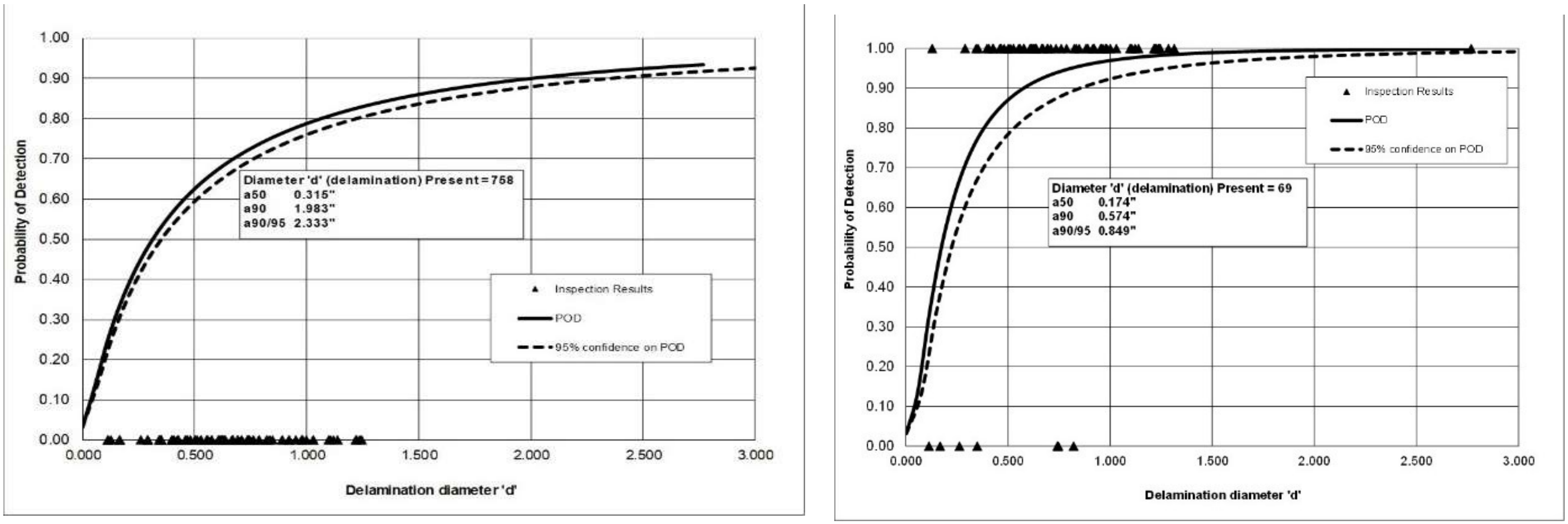
POD Result





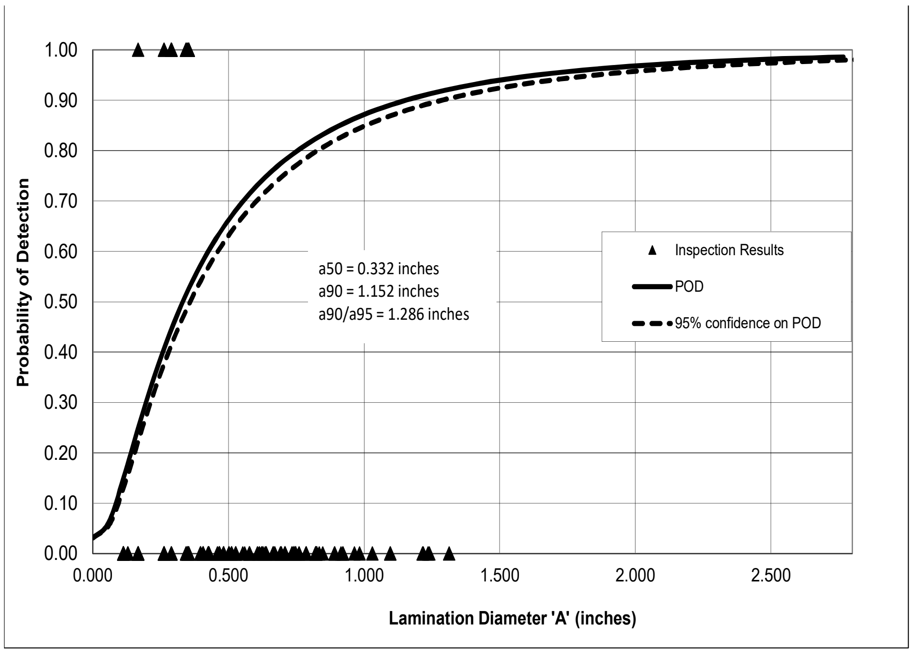
- PoD curve – logit - cumulative for (left) manual tap test data, and (right) automated tap test data

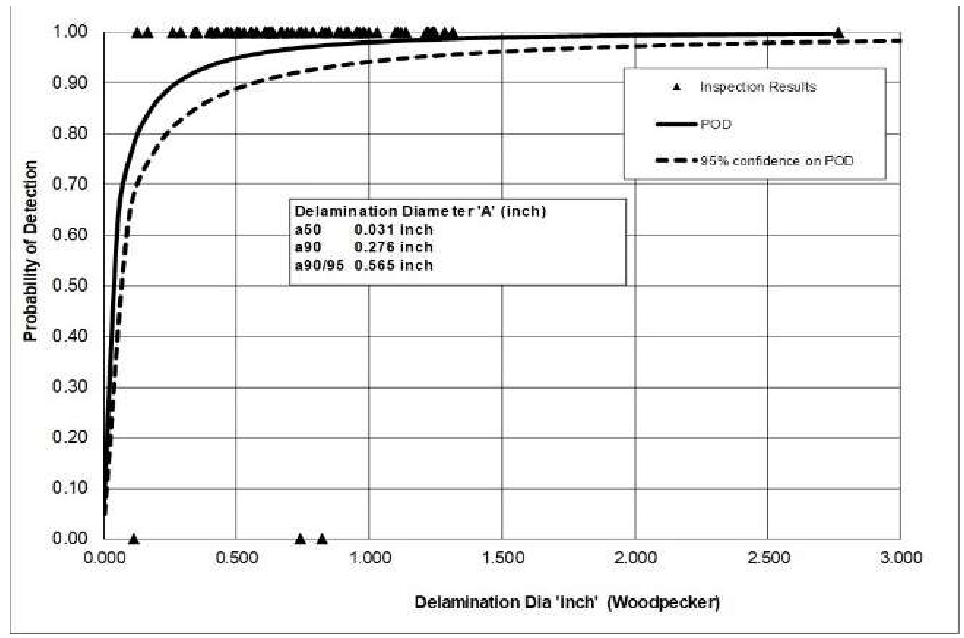
POD Result



- ❑ PoD curve manual tap test log-normal (left) cumulative, vs (right) best inspector

POD Result



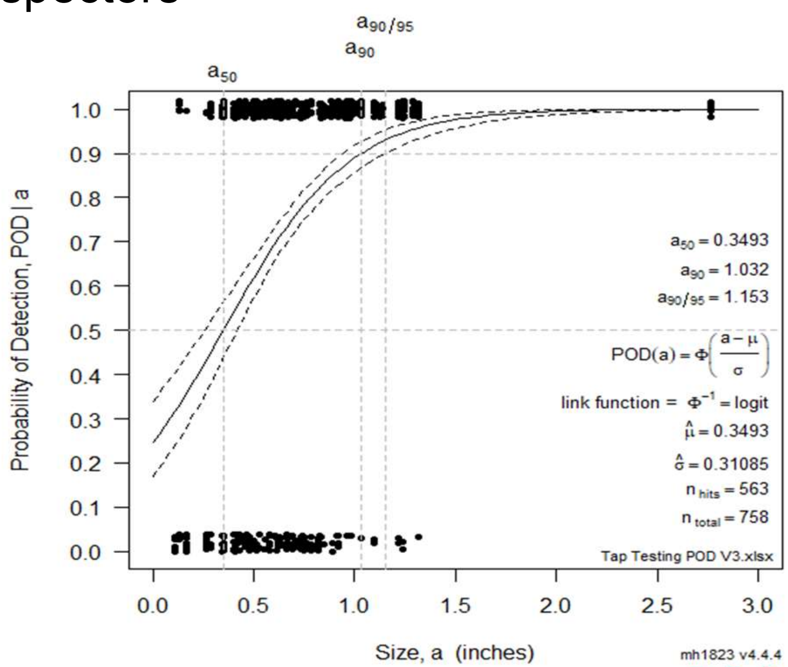


- PoD curve automated tap test log-normal (left) cumulative vs (right) best inspection

Summary of POD Result

$a_{90/95}$ 1.10 inch (diameter) for automated tap testing vs 1.70 inch for manual tap testing when removing the best and worst inspectors

Manual Tap Test		
	Logit	
	a_{90} (inch)	$a_{90/95}$ (inch)
Manual Cumulative	1.379	**1.644**
Manual Best Inspector	0.542	1.002
Manual Worst Inspector	1.704	N/A*
Manual – minus worst and best inspectors	1.390	**1.706**
Automated – Woodpecker		
	Logit	
	a_{90} (inch)	$a_{90/95}$ (inch)
Automated Cumulative	1.032	**1.153**
Automated Cumulative Modified threshold	1.077	1.190
Automated Best Inspector	0.246	0.885
Automated Worst Inspector	1.410	2.756
Automated Cumulative – minus worst and best inspectors	.989	**1.105**



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