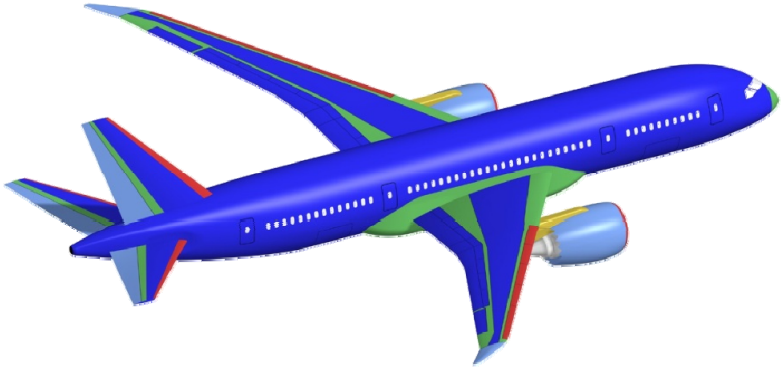
Methodology for Assessing the Reliability of Nondestructive Inspections on Wind Turbine Blades

Dennis Roach
Sandia National Labs
Infrastructure Assurance & NDI Department
FAA Airworthiness Assurance Center
dproach@sandia.gov

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Aircraft and Wind Energy Common "Bond" - Use of Composites and Health Monitoring



Composite Structures on Boeing 787 Aircraft

A380 Pressure Bulkhead

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<u>Common Goals</u>: Improve Flaw Detection Performance in Composite Structure in Order to Prevent Failures, Extend Blade Lifetime, Implement Condition-Based Maintenance

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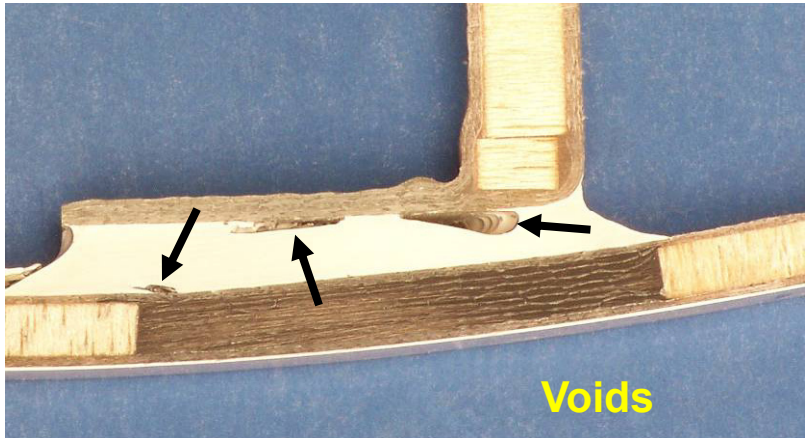
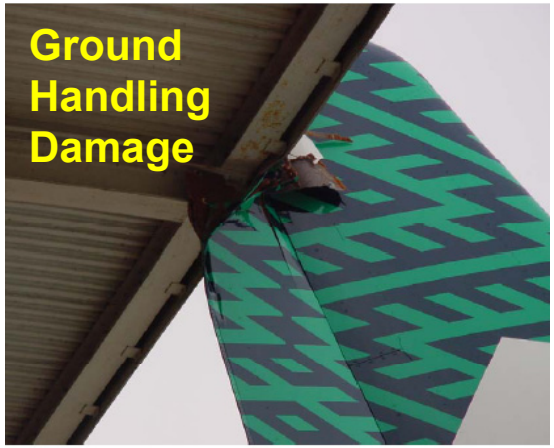
Composite Flaw Scenarios

- Ply waviness
- Erosion
- Disbonds, Delamination
- Lightning Strike
- Impact Damage
- Voids





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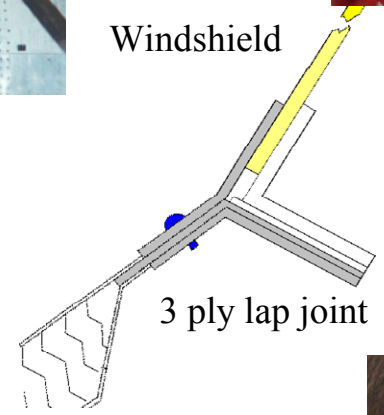
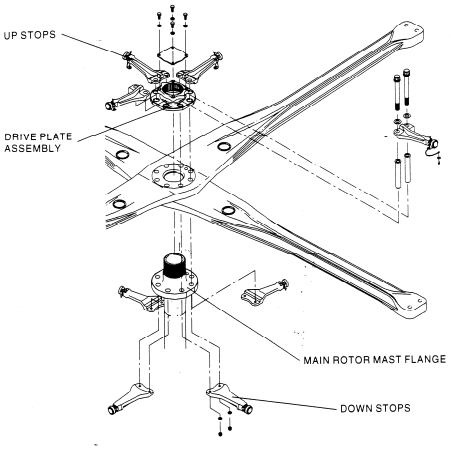
Focused Inspections with Hand-Held Devices





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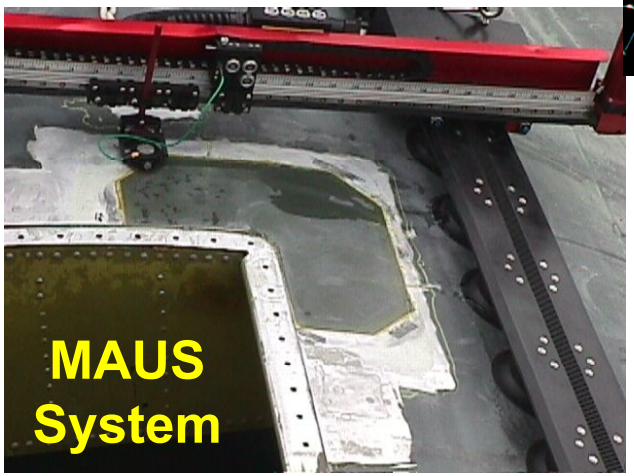
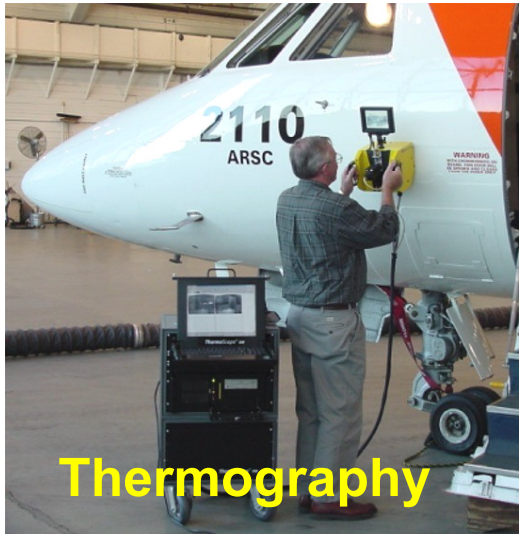
Wide Area and C-Scan Inspection Methods





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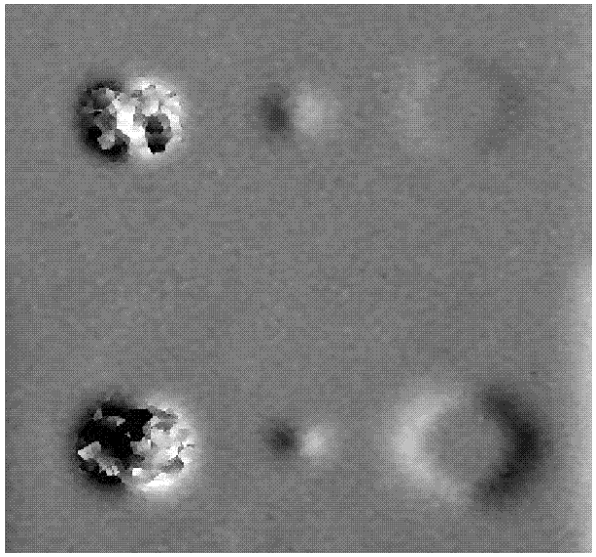
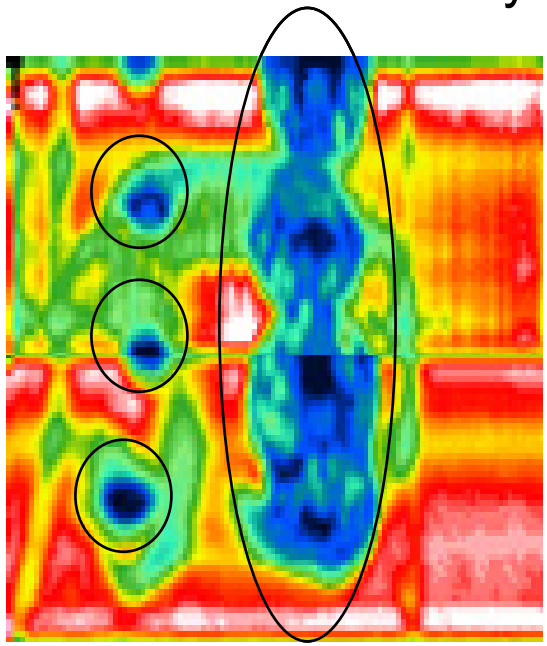
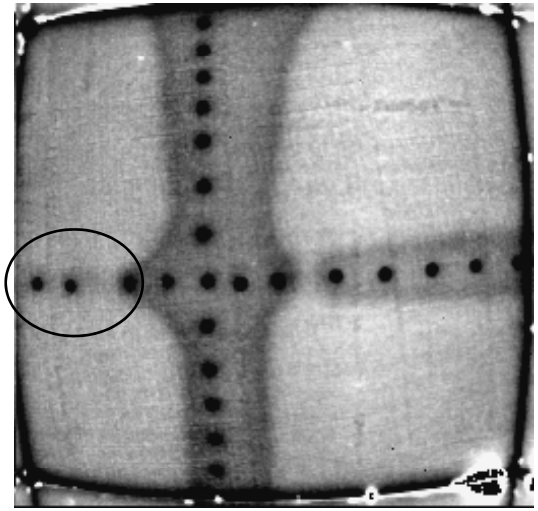
Shearography (LTI) Image

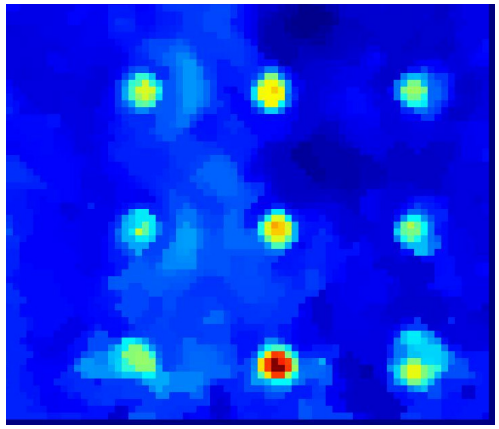


Ultrasonic Wheel Array

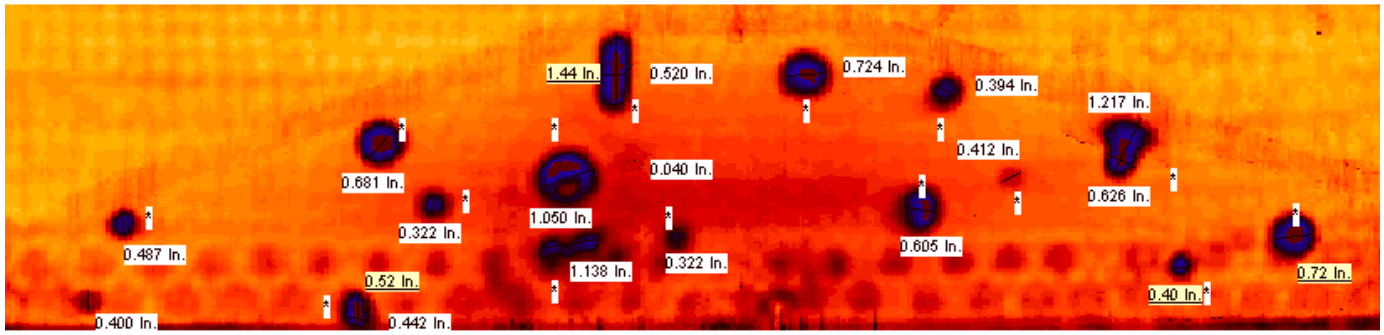


Thermography (TWI) Image





SAM Image



MAUS Image

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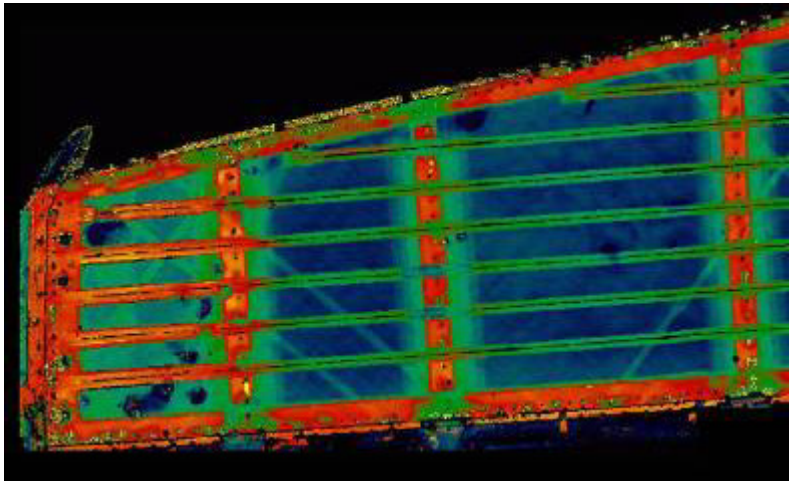
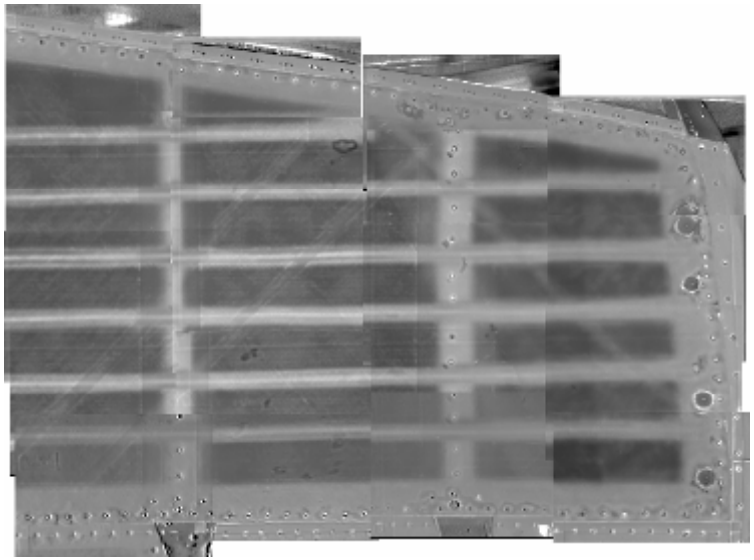
B737 Composite Horizontal Stabilizer

Objective: Assess rapid (wide area) NDI methods that could have applications to B787 production and/or in-service inspection.

Ultrasonic Scan





Thermography Scan

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Determining Performance of Composite Inspections

Composite Flaw Detection Experiment

Participation from over 25 airlines and maintenance depots

Industry-wide performance curves generated to quantify:

- **how well current inspection techniques are able to reliably find flaws in composite honeycomb structure**
- **the degree of improvements possible through integrating more advanced NDI techniques and procedures.**
  - **Statistically relevant and realistic flaw profiles**
  - **Blind application of techniques to study hits, misses, false calls, and flaw sizing**

Experiment to Assess Flaw Detection Performance

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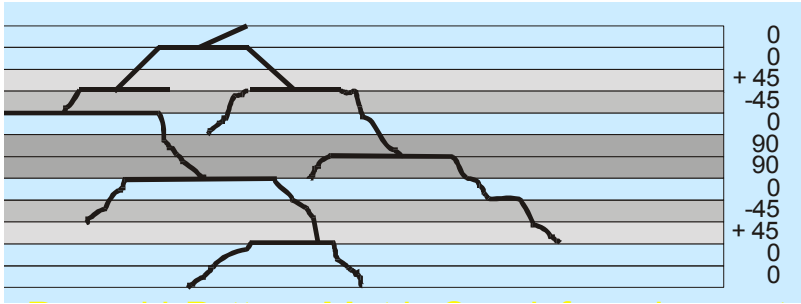
Experiment Design

Specimen Types - modeled after range of construction found on aircraft; Solid laminate carbon (12, 20, 24, 32 plies); Contoured and tapered surfaces, Substructures – (stringers, ribs, spars); Bonded & sealed joints

Flaw Types - statistically relevant flaw distribution with sizes ranging from 0.2 in.^{2} to 3 in.^{2}

1) interply delaminations; disbonds
2) substructure damage
3) skin-to-stiffener disbonds
4) impact damage

Low Energy Impact



Pyramid Pattern Matrix
Crack from impact

Application of NDI - blind tests implemented in aircraft maintenance depots; guideline procedures provided; use of ref. standards to set up equipment

Expected Results - evaluate performance attributes

1) accuracy & sensitivity (hits, misses, false calls, sizing)
2) versatility, portability, complexity, inspection time (human factors)
3) produce guideline documents to improve inspections
4) introduce advanced NDI where warranted

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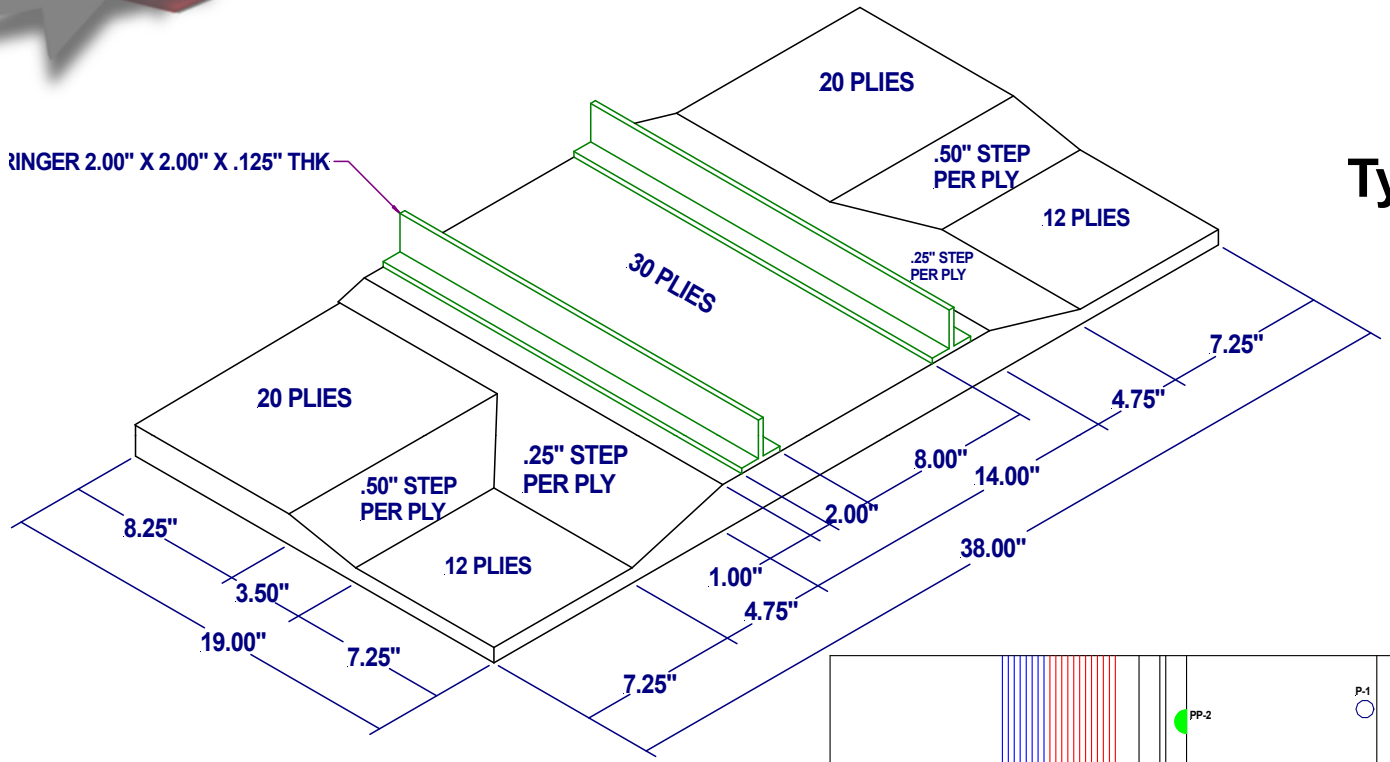
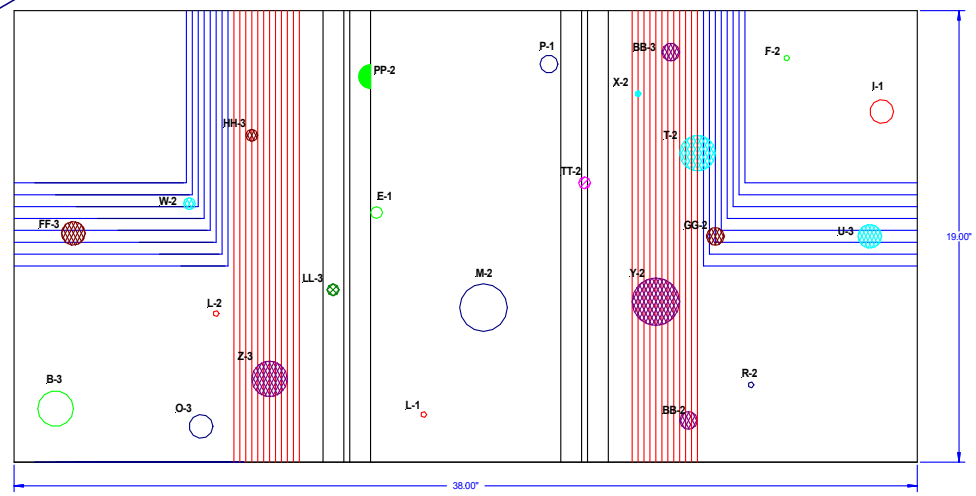
Thick Laminate With Complex Taper



Type I Specimen



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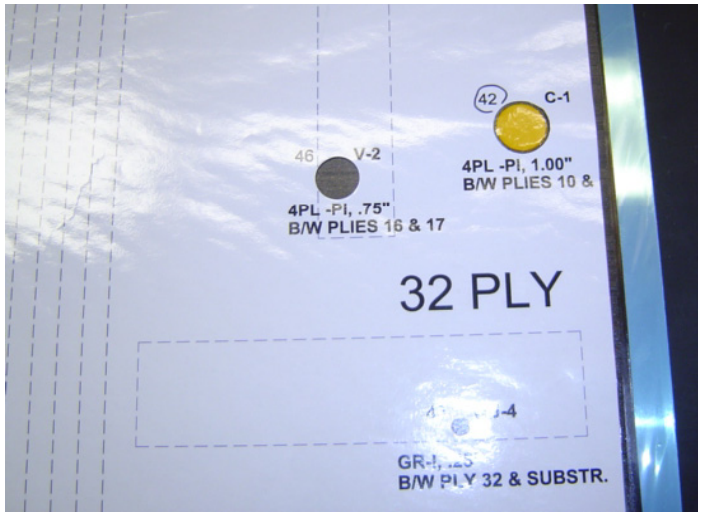
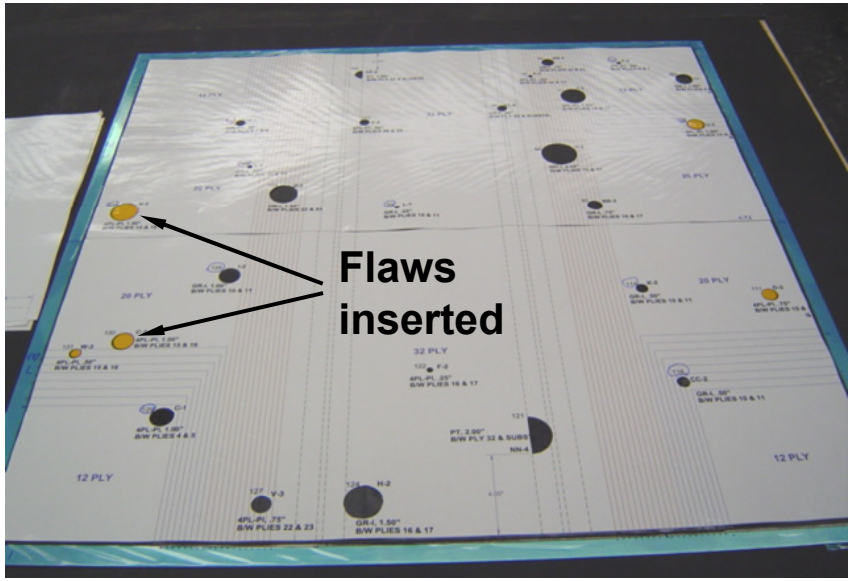
Thick Laminate With Complex Taper - Fabrication

Flaw templates - ensure proper location of flaws





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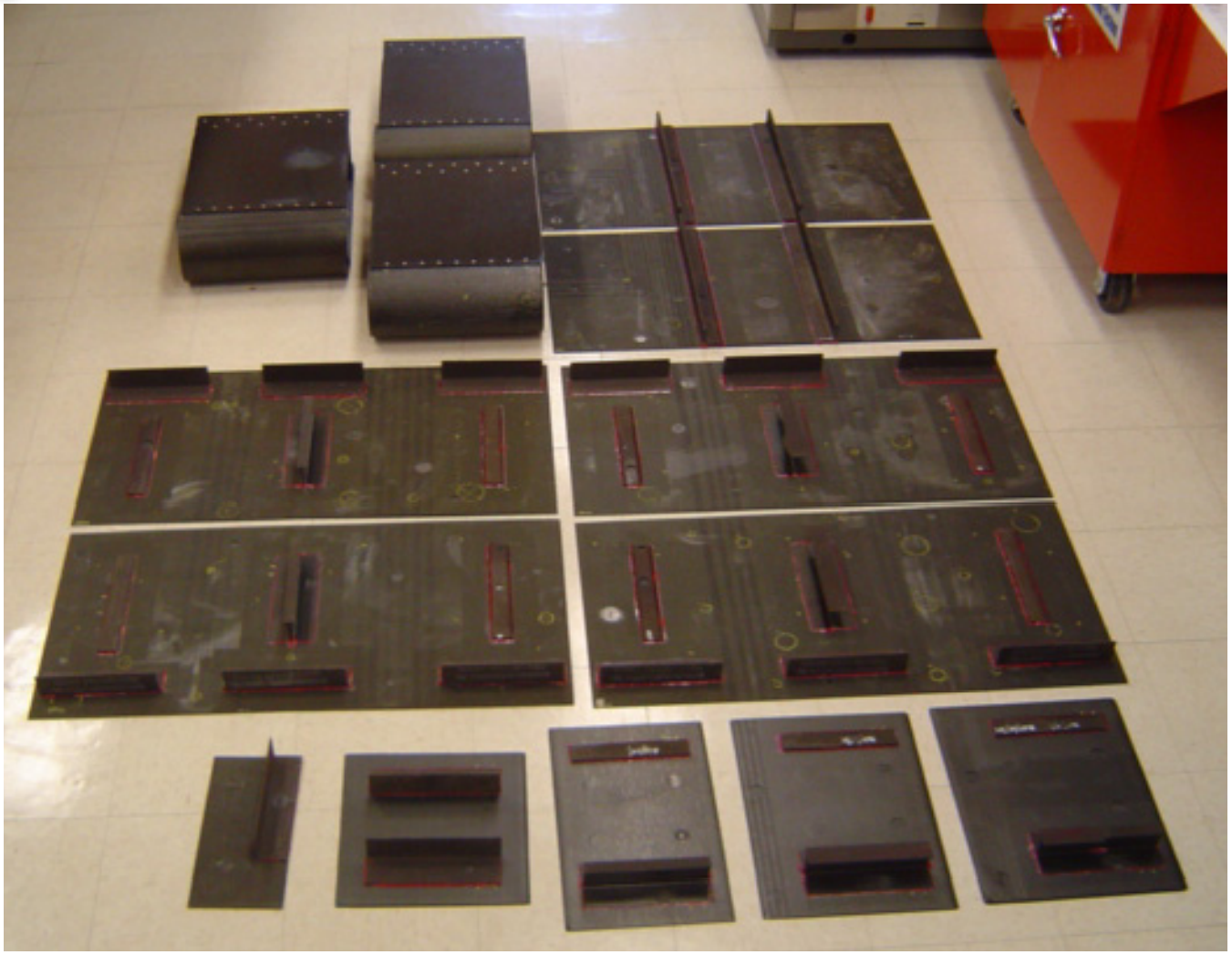
Specimen Set - Flaw Detection in Solid Laminate Composites



Thickness Range:
12 – 64 plies

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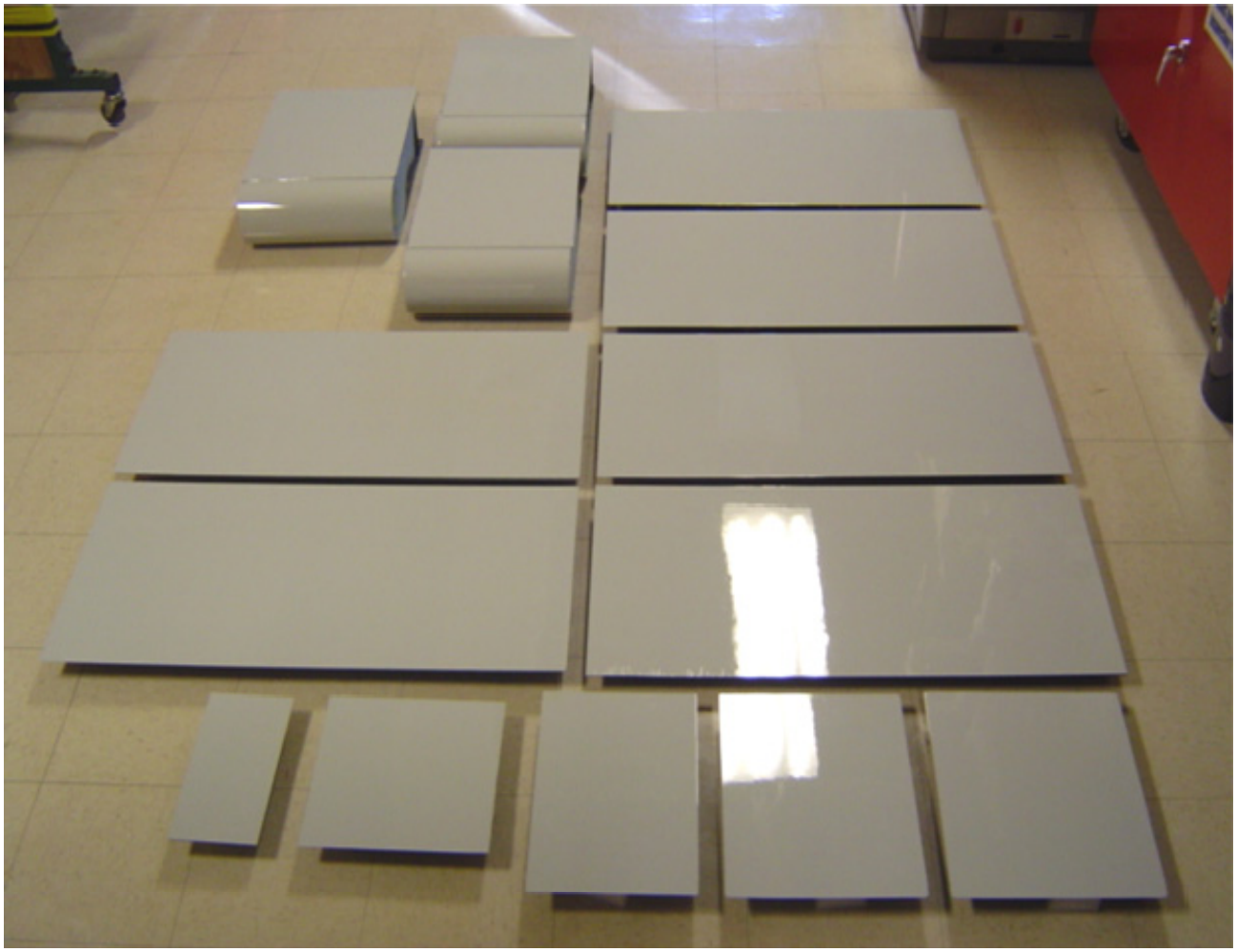
Specimen Set - Flaw Detection in Solid Laminate Composites



Thickness Range: 12 – 64 plies

Simple Tapers

Complex tapers

Substructure Flaws

Curved Surfaces

Array of flaw types

NDI Ref. Stds.

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Experiment Implementation at Airlines, 3rd Party Maintenance and Adv. NDI Organizations

UNITED

SR Technics

AA

BRITISH AIRWAYS

U·S AIRWAYS

KLM Royal Dutch Airlines

AIR FRANCE

Delta

FedEx

Alaska Airlines

NORTHWEST AIRLINES

AGUSTAWESTLAND

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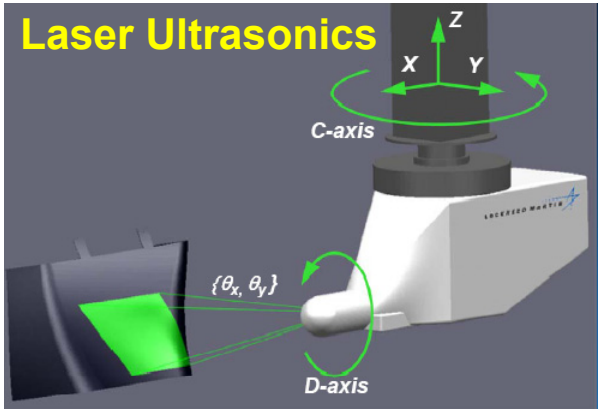
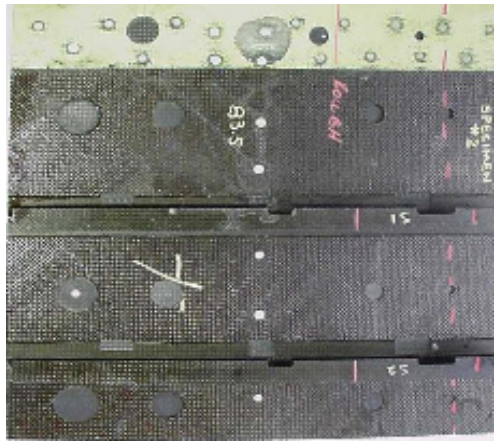
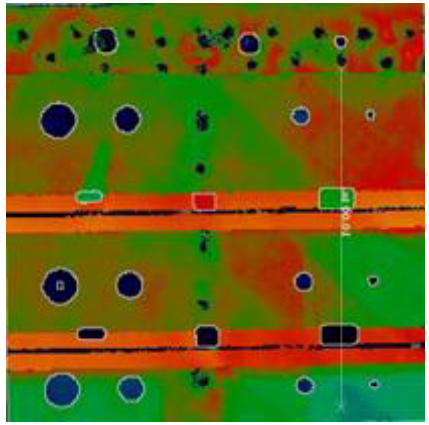
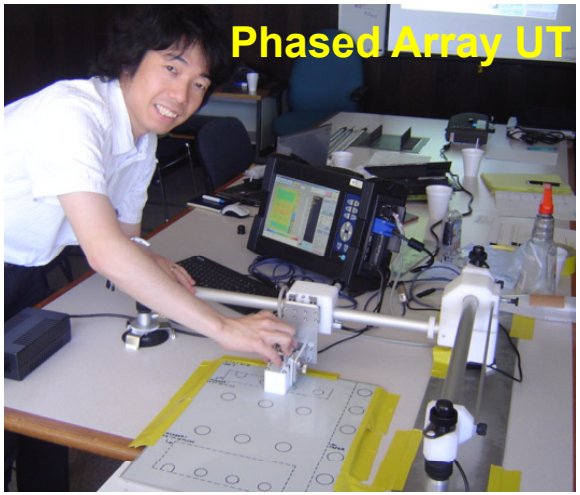
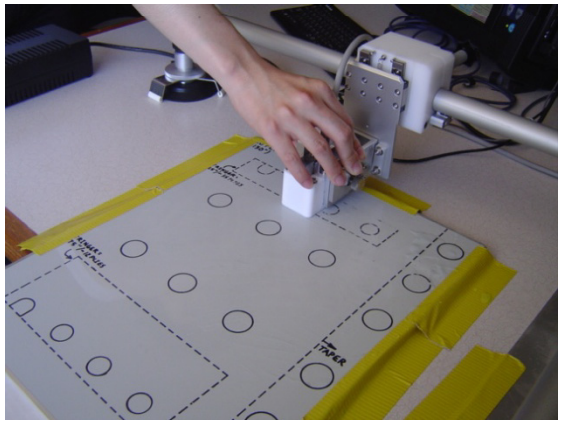
Application of Advanced NDI Methods

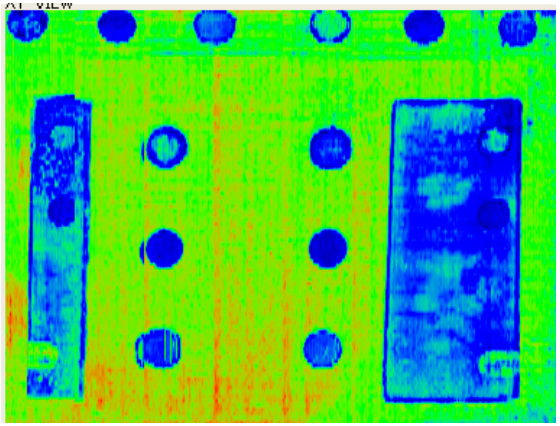












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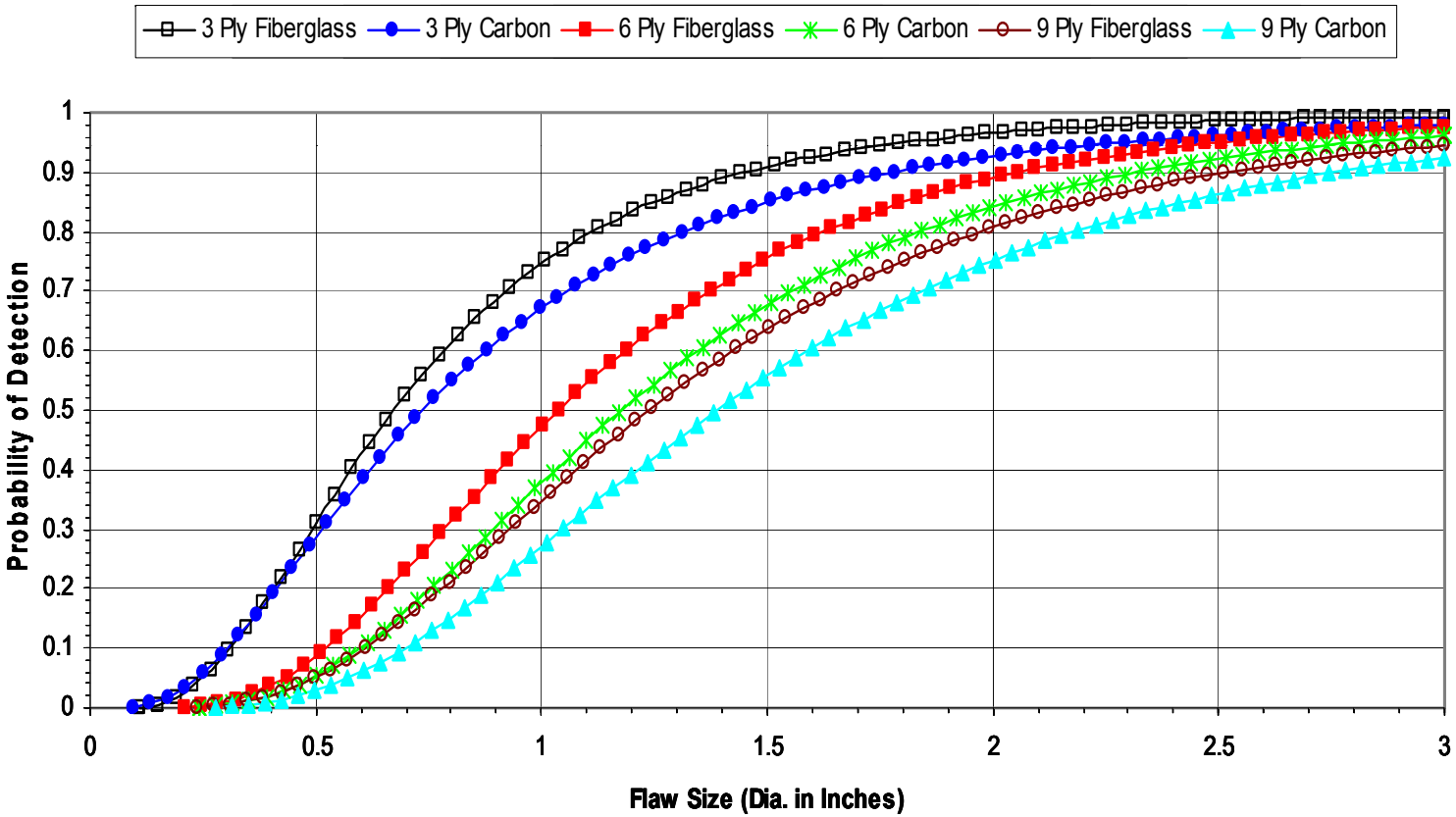
Probability of Detection - Inspection Performance Over a Range of Test Specimen Types

Flaws in Composite Honeycomb Construction



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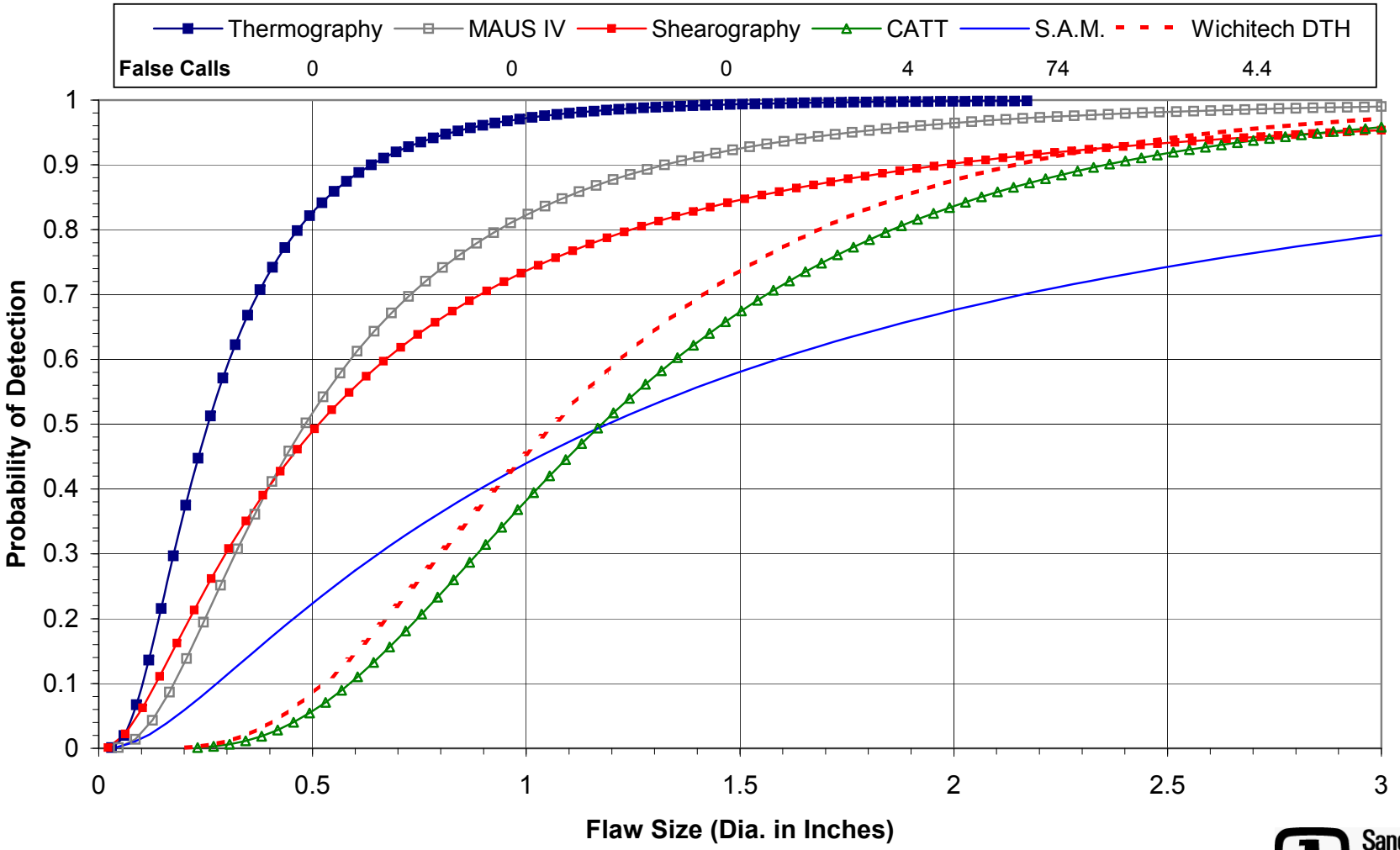
Inspection Improvements Via Advanced NDI Techniques

Comparison of Advanced Inspection Techniques with Best Conventional NDI Result on 9 Ply Carbon



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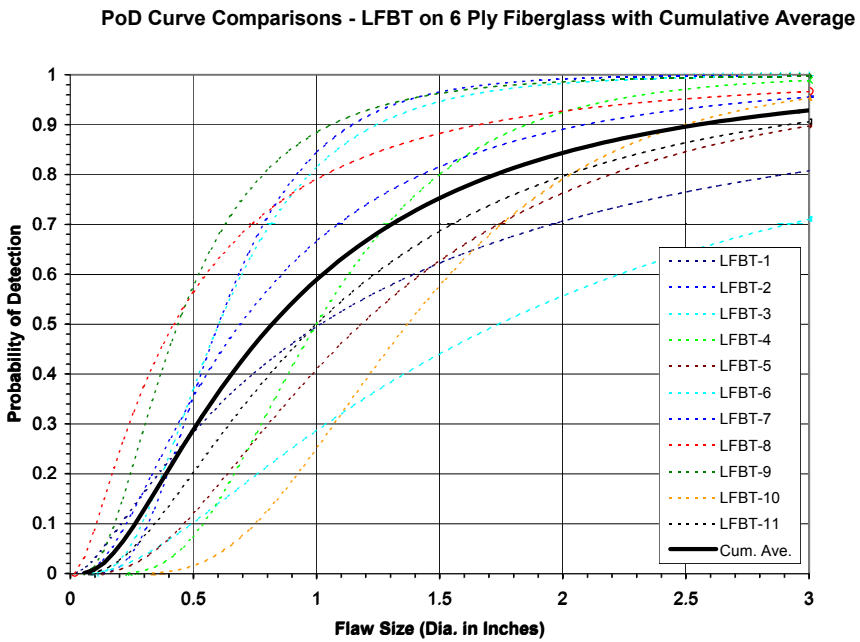
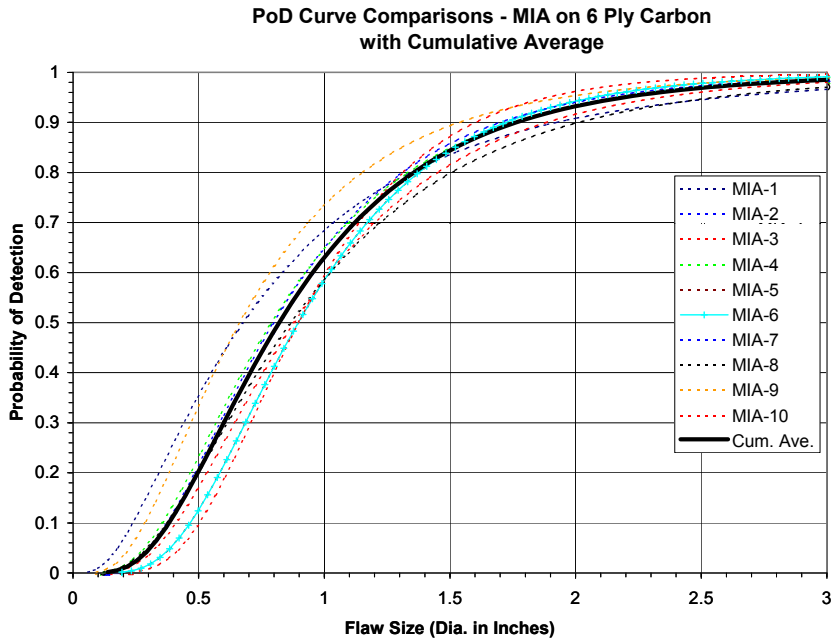
Variation in Performance of a Device Over the Set of Inspectors



Large Variation in Device Performance



Small Variation in Device Performance

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Conclusions from Composite NDI Performance Studies

- **How are we doing? – Flaw Detection with Conventional NDI**
  - 90% POD is not achieved for 1" dia. Flaws
  - POD can improve as inspection time per area increases (up to a limit)
  - Human factors issues (time, attention to detail, proper deployment)
  - Coverage of large areas was random
  - Complex equipment produced large data spread
  - Top performing NDI methods were identified (reliability, repeatability, ease of use)

- **How can advanced NDI help? – Flaw Detection with More Sophisticated NDI**
  - Improvement in flaw detection ranged from 66% to 72%
  - Automated deployment & data presentation/analysis reduces many human factors concerns (100% coverage; flaw recognition on images)
  - Allow for more rapid inspections

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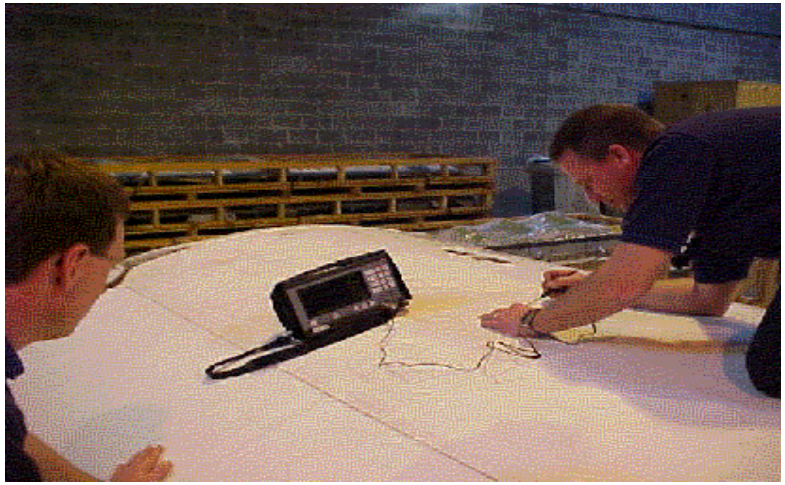
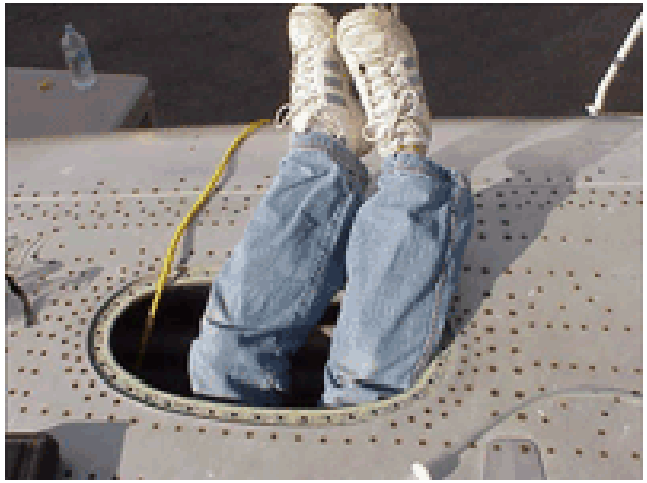
Math, Glorious Math or…..
How do we calculate Damage Tolerance ??

- **<u>Fatigue guy:</u>** **Fantastic! I've calculated K to within 0.5%!**
- **<u>Stress guy:</u>** **Great! I've calculated stress to within 10%!**
- **<u>Loads guy:</u>** **WOOHOO! I think I got the sign right!**
- **<u>NDI guy</u>: You want me to find a crack how small??**





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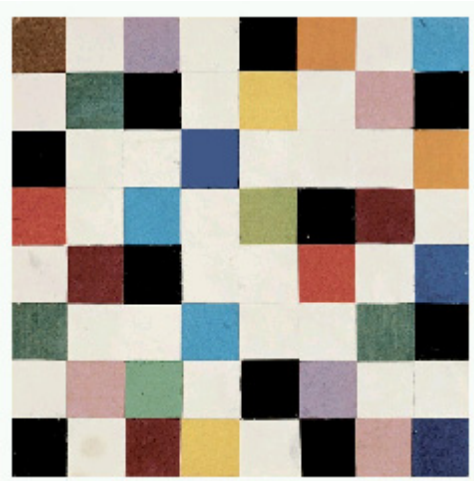
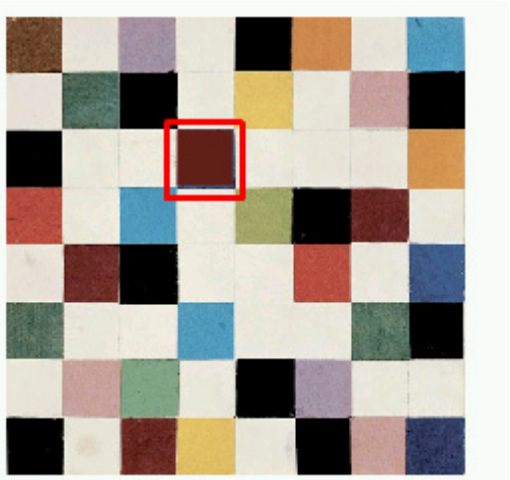
You as the Inspector – Performance Assessment

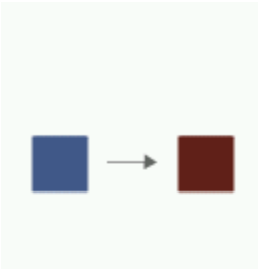
You will be given three seconds to study a piece of artwork.



Then one box will highlight.



You must decide if the box has changed color.



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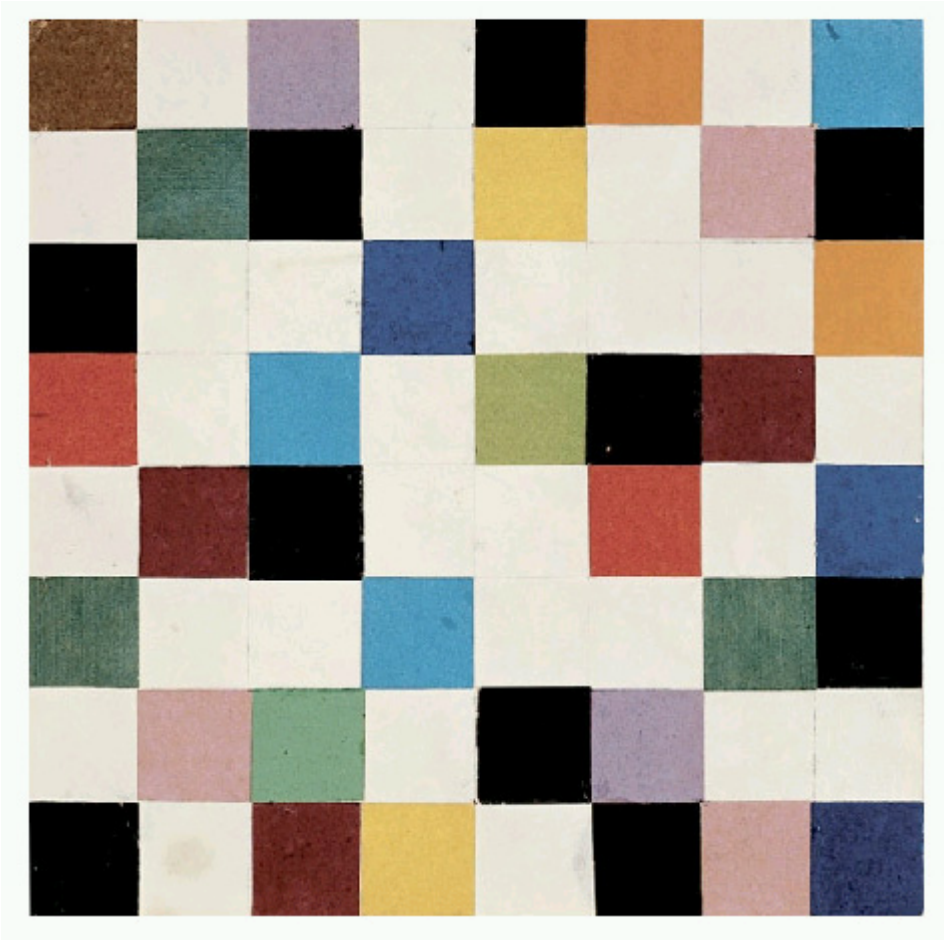

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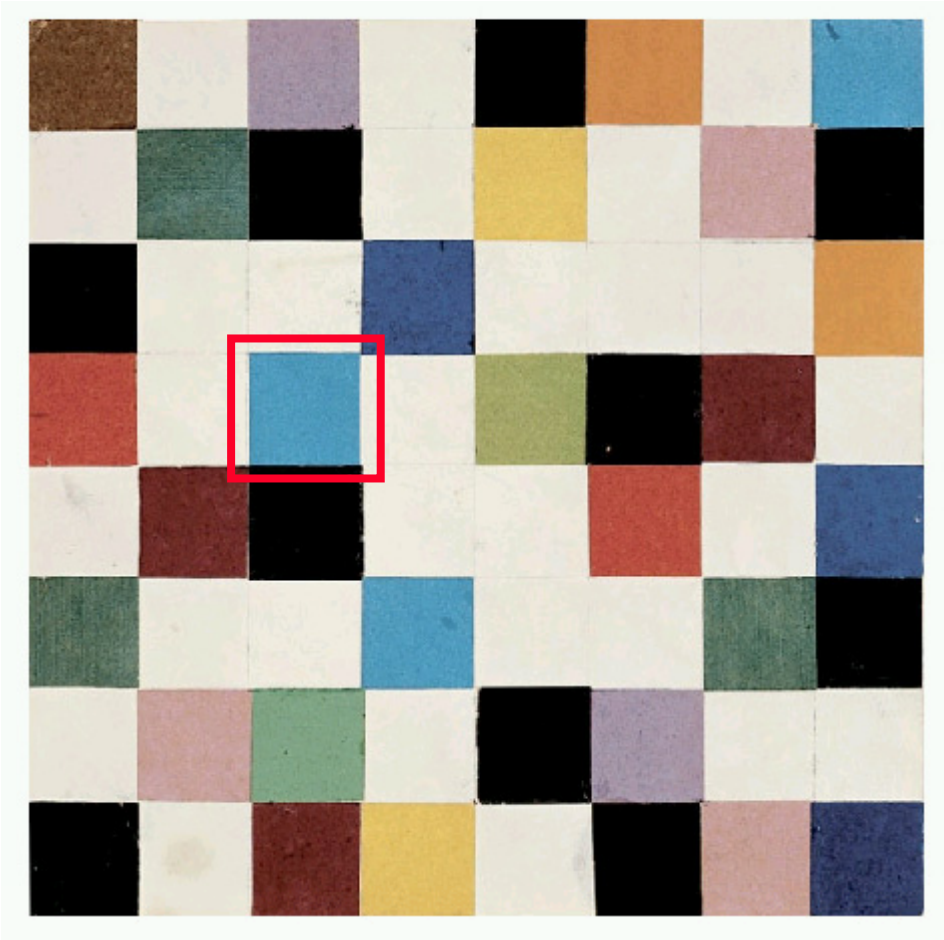

Did the selected square change color?

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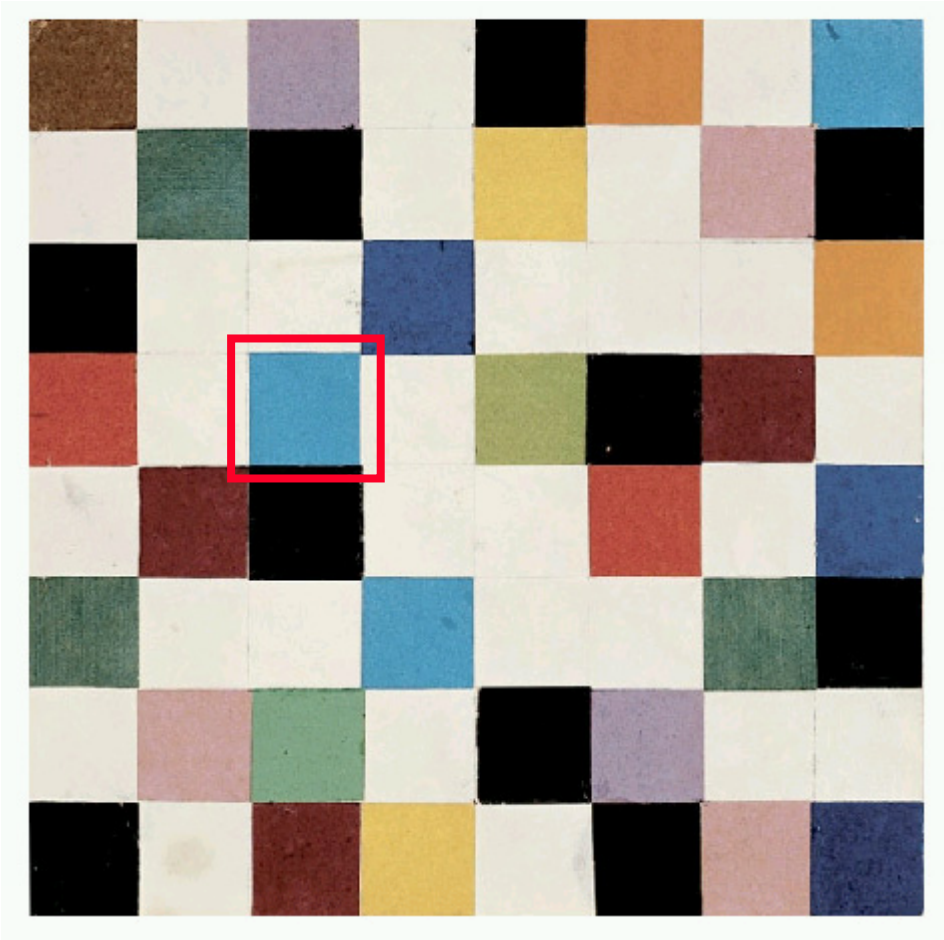

NO CHANGE

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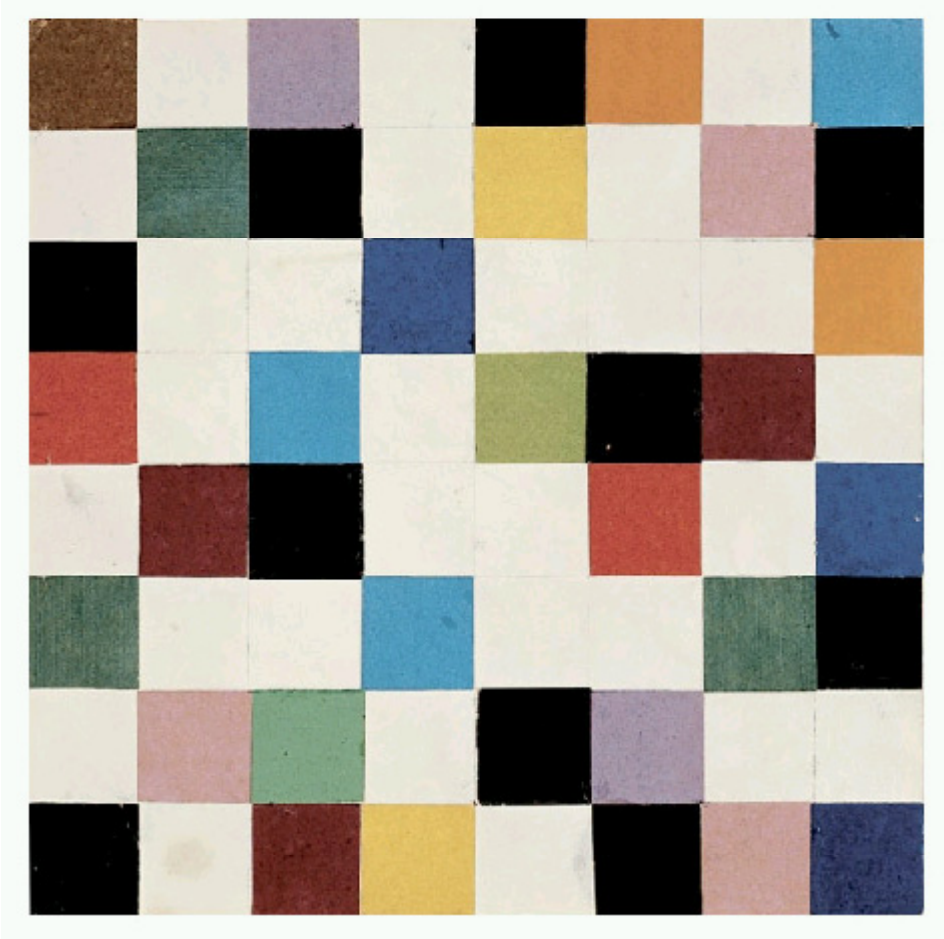

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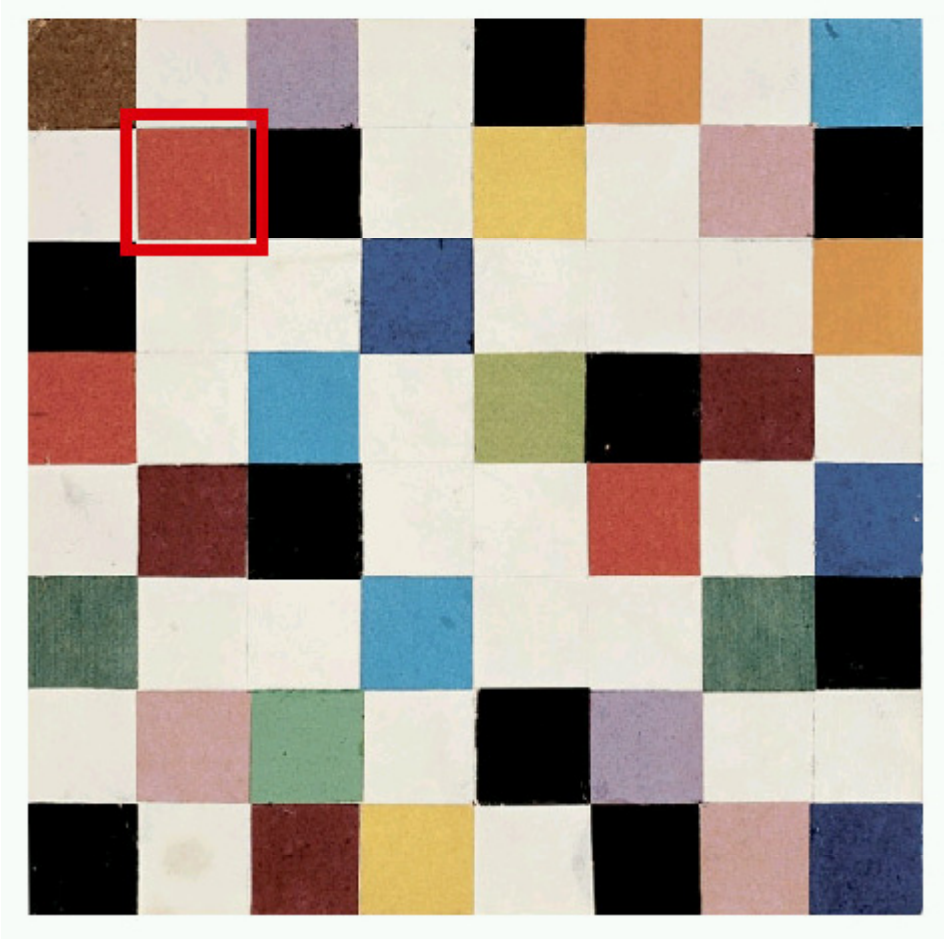

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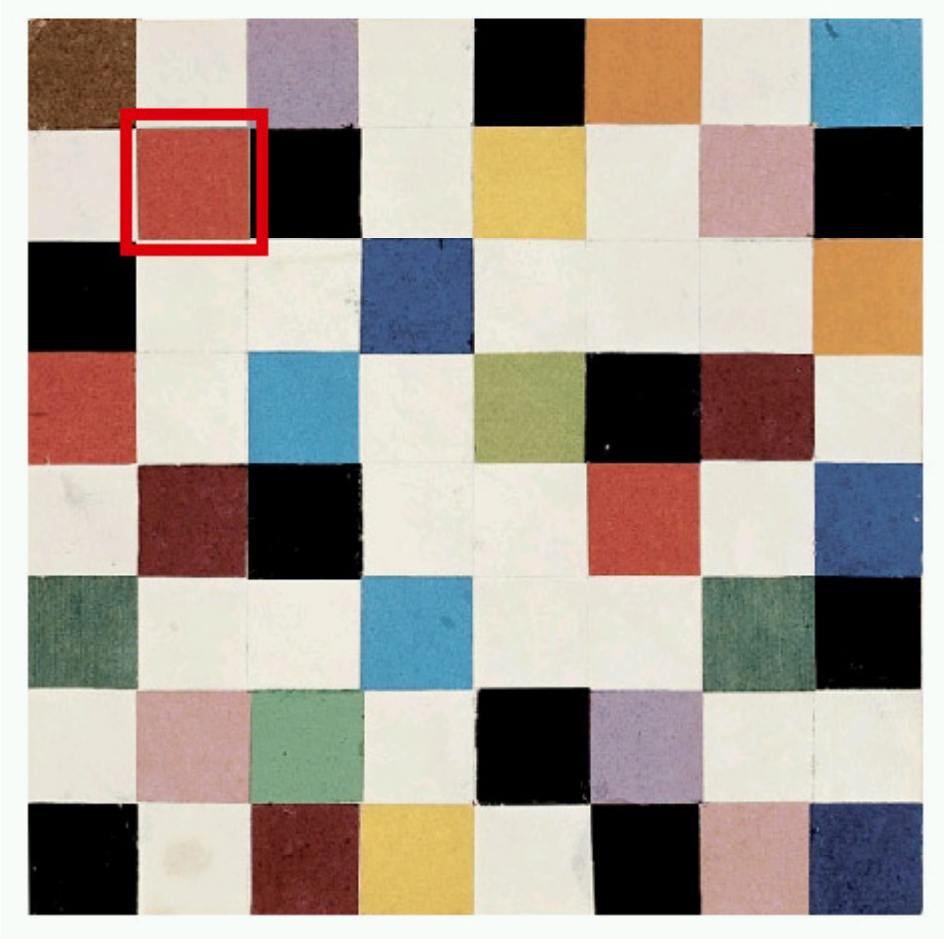

YES CHANGE

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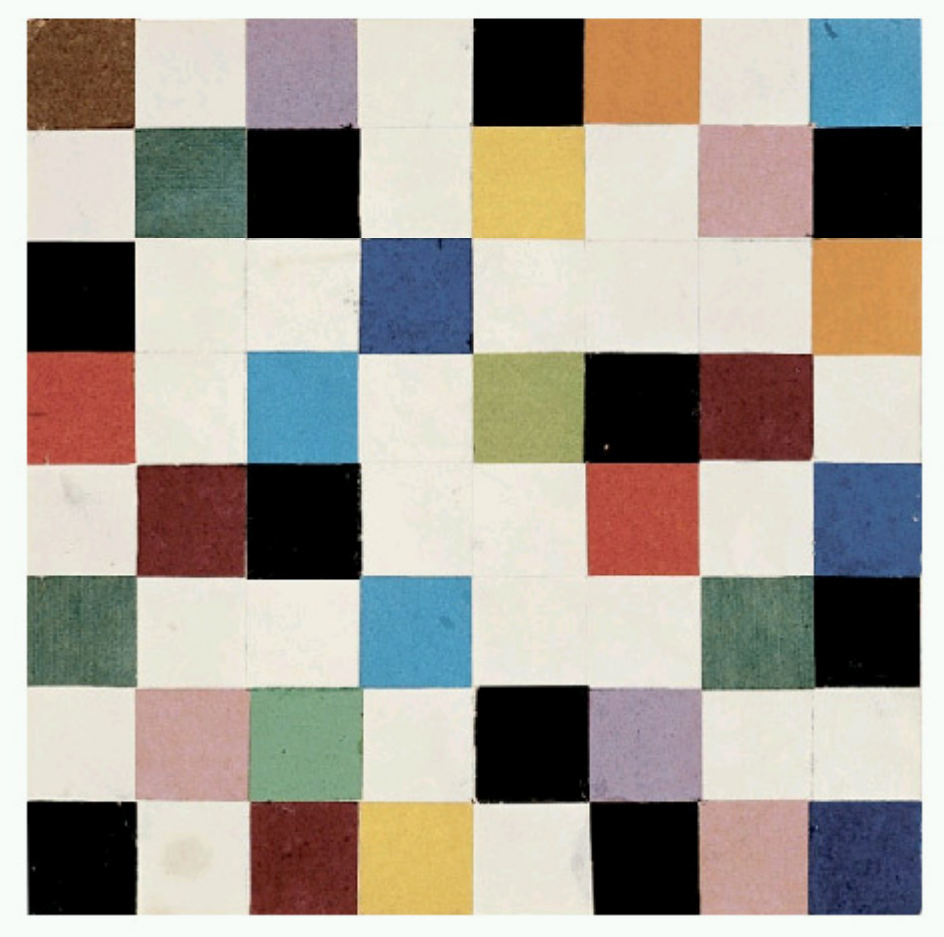

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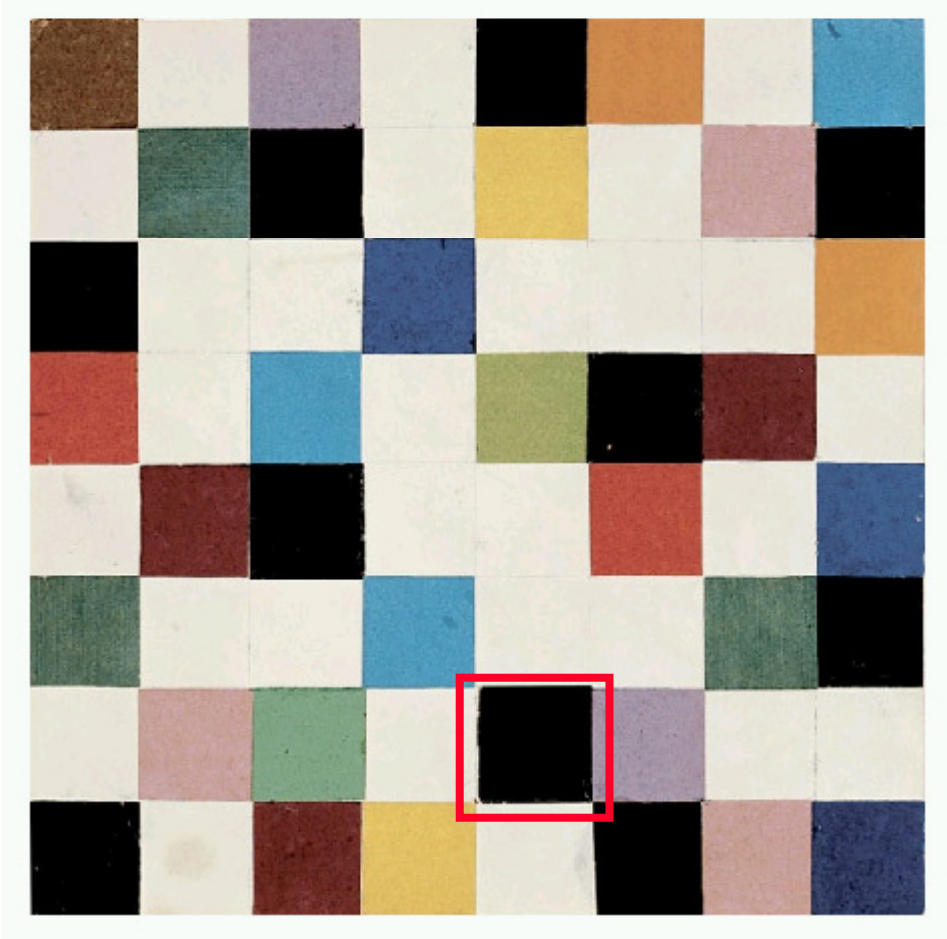

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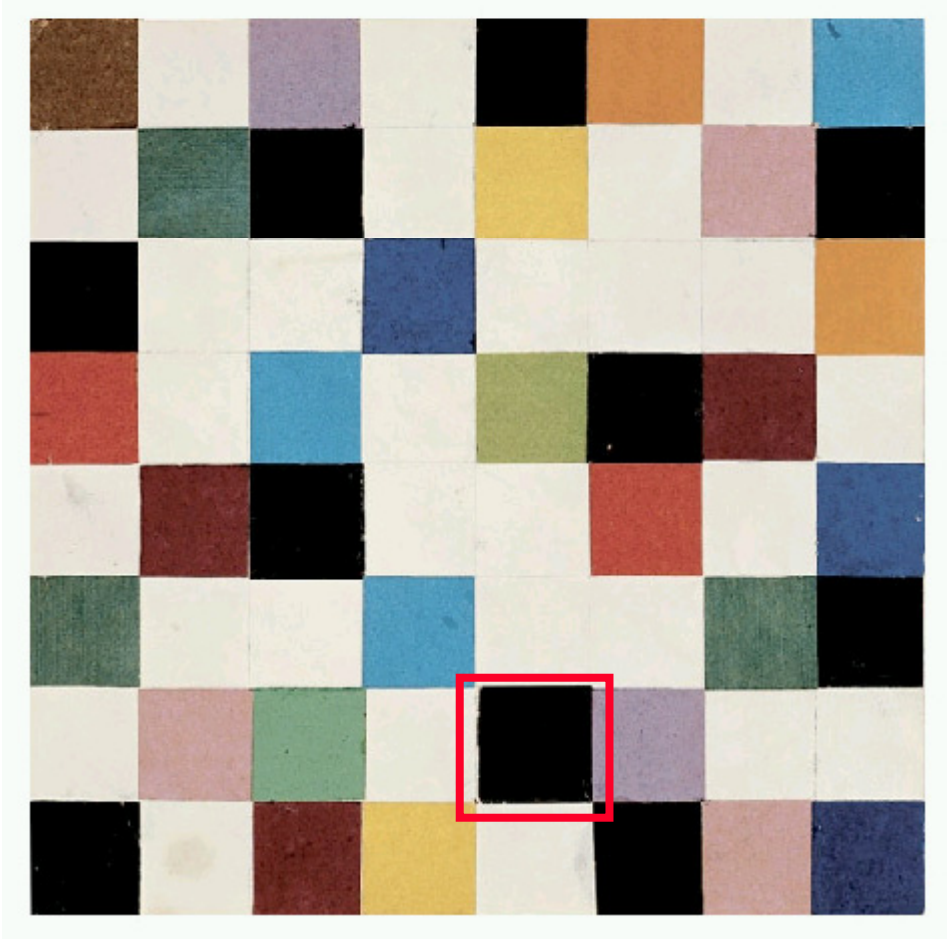

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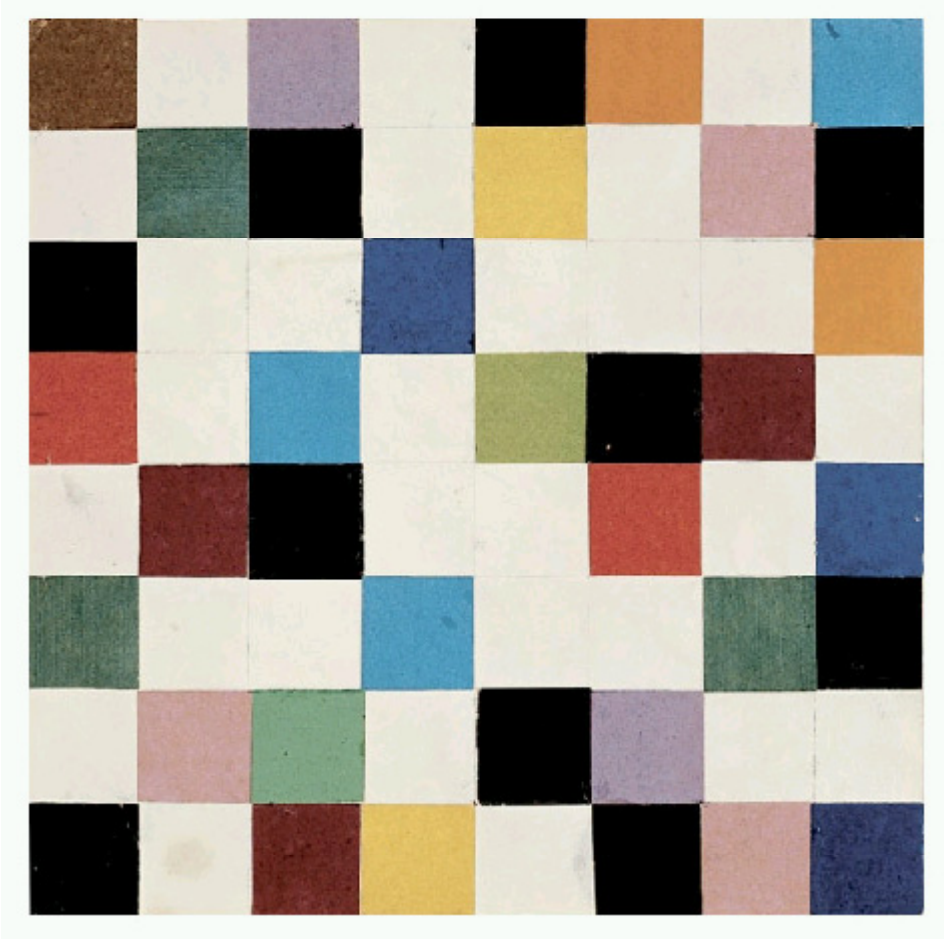

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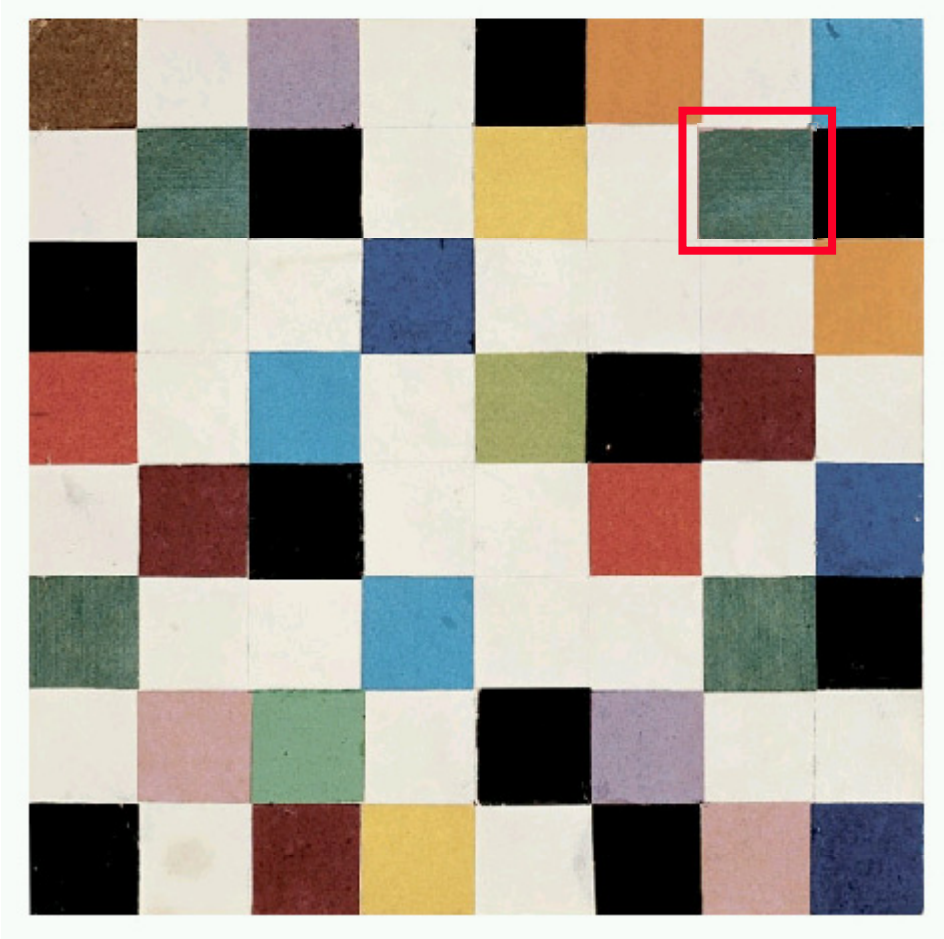

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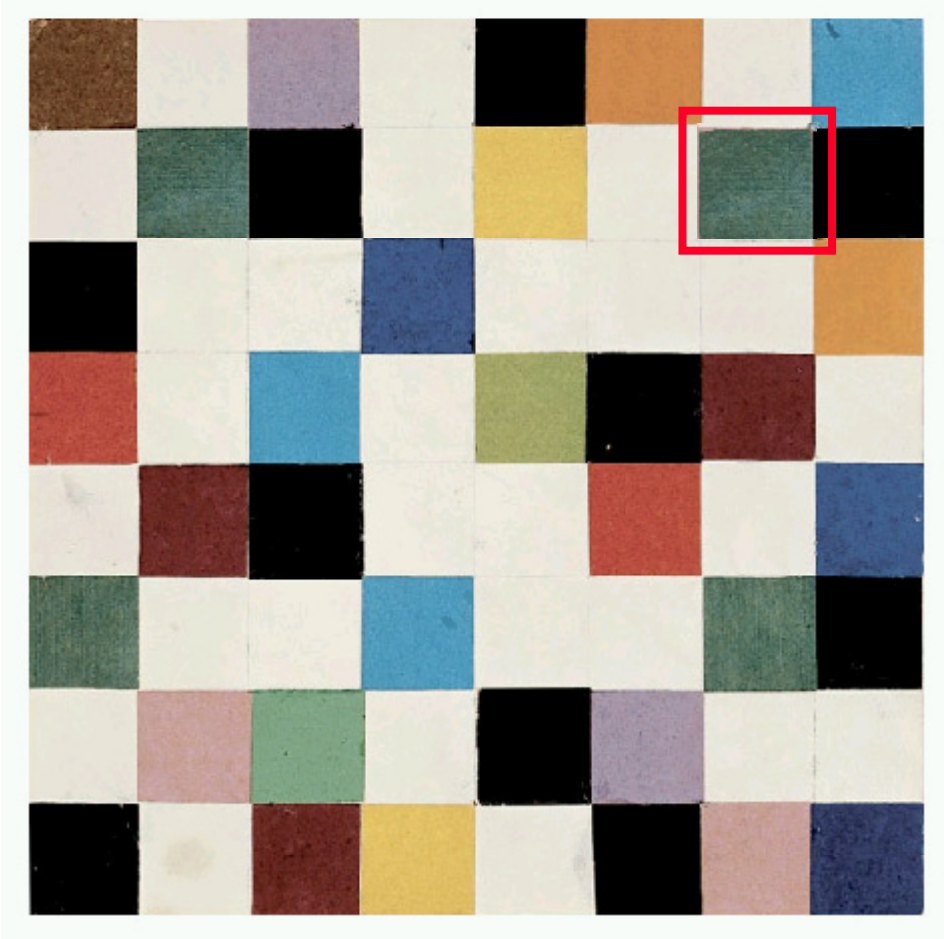

YES CHANGE

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How did you do?

- Did you try to game the system?
  - FACT: inspectors do better where they expect to find flaws
- Did you have the same level of concentration from the beginning to the end?
  - There is significant research on how fatigue and difficulty of tasks affect performance.

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Dennis Roach
Sandia National Laboratories
FAA Airworthiness Assurance Center

As aircraft operators respond to calls for the ensured airworthiness of global airline fleets, the implementation of advanced airworthiness assurance technology is of growing importance. The development and application of new Nondestructive Inspection (NDI) techniques, the use of advanced materials, and general improvements in maintenance and repair practices need to keep pace with the growing understanding of aircraft structural aging phenomena. In 1991 the Federal Aviation Administration (FAA) established the Airworthiness Assurance Center (AANC) at Sandia National Laboratories. The AANC works with aircraft manufacturers, military depots, and airlines to foster new technologies associated with nondestructive inspection (NDI), structural mechanics, repair methods, flight controls, fire safety, and crashworthiness. This presentation describes the structured methodology that the AANC has developed to quantify the performance of NDI techniques. This methodology may be useful to the wind energy industry since many of the inspection challenges, requirements and materials are similar to those encountered in the aviation industry. The aircraft industry continues to increase its use of composite materials, most noteworthy in the arena of principle structural elements. The extreme damage tolerance and high strength-to-weight ratio of composites have motivated designers to expand the role of fiberglass and carbon graphite in aircraft structures. This has placed greater emphasis on the development of improved NDI methods that are more reliable and sensitive than conventional NDI. The AANC has been pursuing this goal via a host of studies on inspection of composite structures. Tap testing, which uses a human-detected change in acoustic response to locate flaws, and more sophisticated nondestructive inspection methods such as ultrasonics or thermography, have been applied to an increasing number of applications to detect voids, disbonds, and delaminations in adhesively bonded composite aircraft parts. Low frequency bond testing and mechanical impedance analysis tests are often used to inspect thicker laminates. Probability of Detection experiments are underway to assess the performance of both conventional and advanced NDI techniques. Industry-wide performance curves are being produced to establish: 1) how well current inspection techniques are able to reliably find flaws in composite honeycomb structure, and 2) the degree of improvements possible through the integration of more advanced NDI techniques and procedures.

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