NRC·CNRC
NRCaerospace.com

Generic Bolt Hole Eddy Current Testing Probability of Detection Study

NRC-IAR, DND, TRI/Austin

Catalin Mandache
NDE Group, Structures and Materials Performance Laboratory

National Research Council Canada
Conseil national de recherches Canada

Canada

Outline

- **Background**
  - Project objectives
  - Design of experiments
  - Experimental results

- **Numerical-based PoD**
  - Approach
  - Considered variables
  - Example: Implementation of modelling results into the PoD

Project Objectives

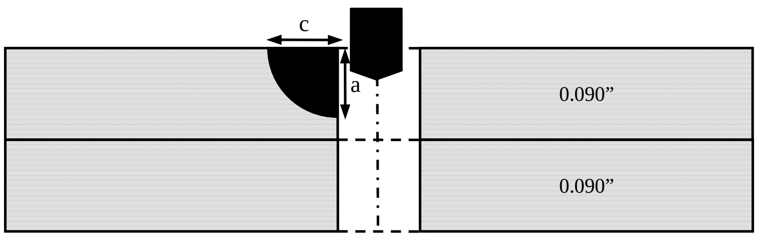
- Generate generic PoD data that could be used for future estimates of PoD for a range of similar constructions
- Validate the currently used 90-95% discontinuity size in fastener bolt holes of aircraft wing box structures when using a DND eddy current inspection procedure
- **Use of numerical modelling to estimate PoD for similar structures and assess variability**

Design of Experiments

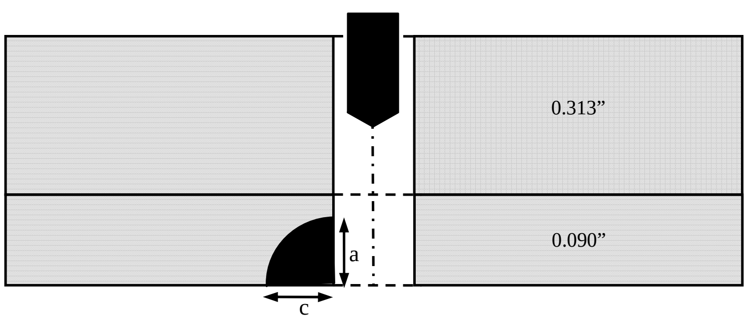
- A large number of inspectors and trainees was used for this study (following the same calibration, inspection, and recording procedures)
- 1,434 coupons made of 7075-T6 aluminum alloy
  - 306 coupons contained laboratory-grown fatigue cracks
  - 180 coupons contained EDM notches
  - 948 coupons were kept blank
- Four defect configurations – each configurations contained 468 inspection sets (72 fatigue cracks and 45 EDM notches)
- Real aircraft specimens containing EDM notches and overload cracks (Wing Splices: 35 cracked holes in 78 bolt holes and Web Stiffeners: 40 EDM notches in 151 bolt holes) – *fatigue cracks were not available*

Design of Experiments

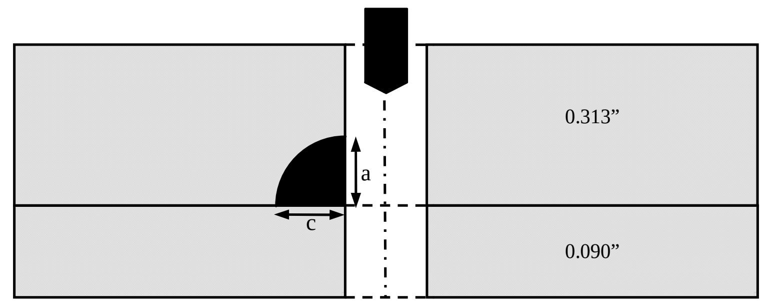
Configuration #1



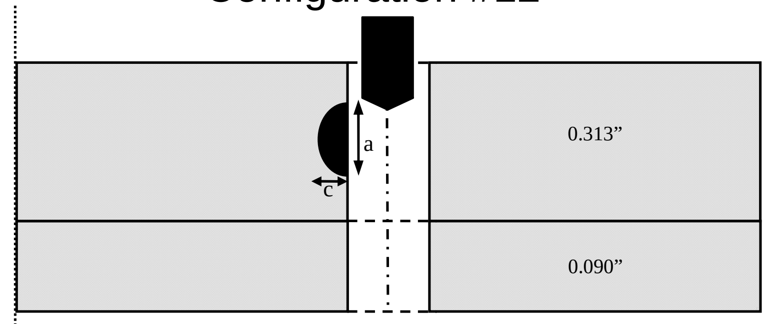
Configuration #5



Configuration #7



Configuration #12



Design of Experiments

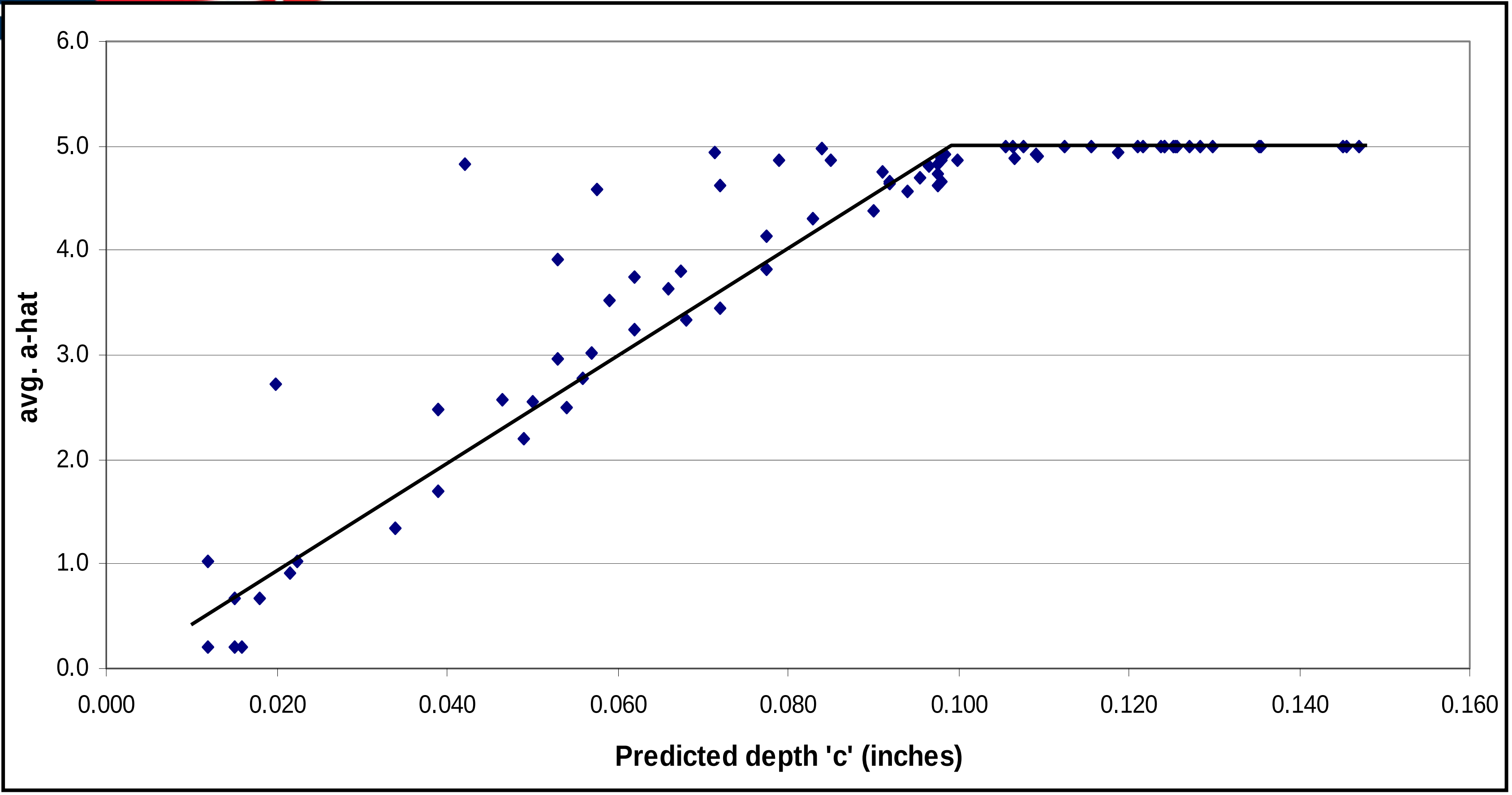
Summary of results

$a_{90/95}$ PoD results ('hit-miss' data) using the log-logistic method (MIL-HDBK-1823-2007):

- Configuration #1: average 0.017" / maximum 0.031" (0.43mm/0.77mm)
- Configuration #5: average 0.012" / maximum 0.022" (0.30mm/0.55mm)
- Configuration #7: average 0.016" / maximum 0.035" (0.40mm/0.87mm)
- Configuration #12: average 0.025" / maximum 0.033" (0.63mm/0.83mm)

- For actual aircraft specimen: average 0.102" / maximum 0.177" (2.59mm/4.50mm)

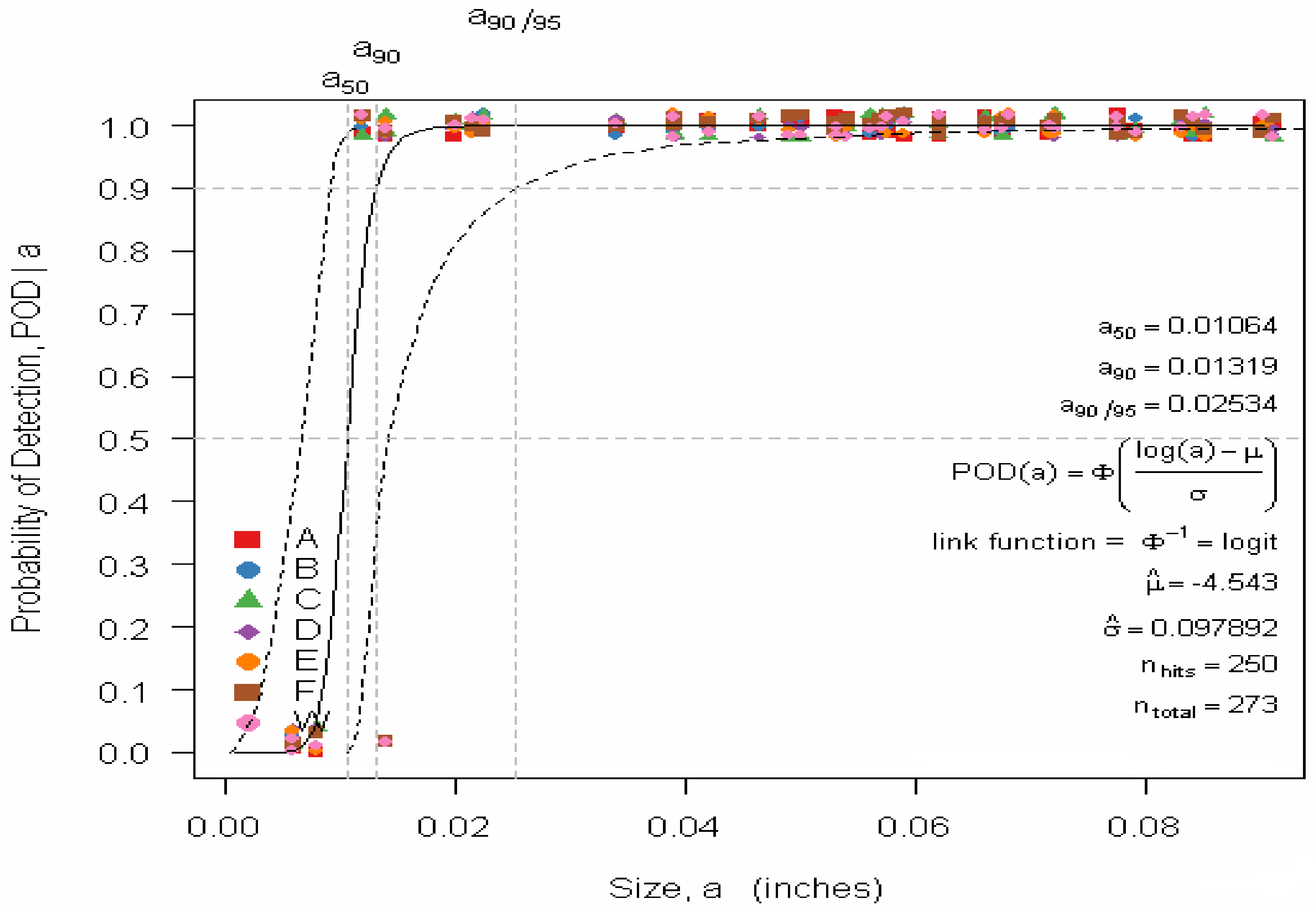
Summary of results



Mid-bore cracks (configuration # 12) were used for the modelling example. Averaged results over 7 inspectors.

NRC·CNRC
NRCaerospace.com

Summary of results



Mid-bore cracks (configuration # 12) were used for the modelling example.

Numerical modelling for PoD

- Represents an inexpensive alternative to costly experimental PoD studies
- Has the potential to partially substitute and complement experimental PoD data
- Reduces cost, effort, resources
- Assures portability of PoD information across similar structures
- Helps in damage tolerance calculations and increases platform availability

Conditions:

- Validate model on a reduced set of specimens
- Use the same variables as the experimental study
- Simulate the same signal features of interest

Numerical modelling for PoD

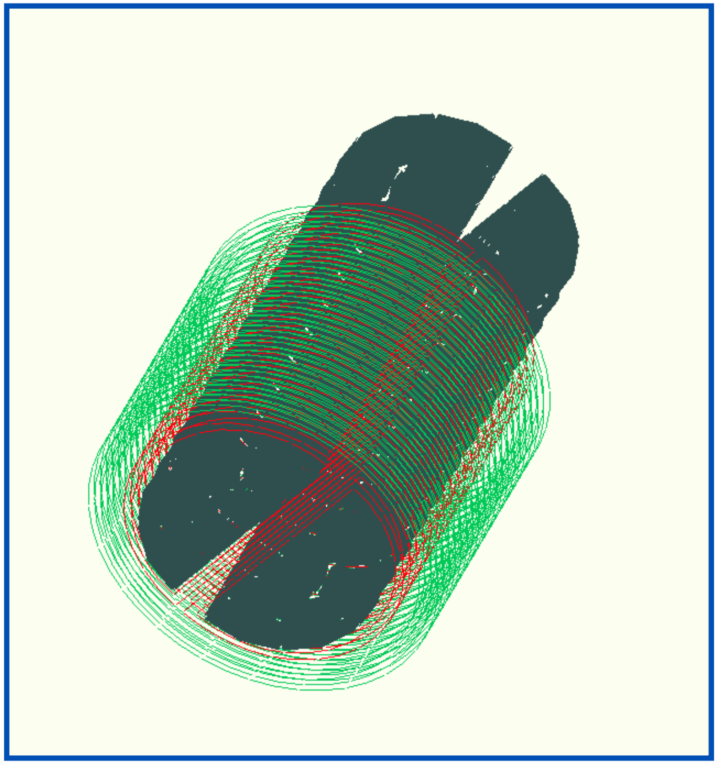
Modelling software:

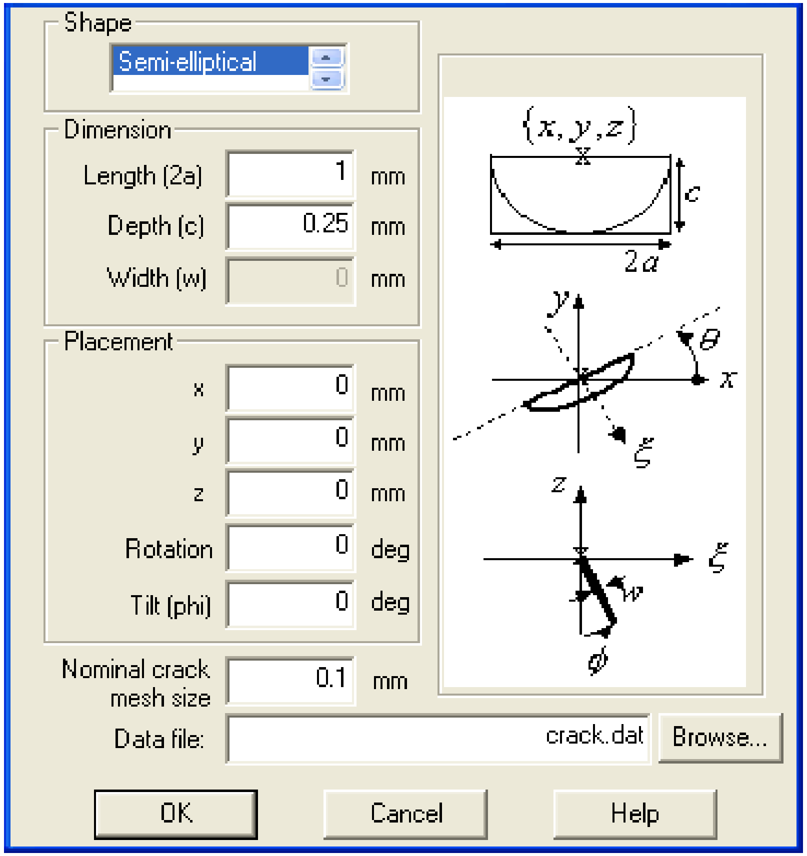
- ECISM by CNDE and NDE Technologies
- based on boundary element method
- single layer
- planar geometries
- no crack width

Input parameters:

- probe geometry
- crack dimensions
- material properties
- eddy current instrument settings

Numerical modelling for PoD

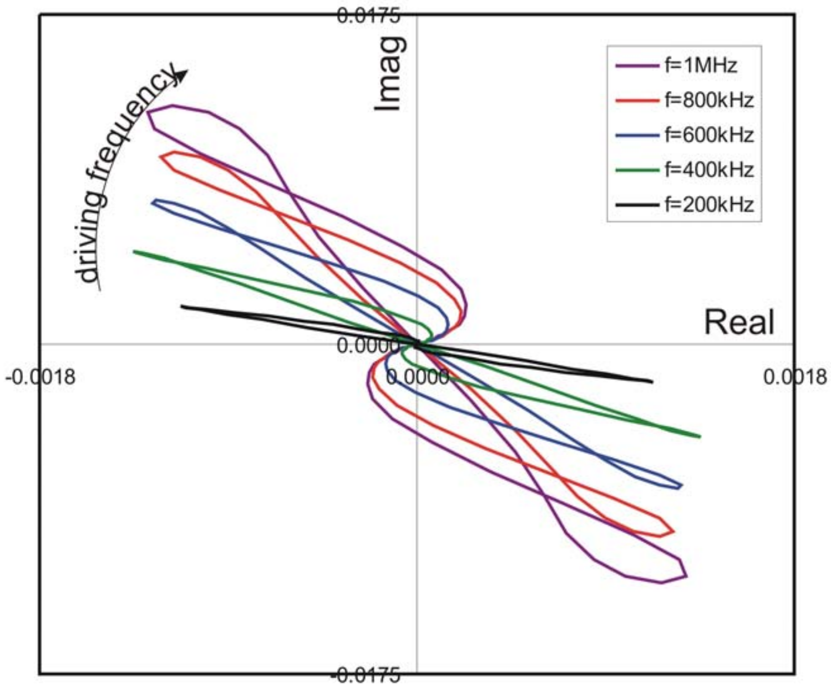


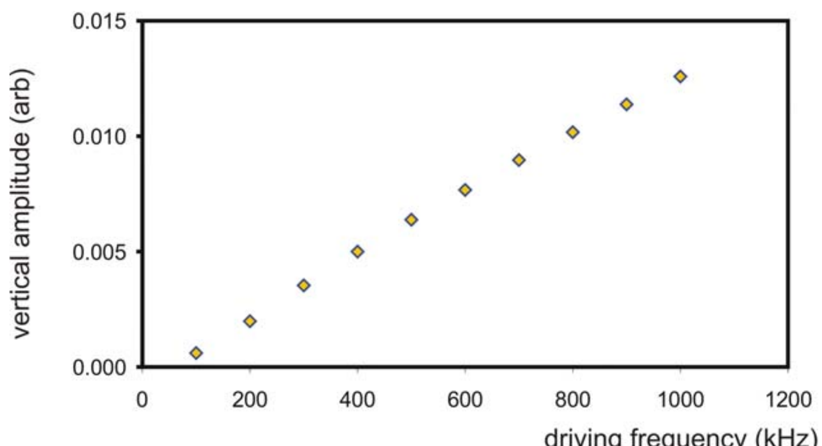


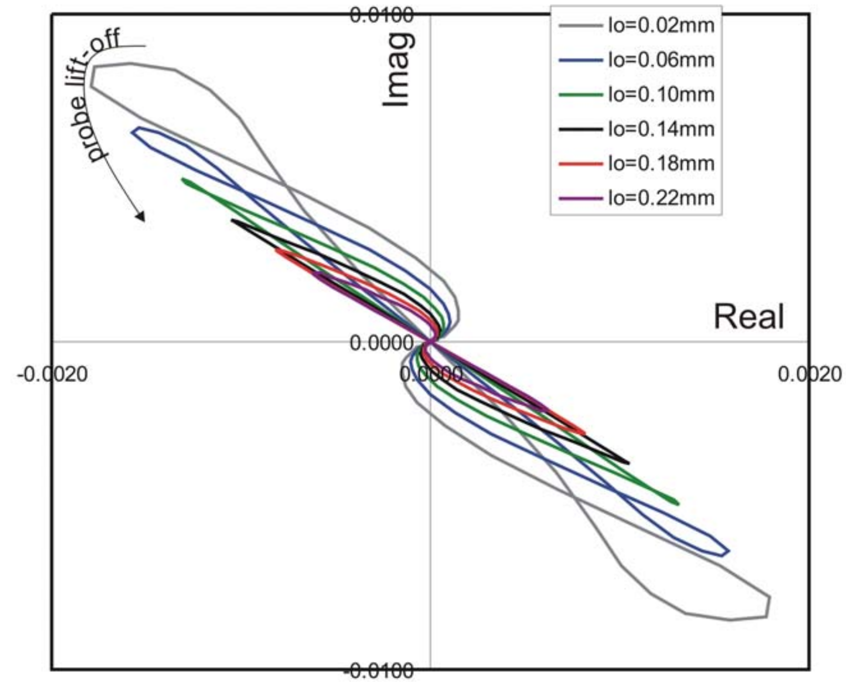
Evaluated variables

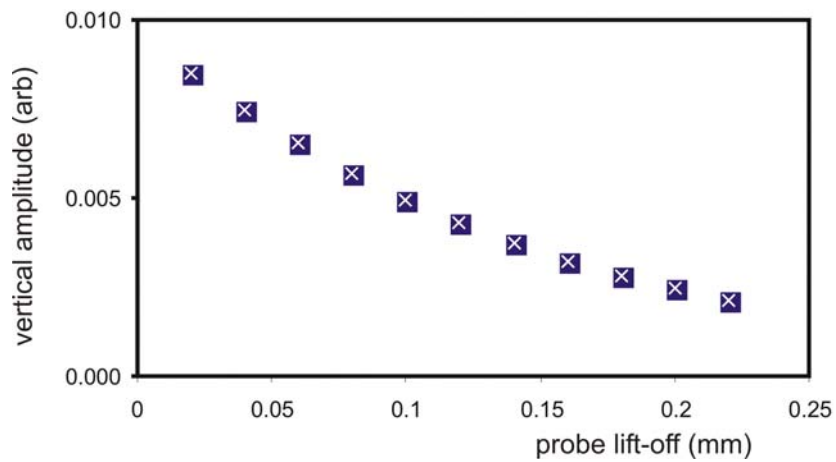
	Name of variable
Probe	frequency
	lift-off
	tilt
	off-centre
Crack	length
	depth
	length and depth
	rectangular versus elliptical shape
Material	electrical conductivity

Examples


0.0175
Imag
Real
-0.0018
0.0000
0.0000
0.0018
-0.0175
driving frequency
f=1MHz
f=800kHz
f=600kHz
f=400kHz
f=200kHz

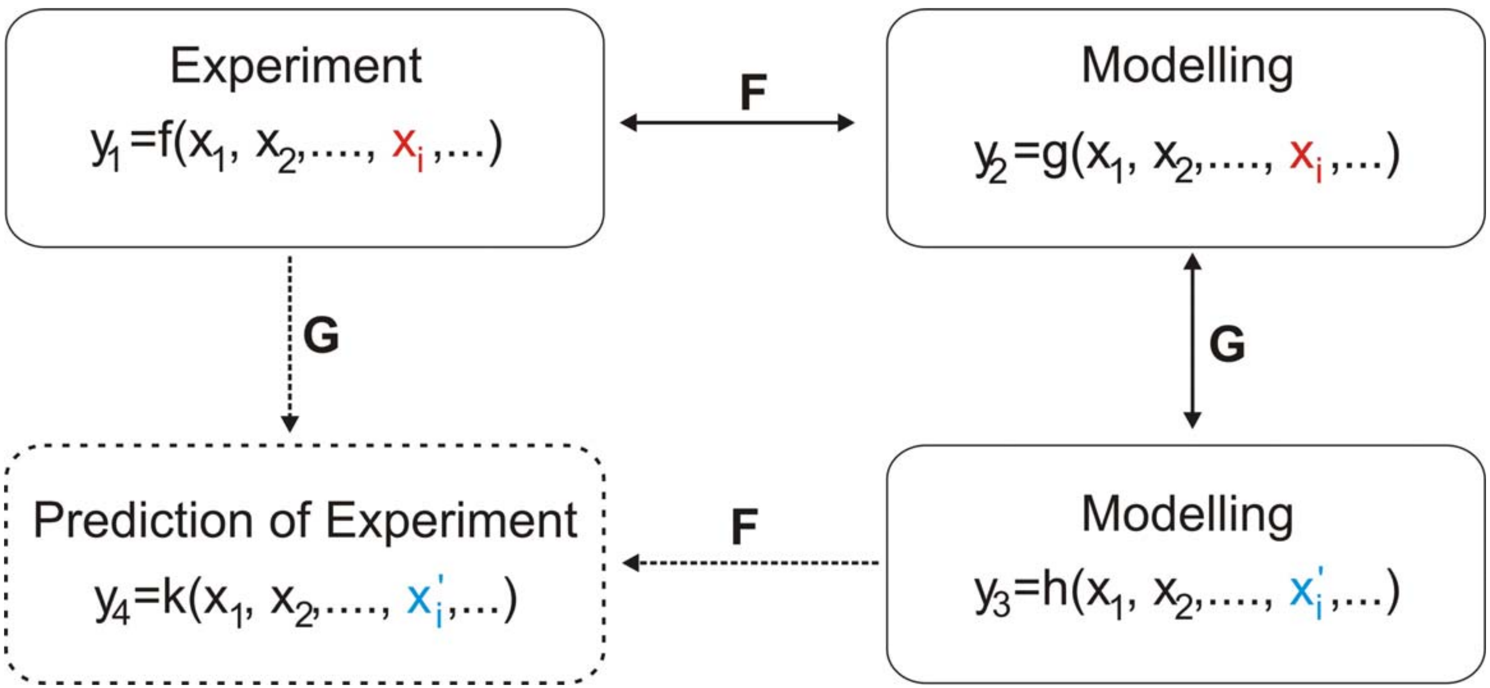

vertical amplitude (arb)
0.015
0.010
0.005
0.000
0
200
400
600
800
1000
1200
driving frequency (kHz)


0.0100
Imag
Real
-0.0020
0.0000
0.0000
0.0020
-0.0100
probe lift-off
lo=0.02mm
lo=0.06mm
lo=0.10mm
lo=0.14mm
lo=0.18mm
lo=0.22mm


vertical amplitude (arb)
0.010
0.005
0.000
0
0.05
0.1
0.15
0.2
0.25
probe lift-off (mm)

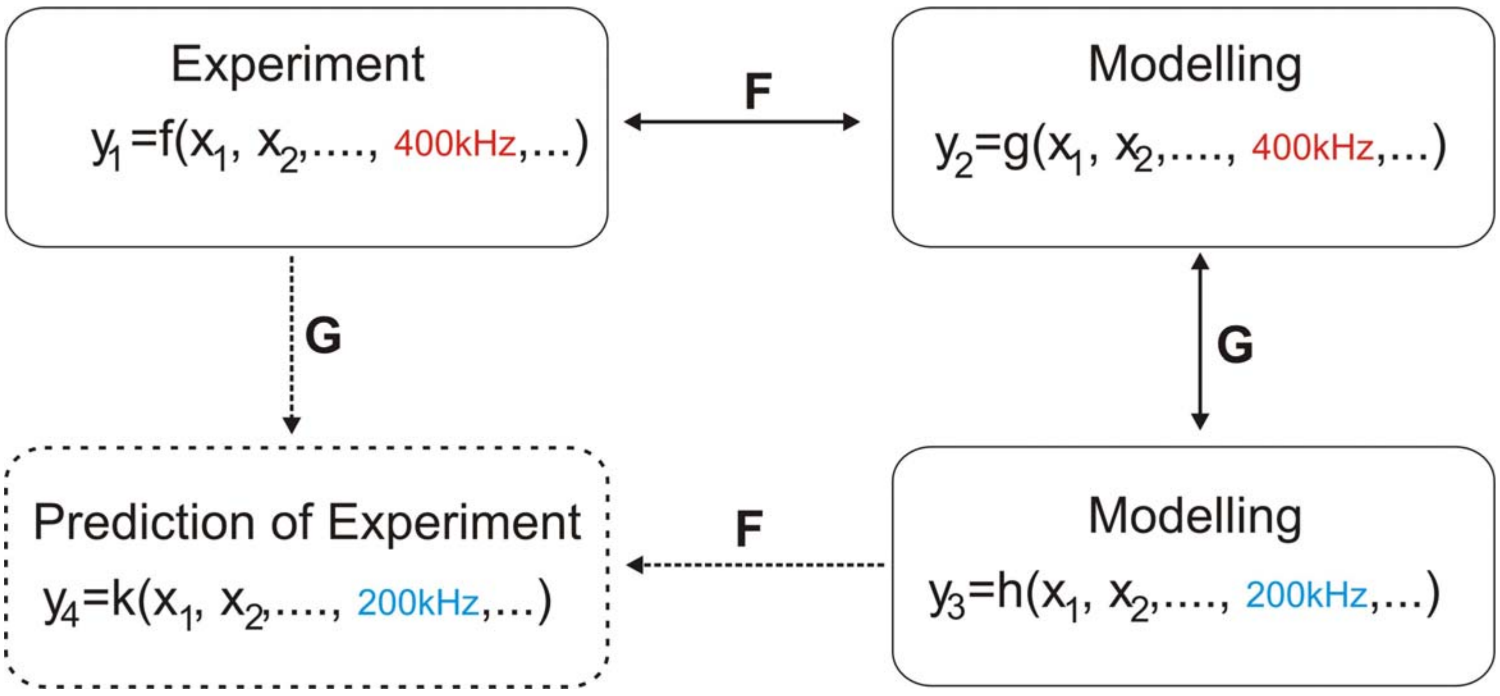
Numerical-based approach

General principles of using numerical-based approach for estimating PoD

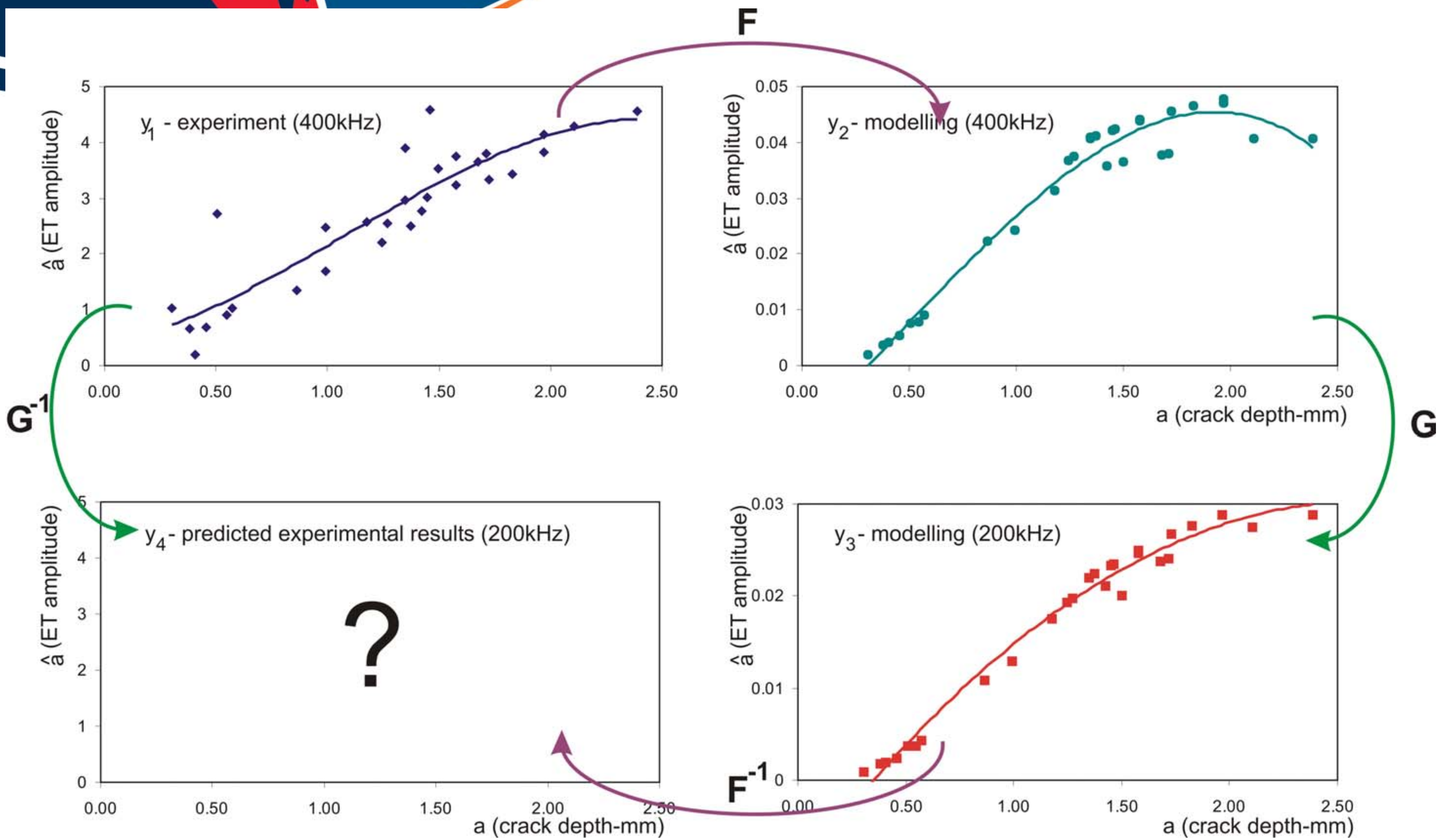


Example

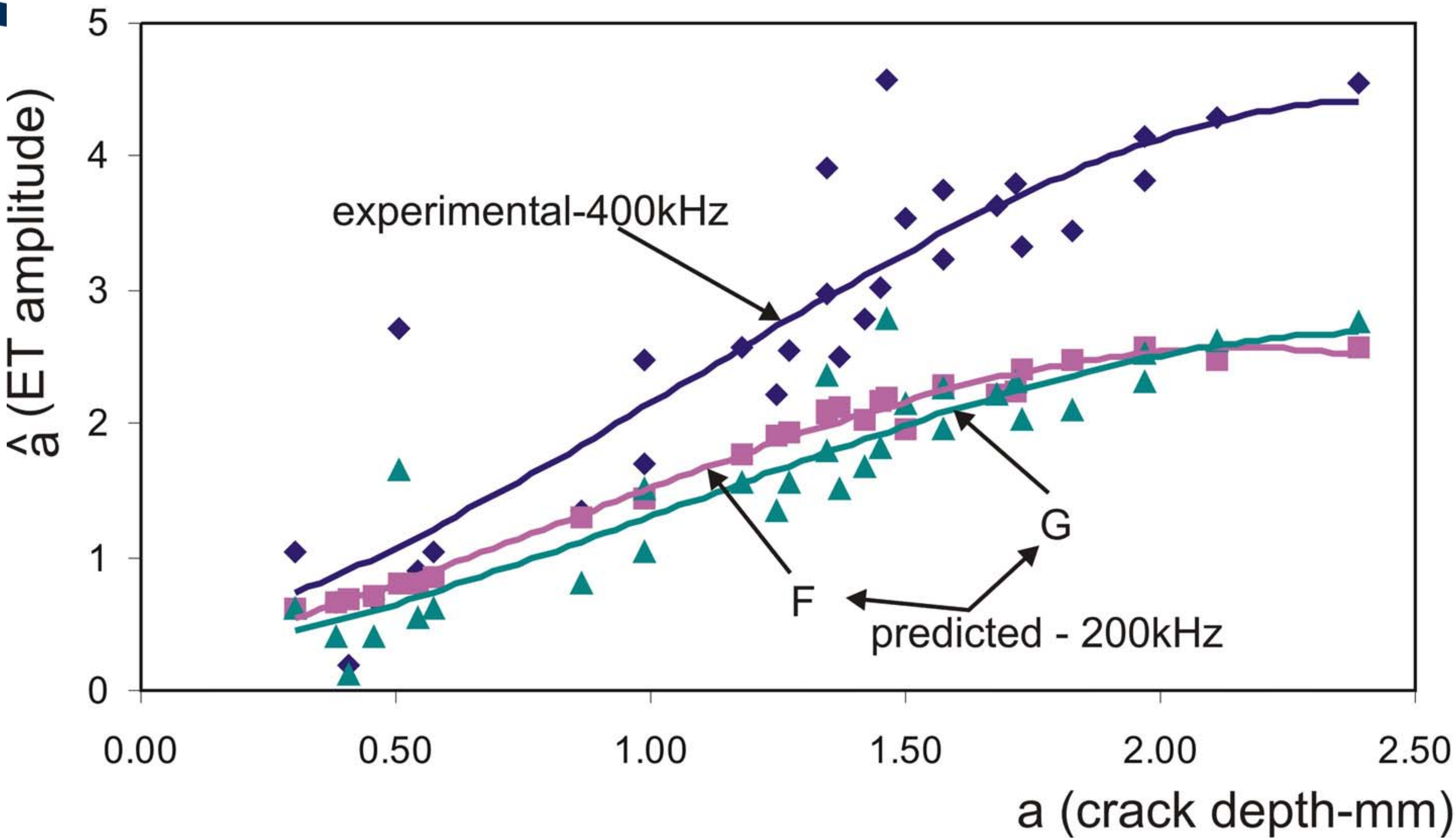
Consider only a change in the driving frequency:



Example


F
G
G-1
F-1
y1 - experiment (400kHz)
y2 - modelling (400kHz)
y3 - modelling (200kHz)
y4 - predicted experimental results (200kHz)
?
â (ET amplitude)
a (crack depth-mm)
0.00
0.50
1.00
1.50
2.00
2.50
0
1
2
3
4
5
0.01
0.02
0.03
0.04
0.05

Example


5
4
3
2
1
0
â (ET amplitude)
experimental-400kHz
G
F
predicted - 200kHz
0.00
0.50
1.00
1.50
2.00
2.50
a (crack depth-mm)

Summary

Numerical modelling:

- Insight into inspectability / detectability factors
  - inspection optimization
  - interpretation of results
- ***Cost-reduction tool for extensive PoD studies***
  - ***PoD studies based on a limited number of inspections***
  - ***transportability of known PoD results to similar inspection situations***

Future work:

- Validation of the predicted results
- Establish new noise levels and threshold limits
- Inclusion of the results in the PoD analysis

Contact info

If you have questions regarding the overall project, please address them to:

Dr. Abbas Fahr (NRC-IAR):

abbas.fahr@nrc-cnrc.gc.ca

Capt. DJ Butcher (DND-ATESS):

butcher.dj@forces.gc.ca

Final Results – to be presented at ASIP 2007, December 4-6