An update on the NDT Model Assisted Qualification (MAQ) programme

Martin Wall (ESR Technology Ltd)
Charles Schneider, Ian Nicholson (TWI Ltd)

The BINDT Aerospace Event 2019, National Composites Centre NCC, Bristol, UK, 9-10 April
Session 3: NDT reliability, 14:05 – 14:30

Materials Joining and Engineering Technologies

Overview

- Project background/motivation
- Project objectives
- Work programme
- Two pre-existing protocols
  - MASAAG Paper 122
  - PICASSO
- Progress on new protocol
- Technical demonstrators (TDs) and case studies of new protocol
- Model validation
- Ongoing/parallel activities
- Human factors
- Summary

Project background

- Project Partners:

- Scope defined in UK Military Aircraft Structures Airworthiness Advisory Group (MASAAG) Paper 122
- 3 Year project commenced May 2016

- ESR Technology sub-contractor to TWI (drafting protocol)
- QinetiQ subcontracted to provide data from previous project for a MAQ trial
- Industry Advisory Group (steering group)

Motivation for new protocol – recap

- Experimental validation of new or improved NDE methods in the air domain is costly and time consuming and is a barrier to introduction of new NDE methods. MAQ potentially allows experimental validation to be more focussed, key parameters to be identified, and for optimisation of the NDE method
- 2017 BINDT Aero Event compared pros and cons of various existing methodologies
- MIL-HDBK-1823A largely based on empirical POD trials
  - Requires large sample of realistic defect specimens (typically ~30-100 defects)
  - Costly & time-consuming
  - May not be practical to induce realistic fatigue cracks in realistic geometry
- ENIQ 'worst case' defect approach
  - No POD, Potentially over-conservative

⇒ Proposed model-assisted qualification approach instead

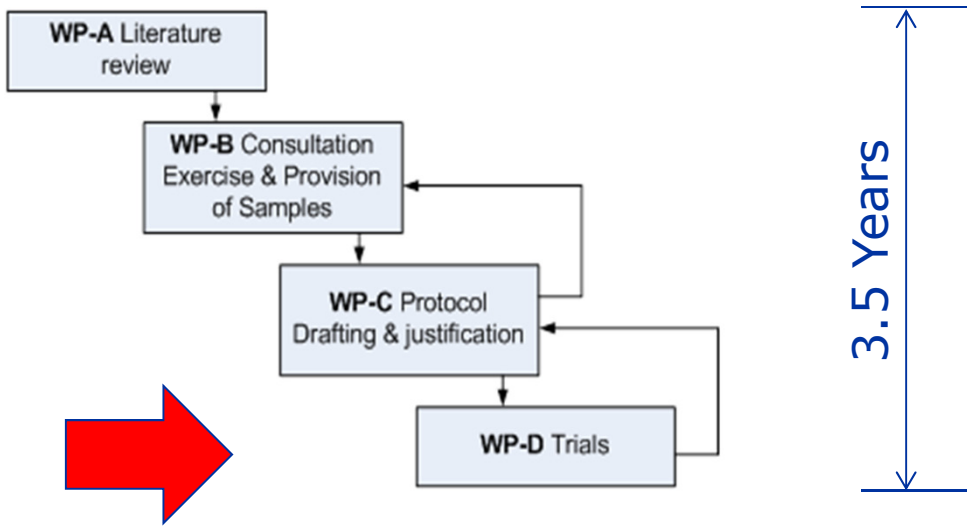
- Builds on two existing protocols (MASAAG, PICASSO)
- Aims to be user-friendly (more detailed guidance)

Project objectives

- To create and demonstrate a protocol for model-assisted qualification (MAQ) including model assisted POD (MAPOD), for inspections in the military air domain
  - Primary focus is delivery of a generic protocol that reduces the cost of POD studies through the use of a smaller number of samples combined with physics-based models
  - Wherever possible, the project will use pre-existing inspection procedures, models and samples
- Protocol initially developed for an existing ultrasonic technique. Protocol to be validated and updated for other inspection scenarios including PAUT sector-scan and FMC

Work programme

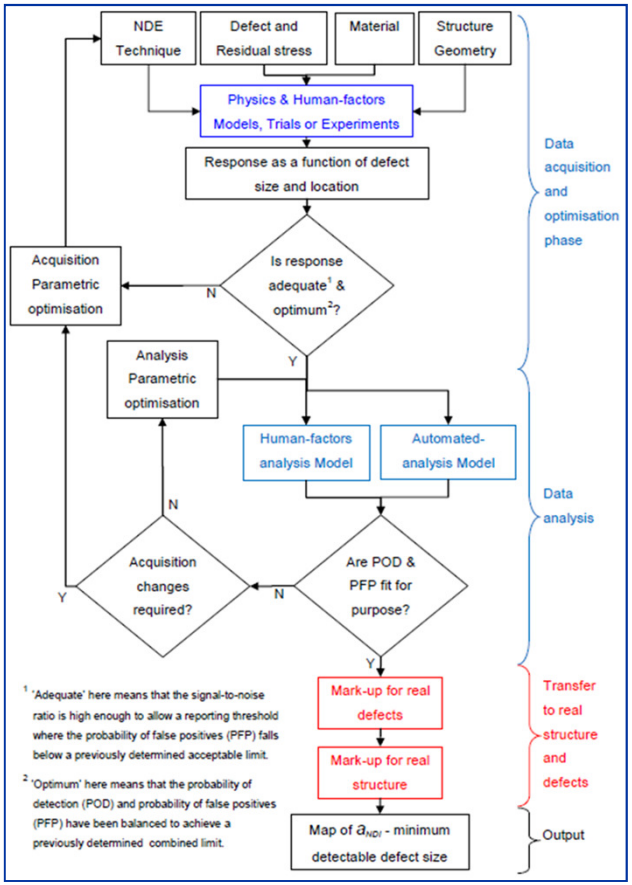
- Work programme
  - After WP-A, several iterations for demonstrations and re-drafting of the protocol



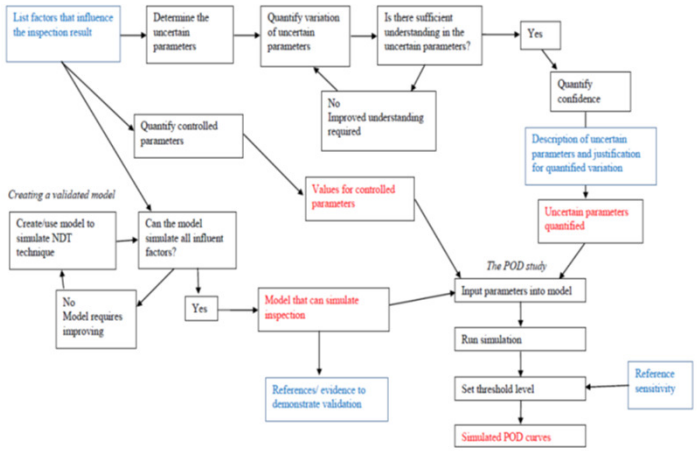
Currently through 6th iteration. Technical Demonstrators in progress

Task TD1 - Manual UT
Task TD2 - Manual PAUT Sector Scan
Task TD3 - Manual PAUT Linear Scan
Task TD4 - FMC
Task TD5 - Automated Acquisition
Task TD6 - Automated Analysis
Task TD7 - Extension to Composites

MAPOD Protocols proposed in MASAAG Paper 122 and PICASSO



MASAAG Paper 122



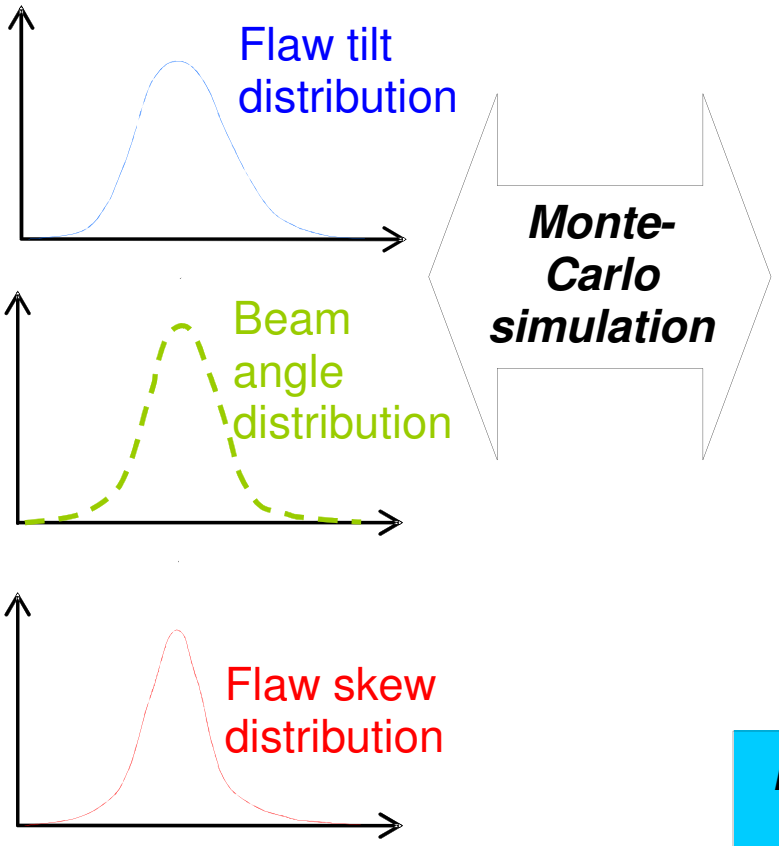
PICASSO

[from PICASSO project, courtesy of Rolls-Royce]

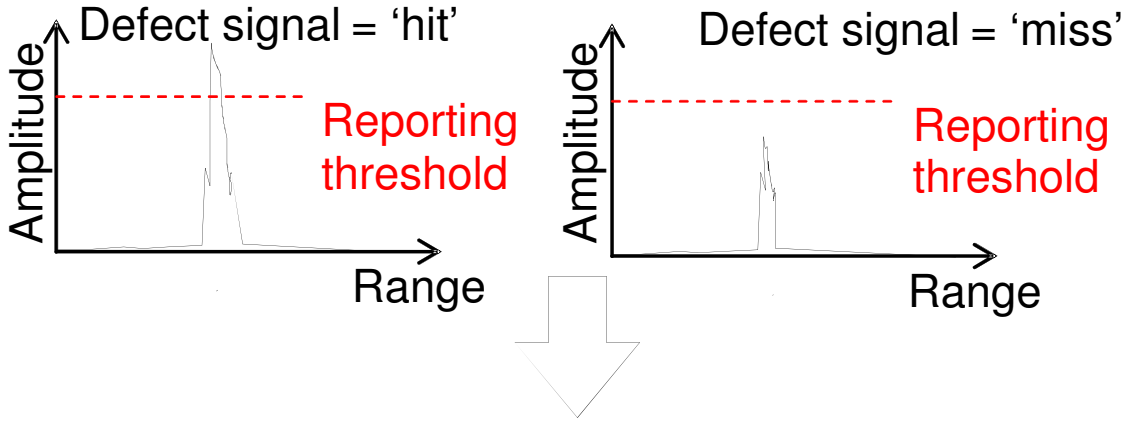
- Takes prior MAPOD protocols as starting point including MIL-HDBK-1823A

  Highlights various issues for protocol
  - *Parametric* optimisation
  - Human factors
  - Automated analysis
  - Mark-ups for real defects/structure (transfer functions)
- 'Physics model' element in blue
  - PICASSO protocol provides more detail

Model-assisted probability of detection (MAPOD) for UT – one approach



For each Monte-Carlo sample (or 'play') – use UT model to compute signal amplitude



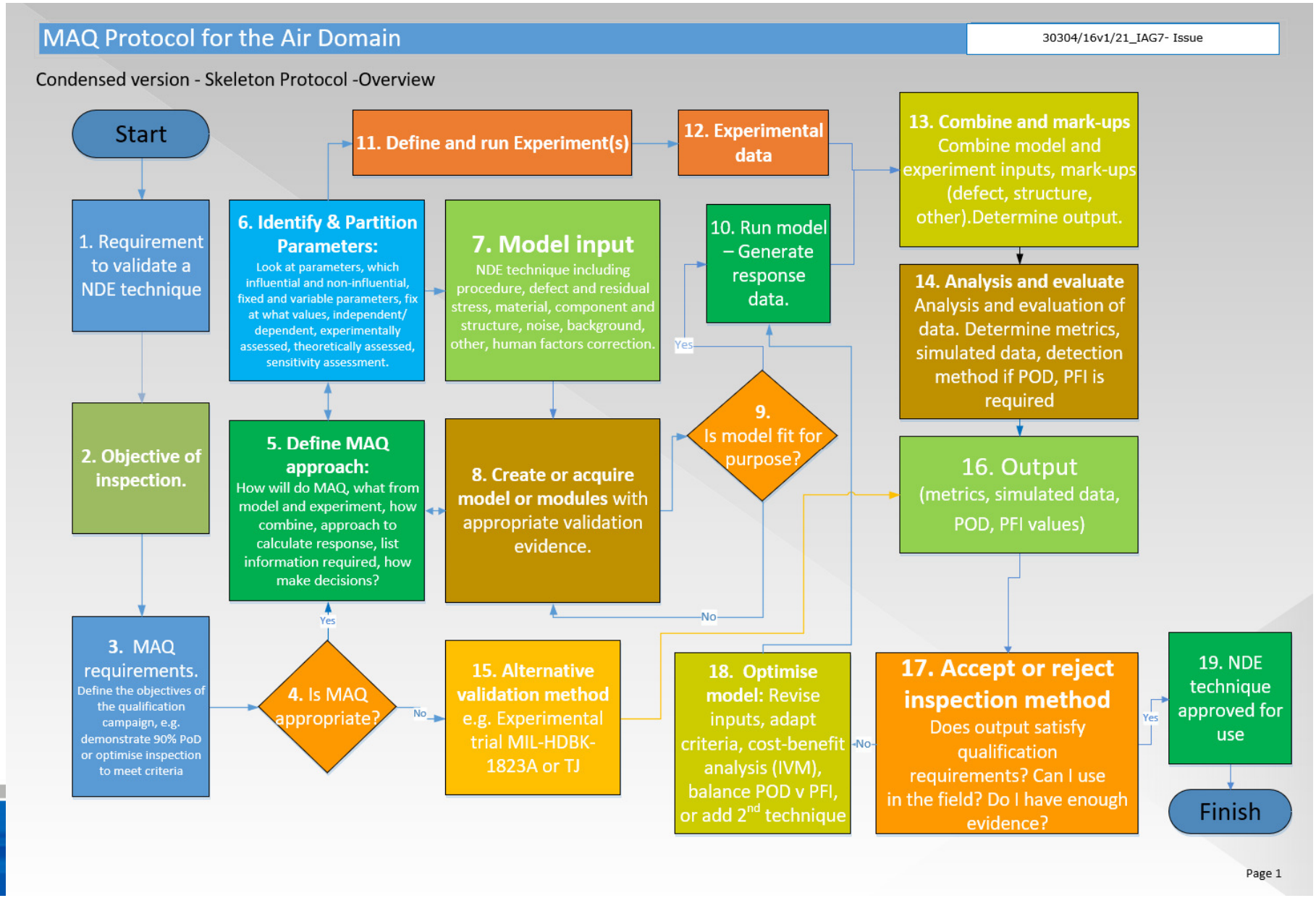
Probability of defect producing recordable signal = Total 'Hits' / Total ('Hits' + 'Misses')

[courtesy Rolls-Royce]

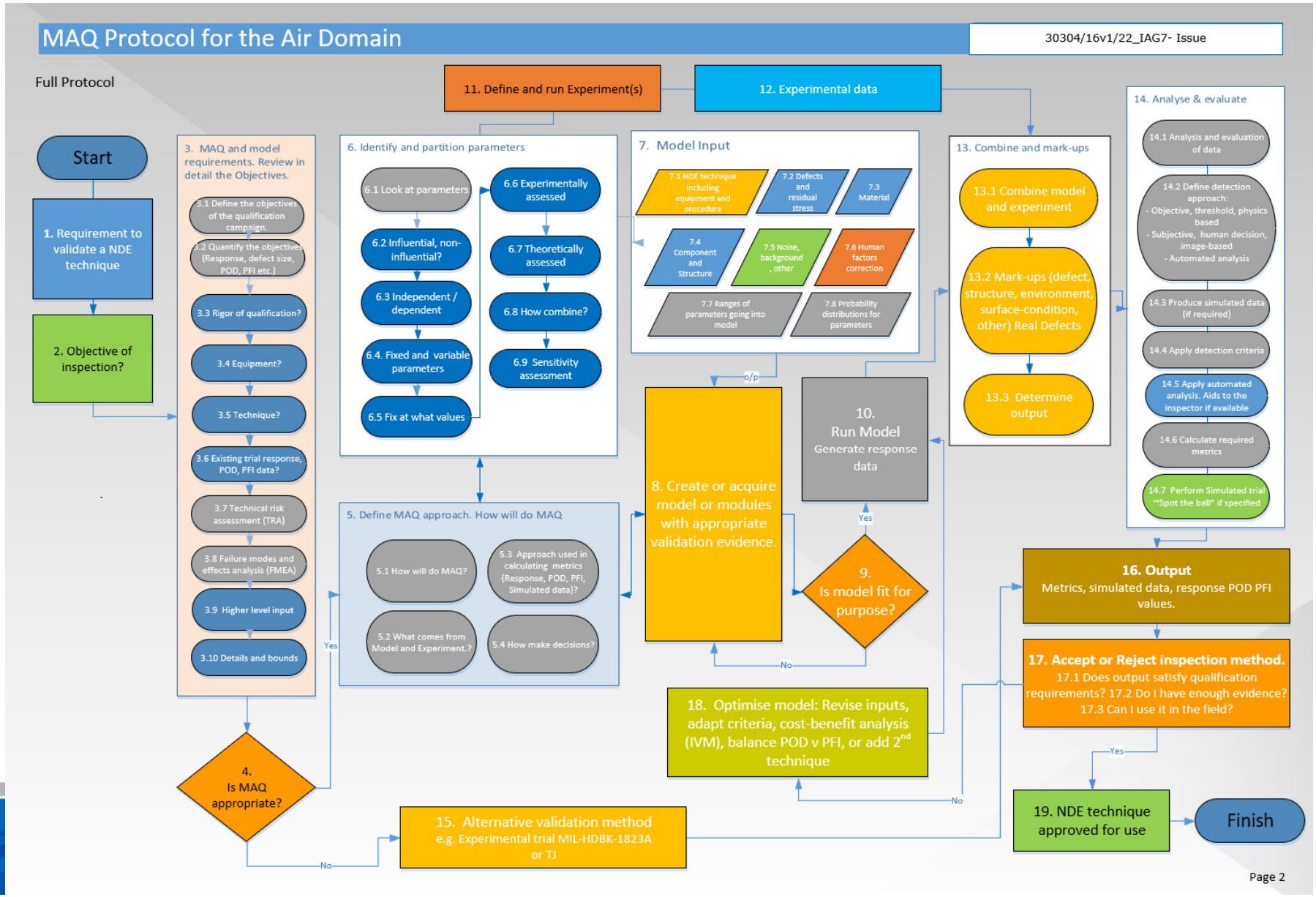
New protocol – stages

- Purpose of inspection?
- MAQ/MAPOD required? Level of qualification rigour?
- Assess controlled and uncontrolled variables
- Define MAQ approach: Transfer function (XFM), Full Model Assisted (FMA), Modular, Simulated trial or combination
- Existing model? Already fit for purpose or need to develop new model?
- Validate software and calibrate model for application
- Define input parameters
- Define detection model/criteria
- Run model. Review and evaluate results. Optimise if required.
- Combine model and experiment. Map to defect. Map to structure

New protocol – Latest 'condensed' version



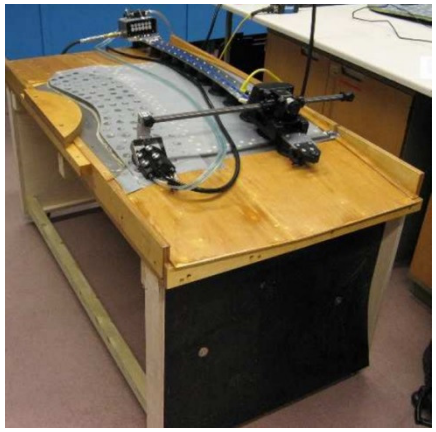
New protocol – Latest 'full' version



Progress since Aerospace 2018

- Protocol has evolved since Draft presented in 2018. Simplifications to flow in MAQ protocol.
- Renumbering of flowchart to better reflect actual sequence;
- Improvements to visual presentation.
- Comprises Protocol 'Flowchart' and comprehensive step-by step guidance document
- Input and workshops with Industrial Advisory Group (IAG).
- Input from University of Bristol including simple case study (Alex Ballisat, Robert Smith)
- A number of Technical Demonstrators (TD) completed and in progress to test out MAQ Protocol
- Reanalysis by QinetiQ of semi-automated PAUT data on tornado wing (Smith & Birt ,QQ procedure Massag 122). Utilised Demonstrator TD3
- Trials single-probe and PAUT on 73-notch Tornado wing reference sample and Ref. samples, RAF Marham July and September 2019. Data utilised in technical demonstrators TD1, TD2.
- MAQ modelling using CIVA by TWI for Demonstrators TD1-TD3.

Protocol Technical Demonstrators (TDs)

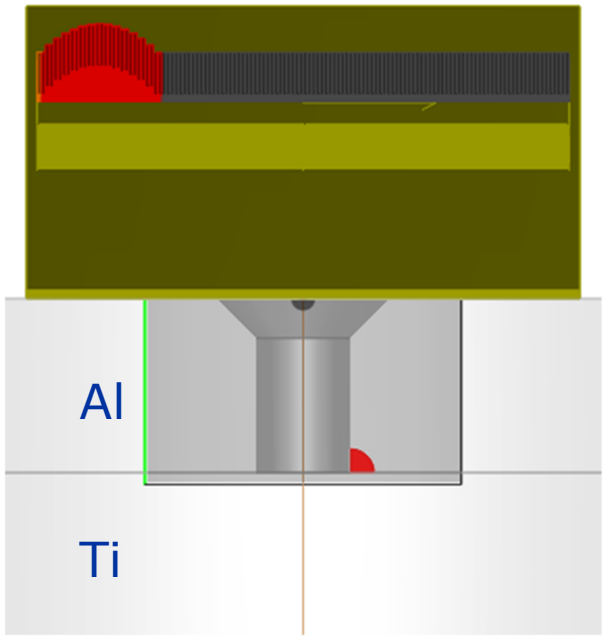


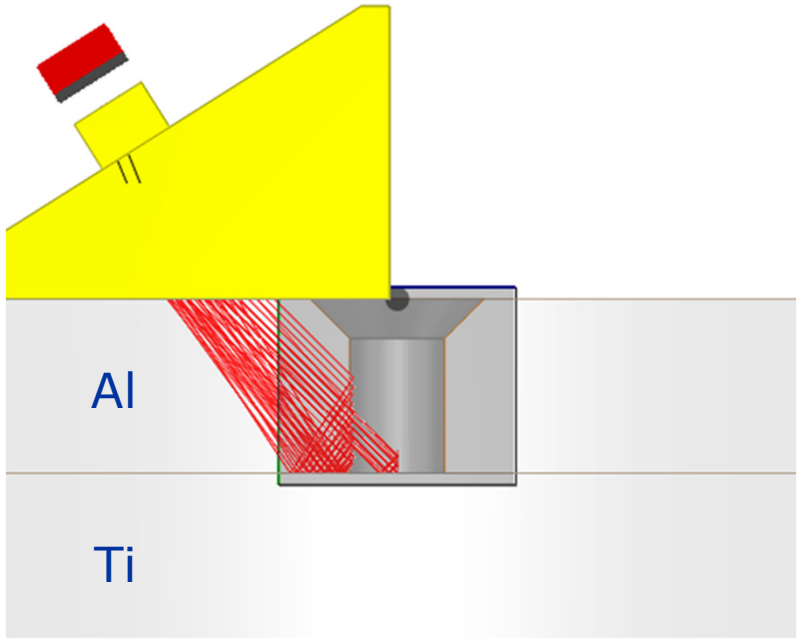
A series of Technical Demonstrators (TDs) being undertaken to test out the MAQ protocol utilising a 73 notch wing development sample

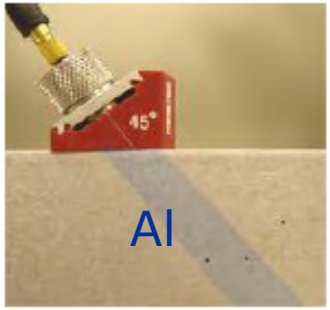
- TD-1 Manual UT
- TD-2 Manual PAUT Sector Scan
- TD-3 Manual PAUT Linear Scan
- TD-4 Full Matrix Capture
- TD-5 Automated acquisition with suitable encoded scanning equipment
- TD-6 Automated Analysis
- TD-7 Extension to Composites

Initial demonstration of protocol – Technical demonstrator (TDs) inputs (1)

- Component – 2-layer Al/Ti structure
- Flaws – corner cracks at bolt holes at back of 1st layer (Al skin)
  - Skewed by up to ±15° from chord-wise direction



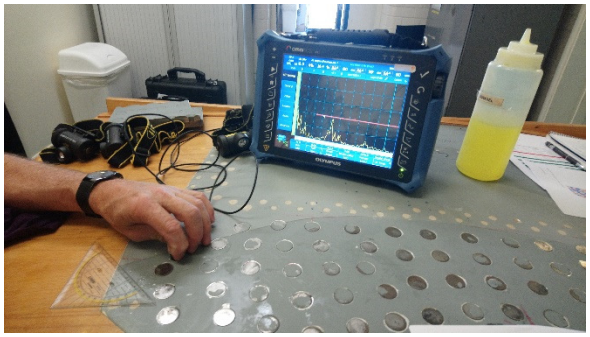




Initial demonstration of protocol – TD inputs (2)

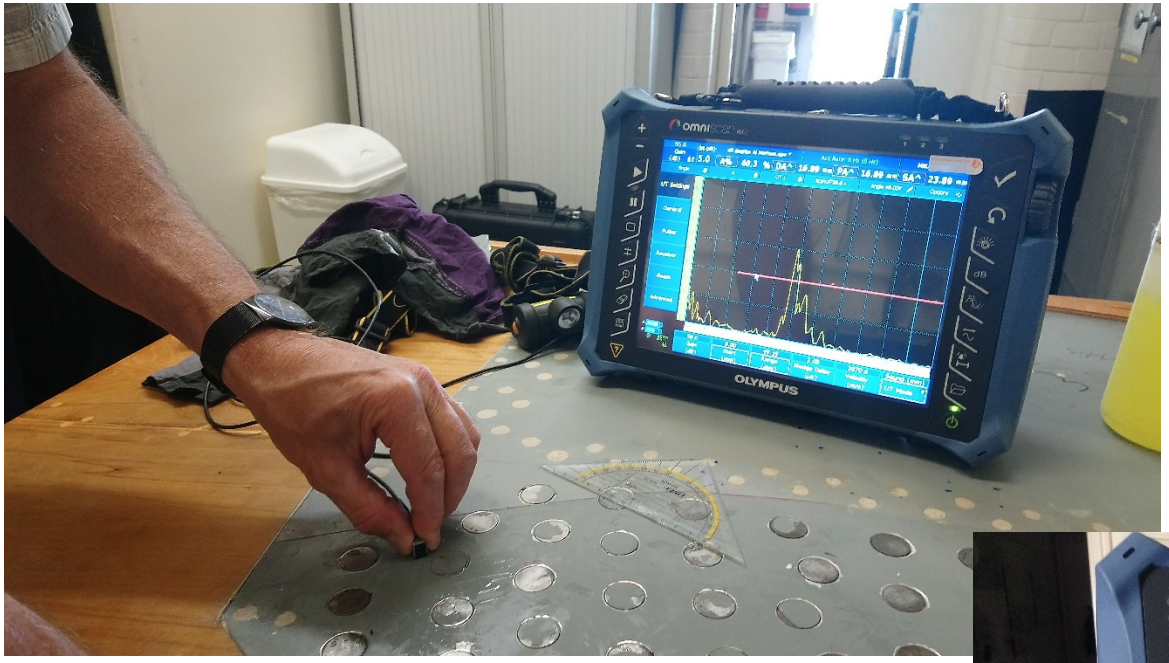
- NDT procedure, equipment & reporting level
  - Existing draft PAUT procedure (courtesy QinetiQ)
  - Threshold recommended during associated development work
- Qualification targets based on earlier work by QinetiQ
  - a_{NDI} = 5mm radius quarter-circle crack (after allowing for 2mm mark-up from 3mm radius EDM notch)
    - Use modelling to estimate 'inherent' POD
  - Largest background/corrosion signals at least 6dB below threshold
    - Estimate associated confidence based on noise levels in existing specimen(s)

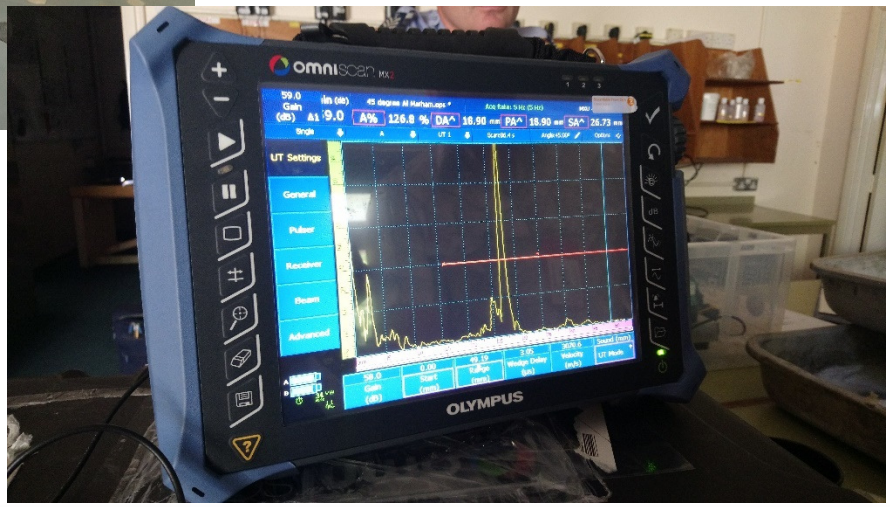
RAF Marham trials wb 25 Jun 2018



- 3.5 day trial on 73-notch development sample at RAF Marham;
- Detailed trial plan with prioritisation of defects
- Two datasets gathered as per trial plan: first set was rotating probe for optimum (Swivel scan) and the second set was passing scan. FMC limited acquisition due to time constraints but repeat visit allowed collection of data.

Trials at RAF Marham June and September 2018 –Single-element UT swivel scan





MAQ trial Data example – PAUT Fastener 1

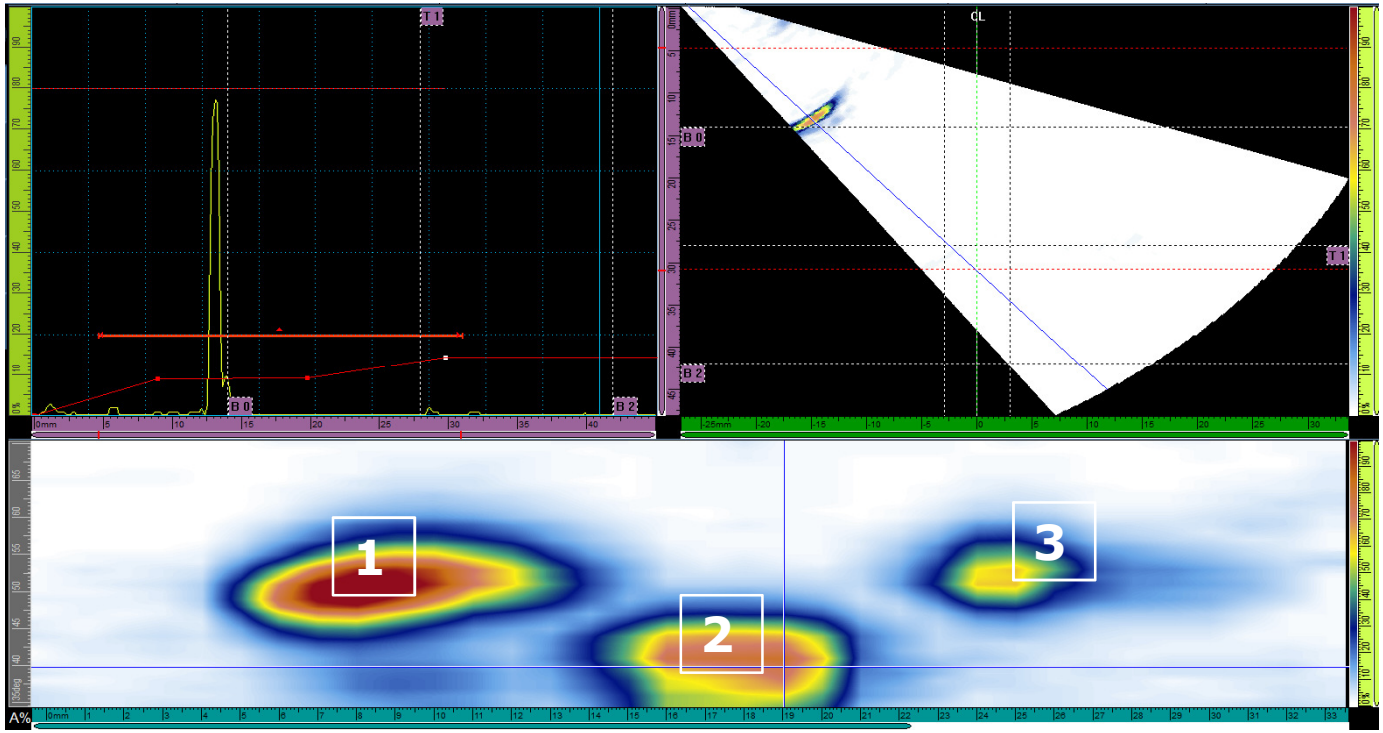
1 = Left hand flaw

2= Bore of fastener

3= Right hand flaw

Data collected includes

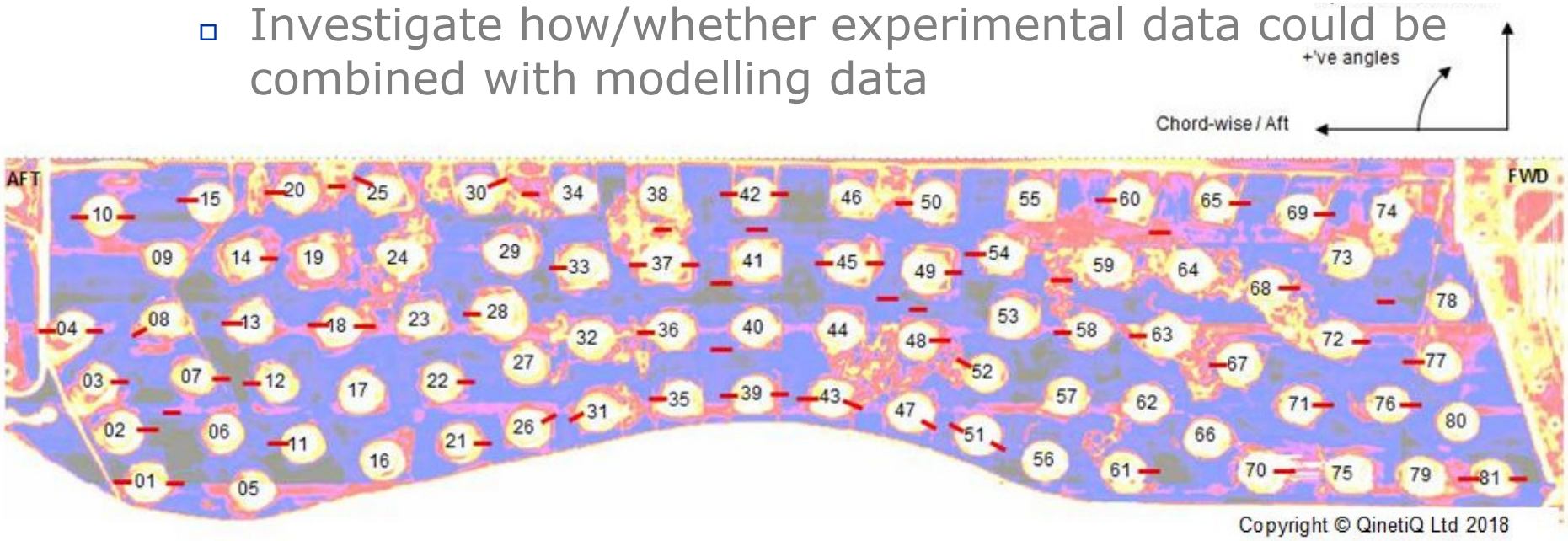
- Amplitude of bore.
- Amplitude of flaw.
- depth
- position
- echo dynamic



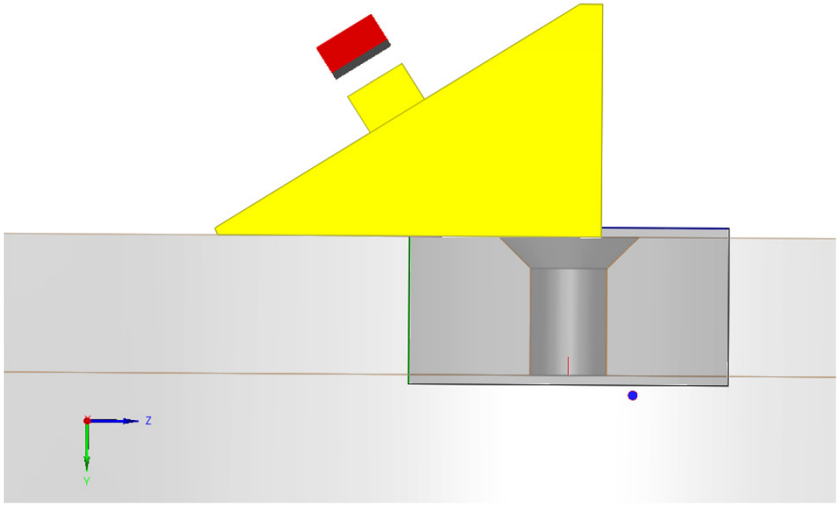
Comparison model with QQ measured signals from notched development sample

TD3 Linear scan PAUT

- QinetiQ provided TWI with PAUT amplitude data from notched development sample
- TWI has compared some of these data with model:
  - Check model is producing useful output
  - 'Calibrate' model if necessary
  - Investigate how/whether experimental data could be combined with modelling data

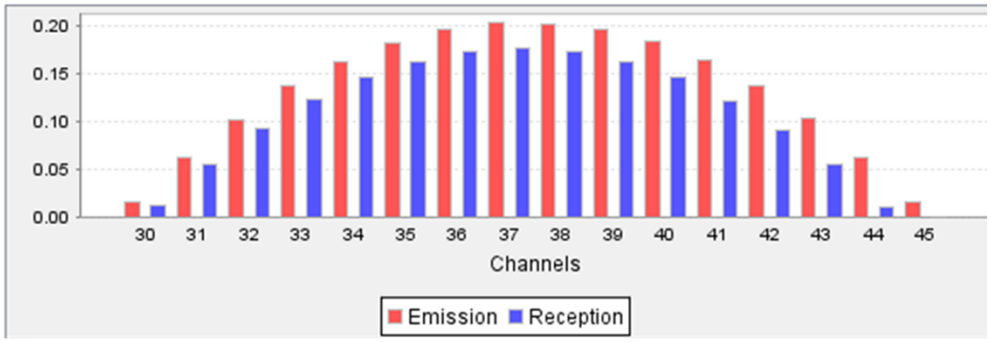


CIVA modelling TD3 Linear scan PAUT



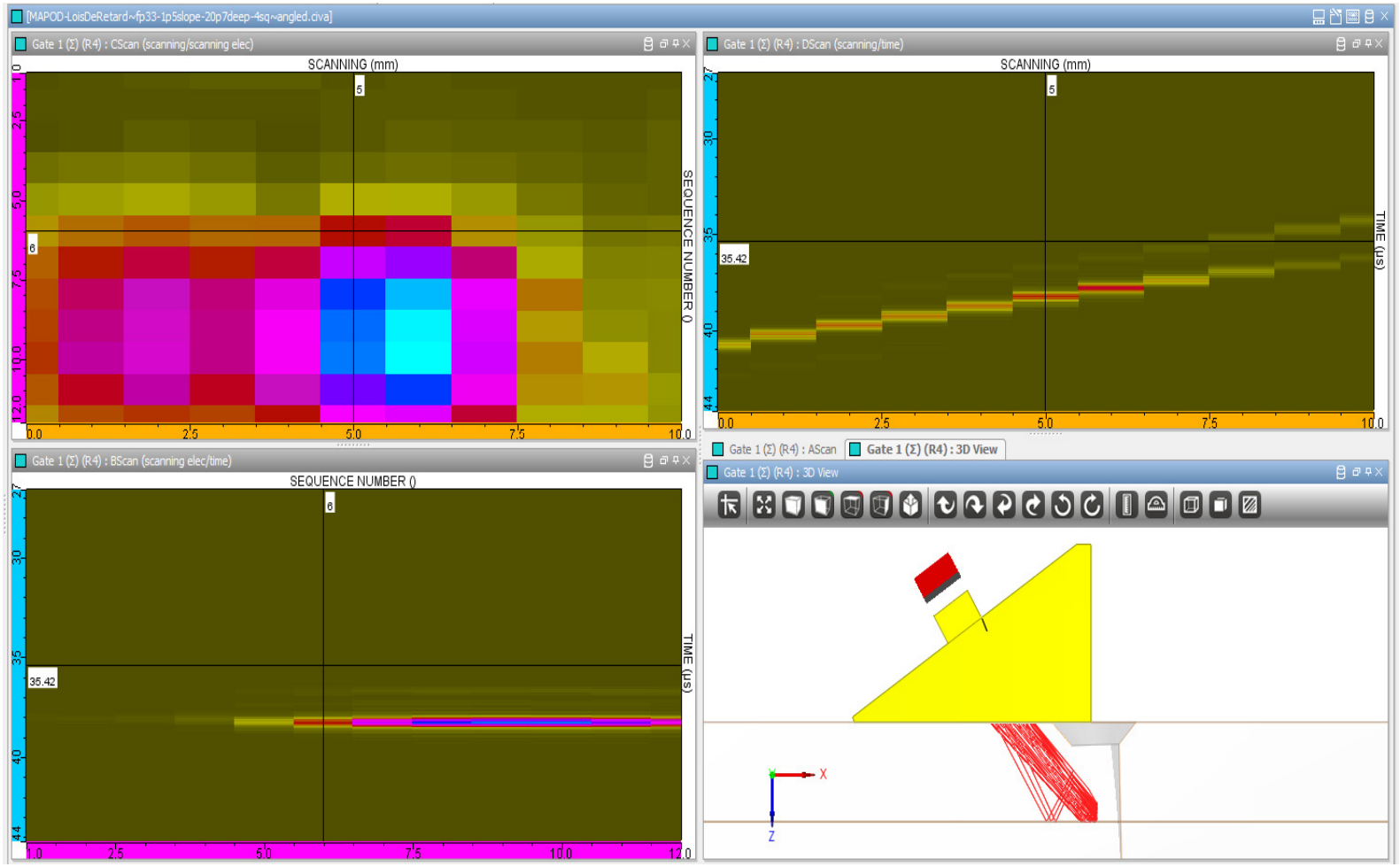
CIVA simulation of the probe and wedge to represent the real standoff and dimensions of the wedge that was used

A 64-element probe was modelled with pitch of 1.051mm and element curvature of 40mm. The probe was mounted on a wedge that was created in CIVA aiming to represent the real standoff and dimensions of the wedge that was used



Phased array delay laws

Example data CIVA model TD-3 Manual PAUT Linear Scan

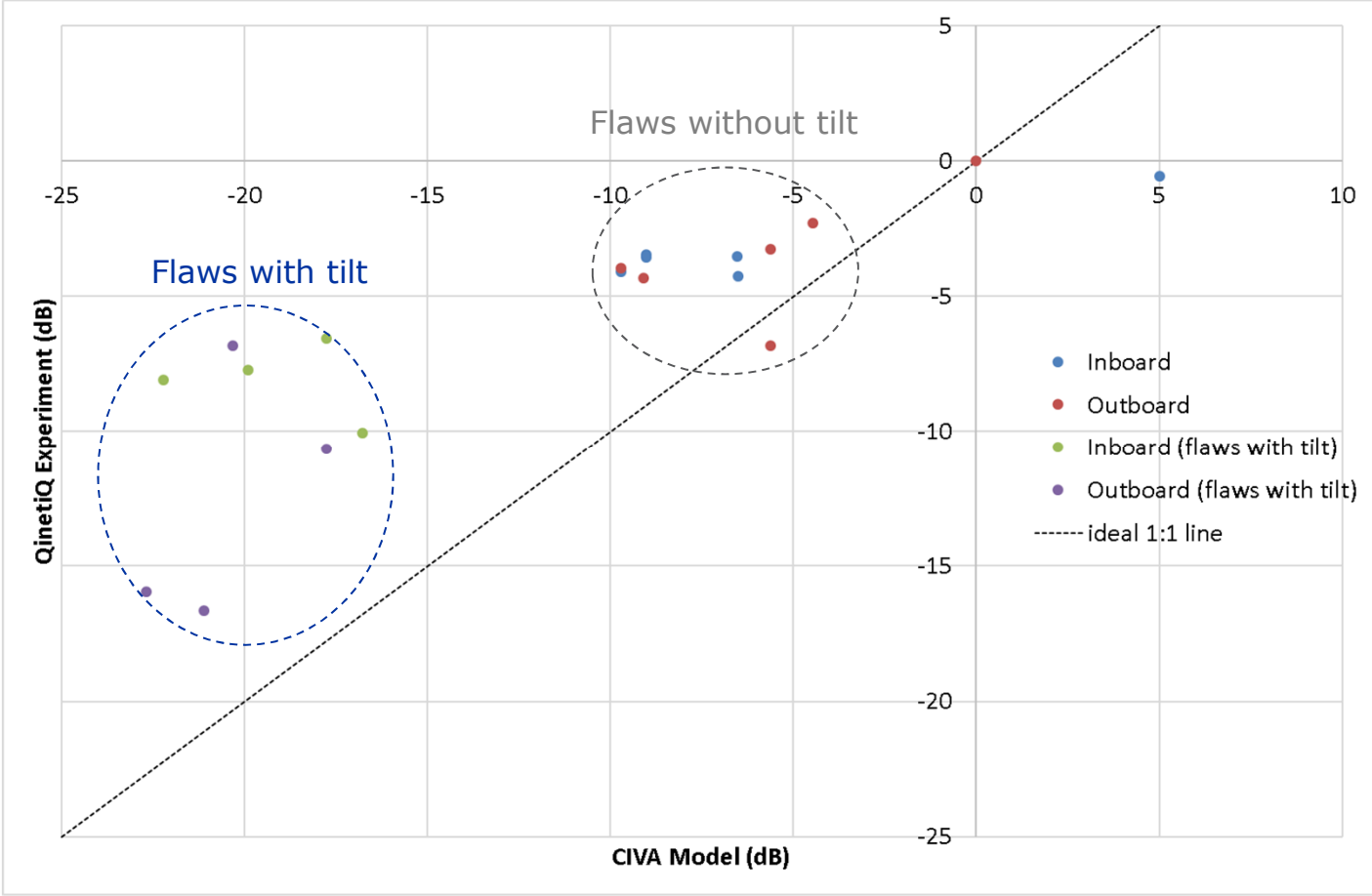


Courtesy DSTL, TWI

Comparison CIVA model v experiment
TD-3 Manual PAUT Linear Scan

Amplitude response (dB) in experiment greater than the CIVA model predictions. *(Note dB changes compared to ref –ve.)*

POD estimates produced utilising same threshold as used in field inspections (**-12dB** or **0.25** normalised units)



Ongoing/parallel activities

- How can the number of simulations be minimised?
  - Use of sampling and interpolation?
  - Should inputs be treated as fixed or variable?
  - Covered by Alex Ballisat (Bristol Univ) EngD project. PhD and ongoing involvement.
- Assessment of human factors (Marija Bertovic, BAM) Reference Marija's presentation later in this reliability session
- Extension to full matrix capture (FMC) TD4
- Extension to automated acquisition(TD5) and automated analysis (TD6) systems
- Extension to composites (TD7)
  - TWI seeking suitable samples (ian.cooper@twi.co.uk)
- Aim for completion end August 2019.
- BINDT Aerospace Group identified need for a higher level guidance document on NDT technique validation
  - TWI plans to progress this further in 2019

Summary

- The cost of POD studies can potentially be reduced through the use of a smaller number of samples combined with physics-based models
- An MAQ protocol has been developed to provide guidance on various approaches to model-assisted qualification for the military air domain
- This is currently being validated through a number of modelling and experimental technical demonstrators (TD1-7)
- An Industry Advisory Group is helping to review project progress and direction
  - Please contact ian.cooper@twi.co.uk to join, or to find out more about using the protocol