Report from the Aerospace Workshop on Technique Validation and Standards

Aerospace Workshop

4 October 2022 | GKN Aerospace, Bristol, UK

BINDT
THE BRITISH INSTITUTE OF NON-DESTRUCTIVE TESTING

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Aerospace Workshop on Technique Validation and Standards

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This workshop intended to provide the background to technique validation and also describe the current practices of technique validation for some key industries, including aerospace, civil nuclear and naval/marine. This provided a contrast between aerospace and civil nuclear, where the structure around qualification is different and both have well-established processes. The naval qualification uses the European Network for Inspection and Qualification (ENIQ) guidelines, providing a good example of how to start a qualification with no previously established processes.

The workshop also included a session on standards, where the process and thinking behind recognising new standards without causing contradiction and confusion in the industry was described. The final session covered historical practices in non-destructive testing (NDT)/technique validation and a proposed draft standard to assist with probability of detection (POD) selection. Finally, the workshop was split into two groups for a discussion session.

The specific objectives of this workshop included:

- *The promotion of discussions with UK stakeholders in the area of technique validation;*
- *Addressing some knowledge gaps around POD and model-assisted qualification (MAQ) by feeding thoughts and ideas into a BINDT general validation document;*
- *The promotion of a greater understanding of the differences between qualification in aerospace and qualifications that use the ENIQ methodology; and*
- *Addressing the state of standards around technique qualification.*

The eight presentations made, which are summarised in this report, were followed by a discussion session with two proposed questions:

- *How can we select PODs from the options available? (List a few basic options); and*
- *What approaches do other people use in the industry for the training of new inspection techniques/methods?*

BINDT Technique Validation Working Group objectives

Tom Bertenshaw, GKN Aerospace

The Technique Validation Working Group is a group that was initially formed from objectives flowed down from BINDT's Council. This group then formed its own objectives, including:

- Leading BINDT strategic activities for technique validation and qualification;
- Publishing and maintaining guidance documents;
- Creating and maintaining a UK community of stakeholders (using seminars, workshops and online meetings);
- Reviewing liability issues around technique validation; and
- Interfacing on behalf of BINDT with the International Committee for Non-Destructive Testing (ICNDT) Specialist International Group (SIG) on NDT reliability.

The group has adopted one of the objectives of the BINDT Aerospace Committee, namely '*to promote and enable the introduction of new NDT technologies by identifying and tackling barriers, and through scientific evaluation, validation and education of manufacturing and maintenance supply chains*', where a working document was produced. This identified a number of parameters surrounding equipment, personnel and the process. A common theme around lack of awareness and knowledge showed that a guidance document would be useful to help with technique validation. Thus, a guidance document around technique validation/qualification was created. This guidance document was adopted by the newly formed Technique Validation Working Group in 2020. This then changed the scope of the document to meet the aims of the group, including applications from power generation (including nuclear civil), marine, oil & gas and aerospace. Some differences between the European Network for Inspection and Qualification (ENIQ) methodology and aerospace have been identified but the same common theme exists, where an understanding of probability of detection (POD) applicability and adoption of model-assisted qualification (MAQ) was needed to help adopt new technologies into industry.

This was the premise of this workshop, to help bring out some of the requirements and common working practices from the sectors described above and to help feed the thoughts and understandings into the general document.

The history and development of POD including model-assisted qualification

Martin Wall, ESR Technology

POD is widely accepted as a parameter for quantifying the reliability of inspection and has played an important role in technical validation and qualification of inspection (NDT) methods since the 1970s. The origin of POD was in the US aerospace industry and the concept developed by Ward Rummel in 1972. The driver was the small critical defect size in airframe structures (~6 mm) and the relatively poor reliability of engine components. Analysis methods were developed, including the Berens method, to produce a POD curve against defect size and minimum detectable flaw size. The usual aerospace requirement is to detect flaws with a probability of 90% at a confidence level of 95%. This flaw size is abbreviated as $a_{90/95}$. POD played a pivotal role in the validation of NDT methods in the US Aging Aircraft programme (1989-1993), with significant reliability improvements.

The POD approach moved in the 1980s and 1990s to the nuclear, energy and other sectors, with the European-American Workshops on Reliability (EAW1-7) organised by Bundesanstalt für Materialforschung und -prüfung (BAM) and the German Society for Non-Destructive Testing (DGZfP) in Berlin, Germany, playing a pivotal role in the development. The latest workshop convened in 2017[1].

POD is normally determined by blind trials on samples with real or artificial defects. The methodology captured in US-MIL-HDBK-1823A[2] includes databases of POD curves (for example the NTIAC, Washington).

As the time and cost associated with experimental POD trials can be significant, emphasis has shifted, with the increasing power of data analytics, to computer modelling and simulation of POD. This has become known as model-assisted POD (MAPOD) or, more broadly, model-assisted qualification (MAQ) of inspection. A new protocol has recently been developed for MAQ in the air domain[3] for the Defence Science and Technology Laboratory (DSTL), which will be published by the BINDT Technique Validation Working Group.

The first POD models were developed in the early 1980s at the UK National NDT Centre (NNDTC) at Harwell (by Wall, Ogilvy, Wedgwood and Windsor) and the Center for Nondestructive Evaluation (CNDE) at Iowa State University. More sophisticated POD models with simulations were first developed in the 1990s by the NNDTC for the European Space Agency (ESA)[4], allowing simulated 'spot the ball' POD trials, as well as physical models. The simulated POD trial approach has been used more recently by Greg Selby at the Electric Power Research Institute (EPRI)[5]. POD modules are now standard in commercial NDE simulation software such as CIVA.

MAQ is complementary to other methods of technique validation, such as ENIQ in the nuclear industry, technical justification and capability-based approaches. POD and MAQ have a range of applications in integrity and life assessment. An area of growing interest is that of how to quantify and integrate the effects of human factors (HF-NDE) on inspection reliability into POD assessments[6].

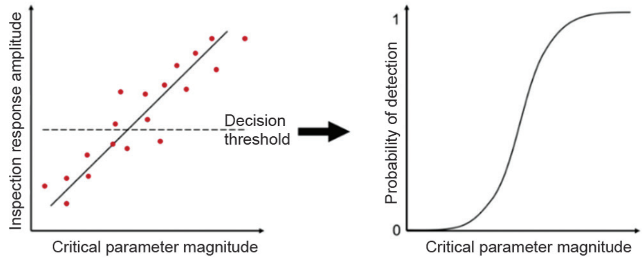

Figure 2. Determining the critical parameter threshold

The role of simulations in technique qualification

Alexander Ballisat, Centre for Modelling Simulation

Qualifying inspections relies on testing a technique on a wide range of samples to demonstrate that it is robust to the variations present in service. This can cover a wide range of possibilities, including variations in inspection equipment, components manufactured to the same standard, different inspectors and

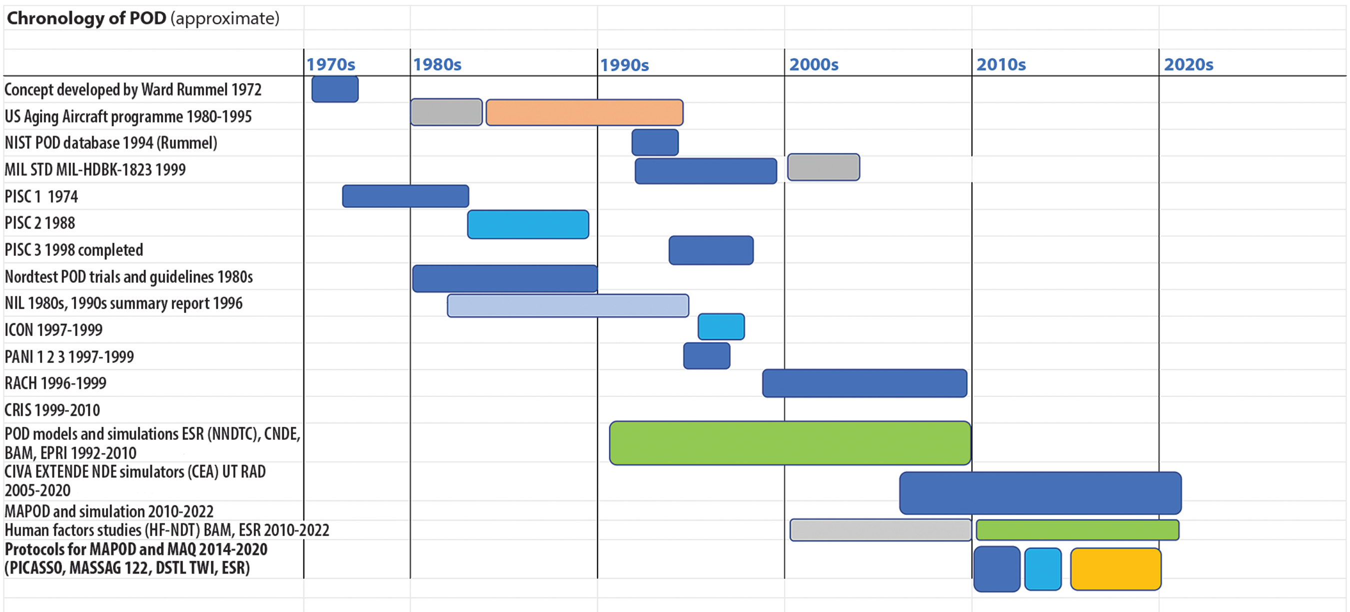

Figure 1. POD chronology plot from the 1970s to the present

different properties of defects, among others. Fully capturing this variability requires undertaking a very large number of trials that account for different combinations of these possibilities. This can be undertaken experimentally; however, this is typically very expensive and time consuming. The advent of cheaper and more powerful computer resources provides the opportunity to replace a significant proportion of these experimental trials with simulated trials. This also allows for more trials to be undertaken, thereby achieving a better understanding of the capability of the inspection. The increase in the number of trials also allows more advanced statistical methods to be used to estimate key performance metrics, such as the $a_{90/95}$ metric used in aerospace. Increasing the number of trials enables other techniques, such as optimisation and sensitivity analysis, to be applied to better understand and improve the inspection. The increasing use of novel manufacturing methods, such as additive manufacturing (AM), which will produce a much wider range of parts, will require more frequent inspection qualifications. Current experimental trial-based qualifications are not going to be able to meet the time and cost requirements and simulations will therefore play a key role in enabling inspections of these processes.

NDE development and qualification in the aerospace industry

Tim Barden, Rolls-Royce plc

Rolls-Royce plc used the introduction of flash thermography to exemplify the implementation of a new NDE technology as a method of production inspection. Initially, an overview of the technology readiness level (TRL) process and how it could be applied to NDE applications was described.

In the initial stages of technology development, the essential parameters are investigated and this work is carried out to understand the process parameters that influence the inspection. Such work is often carried out by universities or research organisations. The next stage involves applying this technology to an industrial application. However, personnel training and approval is required to meet aerospace regulations. At the time that Rolls-Royce implemented flash thermography, there was no Level 3 in the UK and the UK National Aerospace NDT Board (NANDTB) developed a process for the first or 'genesis' Level 3 in a new NDT method.

During the application of a new NDT method to an industrial application, it is important to understand the factors that influence the inspection and develop process checks to ensure a repeatable inspection process. This step is as important in the overall inspection qualification process as blind trials that demonstrate the inspection system must perform as intended.

Qualification in the nuclear industry using ENIQ guidelines

Greg Garrett, Jacobs IVC

The Jacobs Inspection Validation Centre (IVC) is an Independent Qualification Body (IQB) that undertakes inspection qualification of civil nuclear power plant using the ENIQ methodology[7]. This is a well-established methodology that has been in use for two decades.

Inspection qualification is required in the UK to comply with the Office for Nuclear Regulation (ONR) Safety Assessment Principles (SAPs) and contributes to the 'avoidance of fracture' arguments for safety-significant components (high-integrity components (HICs)). The structural integrity safety case relies on applying qualified (capable and reliable) volumetric inspection (principally ultrasonics) during manufacture and in service to ensure the absence of crack-like defects. These inspections of high-integrity components must be qualified by an IQB. The IQB uses an objective-based qualification process following the ENIQ methodology, which facilitates a high level of confidence in the inspection system through technical justification (TJ) and limited practical trials. The technical justification is a written statement of the theoretical and experimental evidence that supports the case that the inspection system is capable of meeting its requirements (ENIQ RP2). The inspection procedure (IP) should provide control of all essential parameters, as well as sufficient instruction for operators to apply the inspection reliably and achieve the same results (ENIQ RP12). When the inspection procedure and technical justification are sufficiently mature, procedure trials are held in which the IQB observes the inspection procedure being applied to a blind test-piece. The test-pieces are designed and manufactured by the IVC and contain samples of worst-case defects (WCDs). Personnel who have been trained on the application of the qualified IP can be admitted into the personnel trials, where they undergo written, verbal and practical examinations. On completion of the practical trials and after the assessments of the IP and TJ have been completed, the IQB issues certification for the inspection procedure and personnel.

Figure 3. Jacobs IVC supporting Hinkley Point C, in Somerset, UK

Qualification of NDT on naval vessels

Tom Barber, BAE Systems

Challenges exist regarding the validation of novel NDT technologies in the naval manufacturing sector. There are several considerations that make NDT innovation difficult. Firstly, some naval platforms are considered 'in-class' with shipping classification societies (similar to commercial vessels), while others are not. This creates a varied set of stakeholders, which can inhibit innovation. Secondly, shipyards and dockyards now have more responsibility to deliver NDT innovation; previously, agencies of the Ministry of Defence (for example the now defunct Defence Evaluation and Research Agency (DERA)) were key drivers of validation activity, with the shipyards more akin to NDT service providers. For these reasons, there is no 'one-size fits all' NDT validation approach carried out by the sector.

As a case study, BAE Systems' successful validation of the ultrasonic inspection of pipe butt welds *in lieu* of radiography was presented. The work started as a university-focused research and development (R&D) project and progressed through to an accepted procedure ready for deployment. There was no established process to approve a novel NDT procedure; the team had to define it and engage with relevant stakeholders as the work progressed. The approach broadly followed the civil nuclear ENIQ methodology; however, elements from other practices were incorporated.

Some of the pitfalls and lessons learnt when taking an inspection from R&D through to implementation were discussed. These included the need to consider validation and performance requirements as early as possible in the technology development process and also to include 'front-end' inspectors as early as possible in the practical elements of development and validation. The presentation finished on the view that some Level 3s may find it difficult to interpret some of the validation methodologies already published if they are not familiar with them from their role. It was suggested that general training on how to validate NDT procedures should be considered within all NDT certification schemes.

Figure 4. Queen Elizabeth-class aircraft carrier – in-class and therefore subject to Lloyd's Register shipbuilding and NDT requirements

Standards development

Alex Price, BSI

The development of standards in any area gives assurance, safety, relatability and repeatability. The wide coverage of standards goes across sectors; although the development of horizontal standards applicable to different industry sectors is desirable, there is also a need for specific industry standards. Standards are developed for industry by industry; a standard needs to answer a specific problem. All standards are applicable to answer a problem, from industry-accepted codes to BSI PAS/Flex standards to international standards. There is criticism of standards from different standards development bodies, as developing similar standards (see Figure 5) can cause confusion within the industry. BSI tries to avoid this.

NDT standards are well established in the industry in broad categories and follow a quality management approach, with understanding of the relevant standards in the following areas: competencies, systems, material and the manufacturing process. Additive manufacturing is a technique that has a number of relatable areas and has called up the use of NDE during in-process monitoring during the build and post-process monitoring of the final build. Standards should be considered in the overall systems, for example for use in the assessment of critical structures.

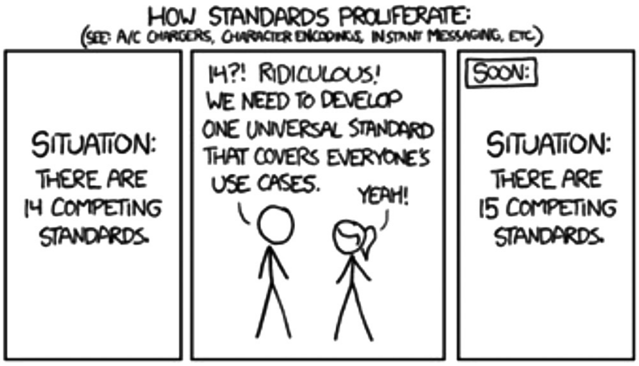

Figure 5. Standards proliferation

The use of test artefacts as reference materials of self-seeded flaws (BS ISO/ASTM TR 52906:2022) to evaluate methods was raised, with particular mention of a US National Institute of Standards and Technology (NIST) test artefact (see Figure 6). The benefit of the AM process is that in-process monitoring can act as a 'marker' if there is a problem during the build and post-process NDT can then be used to target the area.

Passing thoughts were also given to the area of unmanned aircraft systems (UASs) and drones used to evaluate critical infrastructure, which may be working at height or in environments where human operatives are unable to work.

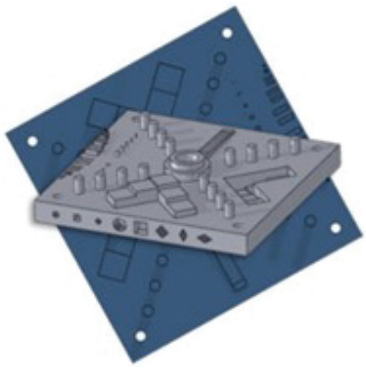

Figure 6. Additive manufacturing standards

ICNDT standard on POD

Daniel Kanzler, AV-NDT

Over the last 20 years, probability of detection has been used in a standardised way. This is possibly due to the first version of the MIL-HDBK-1823 standard. While the POD process from the MIL-HDBK 1823A standard is widely accepted within the aviation industry, ENIQ-based standards aid in reliability procedures in the nuclear energy sector. However, there is also a huge need for reliability evaluations among different industrial sectors, such as the civil engineering, oil & gas, offshore, automotive and railway sectors. Based on the different standards from the nuclear industry, the advanced technologies in testing should also be included in a new standard, which is also accepted outside the field with POD experience. A first step towards this was carried out within the normPOD project, based on two different case studies (ultrasonic testing (UT) of ferritic welding and impulse echo testing of reinforced concrete) for demonstrating a general procedure on how to carry out reliability evaluations. This first step should help to simplify the initiation of the process and to show the advantages

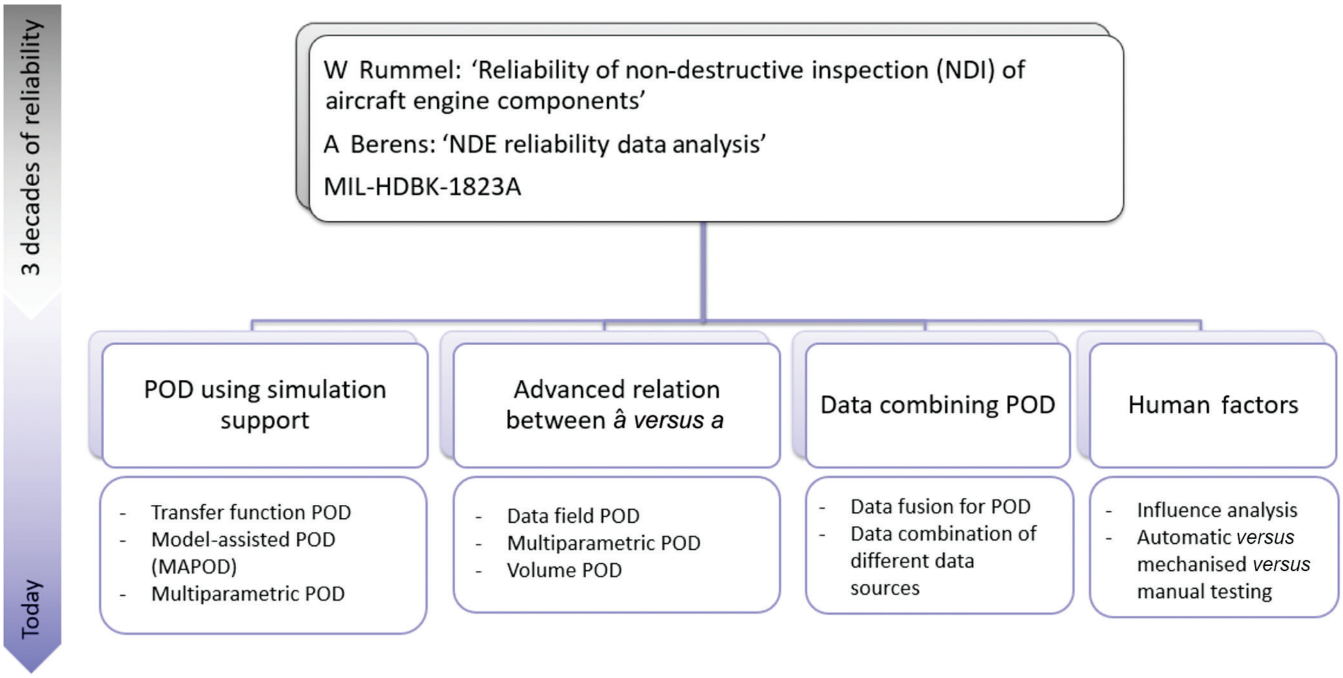

Figure 7. ICNDT guidelines – walk-through for the reliability toolbox

of the reliability evaluation itself, without taking a deep dive into the mathematical/philosophical discussion surrounding the details.

The information regarding this project will be used in German standardisation concepts in the near future. At the same time, it builds the basis for the ICNDT guidelines and the discussion on advanced methods (see Figure 7), such as model-assisted POD, alternative signal-response approaches, data combination and approaches including human factors.

The guidelines will originate from the regular meetings of the ICNDT SIG[8] and the 8th International Workshop on Reliability of NDT/NDE[9]. Further work is needed to provide guidance for reliability and ensure that it is standardised for all industries.

Discussion session

How can we select PODs from the options available? (List a few basic options)

The discussion showed that it is difficult to define exactly how to select a POD using a flowchart with questions to guide the user.

It was agreed to loosely group POD in terms of parametric and non-parametric. It could also be further grouped by binary Hit/Miss and '*â versus a*', which generally fall under parametric. For *â versus a*, this is for parametric data that has a range of values, and there are many models that fall under this, to help the data fit the POD curve. For example, log-log transformation can be used for right-skewed data. It was also pointed out that the Hit/Miss method can be multi-parametric or non-parametric.

MAPOD was also discussed. Simulation can open the space to run multi-parametric or non-parametric PODs. As alluded to in earlier presentations, this allows the amount of physical testing to be reduced, while maintaining the reliability of an inspection.

What approaches do other people use in the industry for training in new inspection techniques/methods?

A number of training examples were given during the discussion, showing that the process for training is well established. In the case of new techniques, depending on the company's written practice, this can also be accommodated using specific training on top of the general method that the new inspection technique falls under. Other observations from this discussion included:

- Specific training (full or refresher) should be given to operators who have a significant gap in their work history in terms of the application of critical and novel inspections.
- Inspections that are seen as common practice, that should be performed easily by a competent Level 2 operator, may require a practical validation examination. This is particularly relevant to industries that have shutdowns/refits and utilise a transient workforce to perform the inspections.
- An example was provided regarding the idea that some very limited certification for specific applications (including specific equipment) would allow for a reduced number of experience hours, where a full certification at Level 2 would require the mandated 800 h.
- The equipment must be made available for training and the procedures must be written to reflect the inspections.

The culture of the department can, at times, hinder progress and innovation, where people's perceptions and misguided loyalties can stifle development (the 'if it isn't broke, don't fix it' approach).

Final thoughts from the author

The workshop and this report have outlined some useful information relating to POD and qualification and have proven successful in providing a useful reference for those who are new to qualification practices. They have identified that there are no up-to-date guidance documents/standards for aerospace, although the ENIQ reports are available for the nuclear civil sector. Future guidance documents and/or standards have been planned by BINDT/ICNDT to address this. The references provided will be helpful for future activities relating to technique validation.

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Published by:
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