Simulation Assisted POD in the Aeronautical Context

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Abstract

Performances and reliability of NDT operations are often quantified through the determination of Probability of Detection (POD), which can then be used in lifecycle management approaches like the damage tolerance design. Cost issues often limit the possibility to access POD curves. Recent progress in NDT models and POD methodology by means of uncertainty propagation through simulation codes open the door to powerful simulation-based POD curves. This helps to drastically decrease the cost of a POD study. In the present paper we present applications of POD curves obtained using simulation for the aircraft industry. The use of such results in justification documents requires careful validation and robustness demonstration. This paper proposes solutions to address these issues and progress towards a use in the industry.

This work was also presented at the QNDE in 2013. The paper titled “POD Evaluation Using Simulation: a Phased Array UT Case on a Complex Geometry Part” Nicolas Dominguez, Frederic Reverdy, and Frederic Jenson can be found in the proceedings of this conference.

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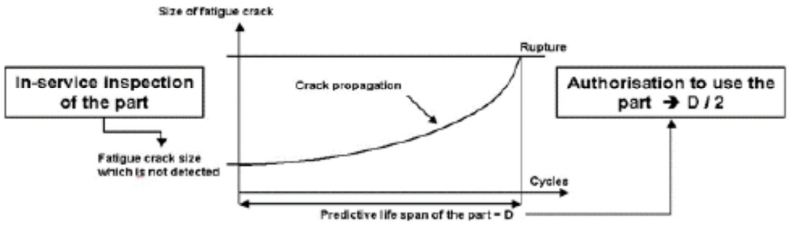
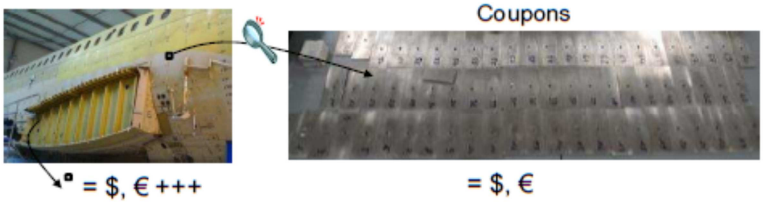
POD - GENERALITIES

- POD is often used to assess the detection performances of an NDT procedure
- POD has the advantage to integrate all sources of variability in a quantitative result, coming out of a statistical estimation
- It has become the rule for structures designed in damage tolerance particularly in aeronautics



POD - GENERALITIES

- POD is the result of a statistical analysis
- Statistics needs data thus samples and resources



- Lower costs of POD studies (reduce number of real samples to produce).
- Make a POD evaluation possible (sometimes getting the real samples is just not possible).

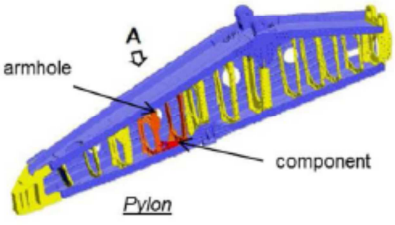
➡ Last years R&D has focused on using simulation for POD estimation*,**

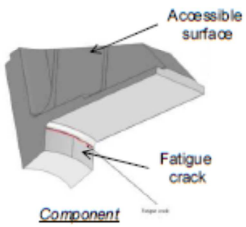
* MAPOD group
** SISTAE French National project & PICASSO European project

CASE STUDY

NDT of fatigue cracks in an engine pylon part

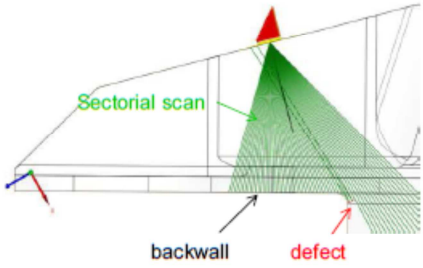
- The component is part of the internal structure of an engine pylon. It is a "3D part" made of Titanium alloy.
- The operator has access to the component through an armhole. He doesn't see his hand when positioning the probe over the component.
- Fatigue cracks may appear along the cylindrical part of the component.
- Only the top surface of the component is accessible.

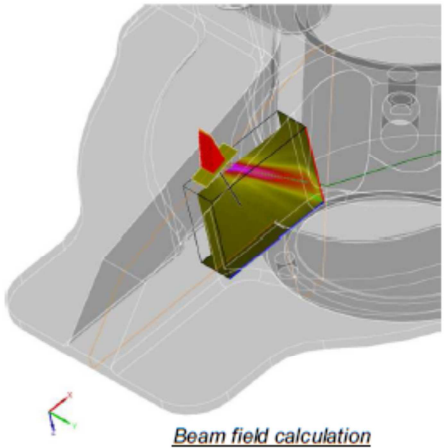




CASE STUDY

- The procedure uses a linear array directly in contact with the component
- A sectorial scan is applied to the probe





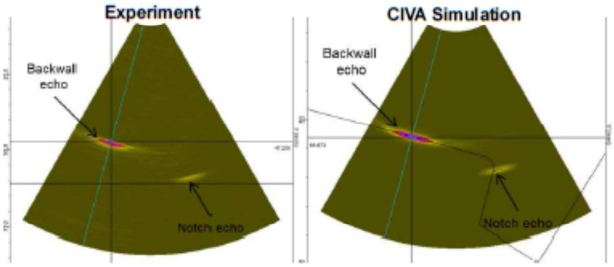
Beam field calculation

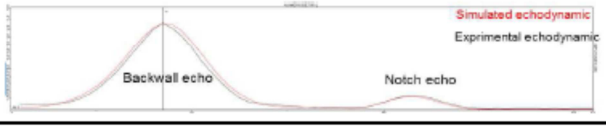
Calibration: Backwall echo

Conditions: Limited access (armhole).
The operator does not see his hand.

VALIDATION OF SIMULATION

- To use simulation to calculate POD curves, it is necessary to check that the simulation tools are able to model properly the inspection case
- Material properties and probe characteristics were measured on a sample that contains a 5x3mm notch and used as input of the model
- The experimental and simulated Sscans are compared

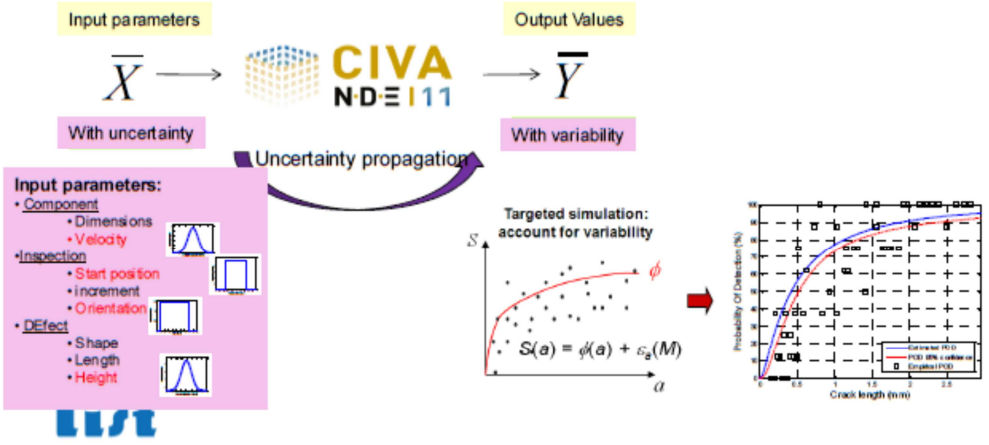




Difference between experiment and simulation< 0.1 dB

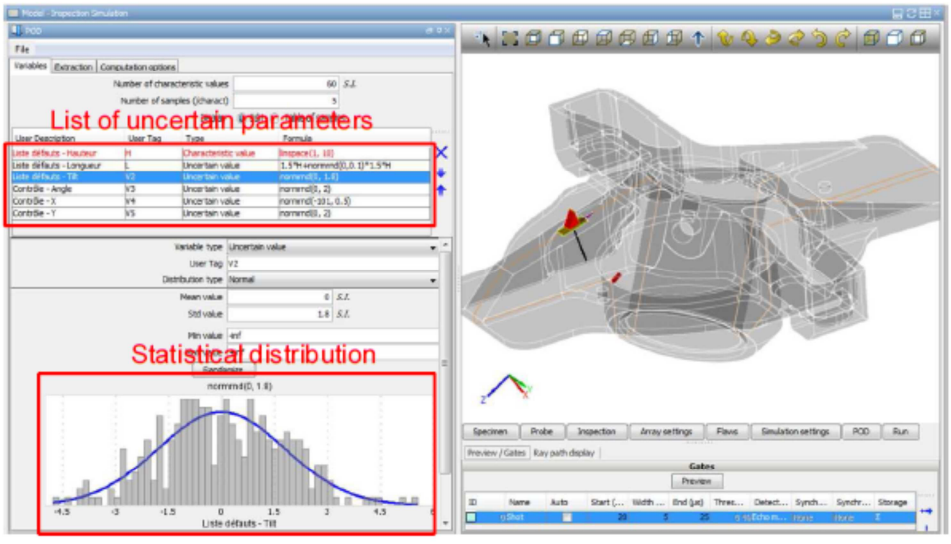
SIMULATION-POD: METHODS & TOOLS

1. Definition of the inspection setup
2. Description of uncertainties on a set of input parameters
3. Propagation of uncertainty through the model (e.g. CIVA)
4. Estimation of POD



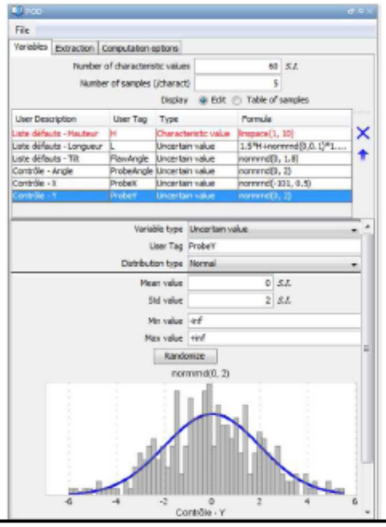
UNCERTAIN PARAMETERS

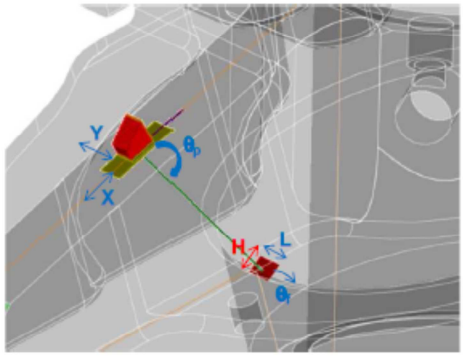
- The user selects in CIVA the uncertain parameters and associate a statistical distribution that represents the variability of this parameter



UNCERTAIN PARAMETERS

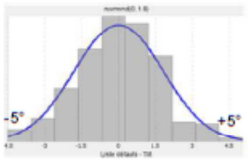
- The characteristic defect feature, against which the POD curve is plotted is imposed by the design office who wants to know the POD as a function of the crack height H.
- The crack length is dependent on the crack height and entered thanks to a formula in CIVA



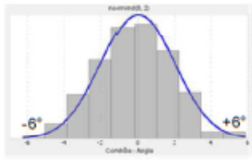


UNCERTAIN PARAMETER DISTRIBUTION

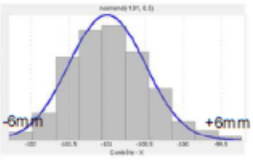
- Nominal values are considered as the most probable values ⇒ **Gaussian distributions**.
- Standard deviations are set so that the limit values have less than 5 % chance to be picked up.
- Some parameters have a mechanically limited range (not possible outside the range) ⇒ truncation
- Notice: Manual displacement of the probe is taken into account in the calculation to represent the fact that the backwall echo should always arrive in between a certain time interval (procedure indication).



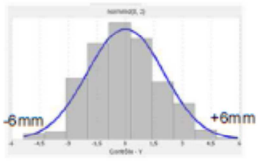
Crack tilt



Probe angle



Probe X position

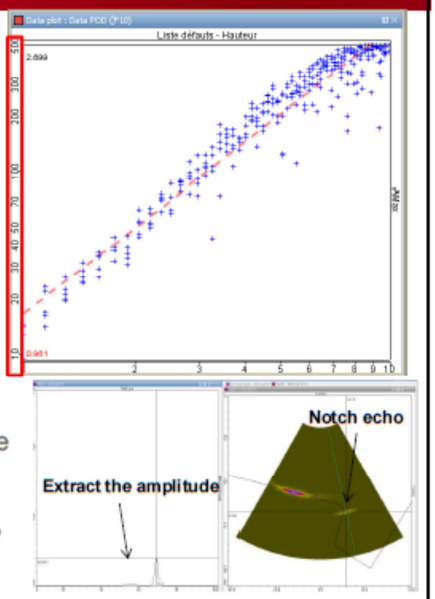


Probe Y position

Calculations for 60 crack heights and 5 samples per crack height

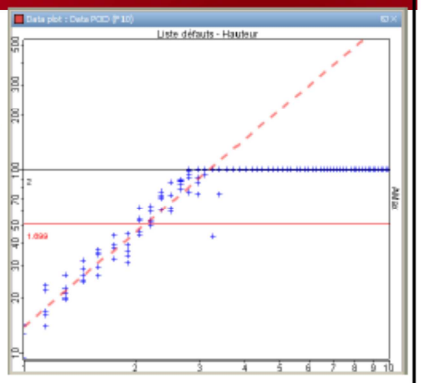
THRESHOLD SETTINGS

- We obtained a data plot amplitude (arbitrary units) vs crack size
- Three thresholds have to be set: **Saturation, Detection and Noise** to estimate the POD curve
- The procedure indicates: a 80% screen height for the 5x3 mm notch then add 6 dB gain.
- We thus extract the amplitude for the 5x3 mm notch from simulation and divided by two to take into account the 6 dB
- The obtained value is used to calibrate the 80% value in the POD data.
- Once calibrated, the simulated data can be handled as if they were experimental ones



THRESHOLD SETTINGS

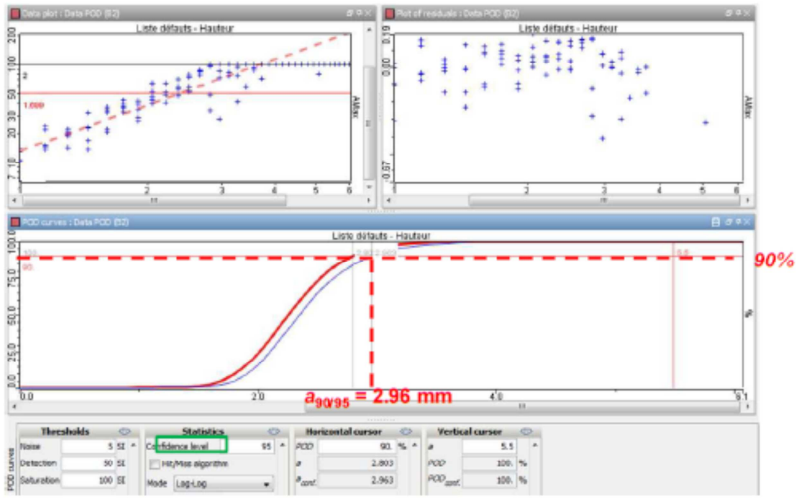
- We obtained a data plot amplitude vs crack size
- Three thresholds have to be set: **Saturation, Detection and Noise** to estimate the POD curve
- Saturation threshold is set at 100% (Full Screen Height).
- Detection threshold is set at 50% as indicated in the procedure.
- Noise threshold is set to 5%.



Compute the POD estimation. Classical Maximum Likelihood Estimation according to the recommendations of the MIL-HDBK1823a

POD ESTIMATION

- POD curves for linear-linear and log-log spaces are calculated.
- The log-log fits better the estimation hypotheses and is more conservative.



- $a_{90/95}$ = 2.96 mm (height of the defect).

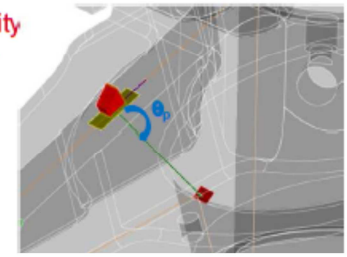
CONFIDENCE IN POD USING SIMULATION

To evaluate whether the robustness of the POD result, it is useful to perform a sensitivity study by varying the input probability distributions of the uncertain parameters

- The difficult step in the uncertainty propagation process is to define the probability laws describing the input parameters
- Some of them may be tricky to provide and are then subject to some engineering judgment; it is often the case for the standard deviations of Gaussian laws
- Mean values are usually easier to provide since nominal values are generally well known for the parameters.

CONFIDENCE IN POD USING SIMULATION

Computation times are such that making a large sensitivity study is (today) prohibited. A pragmatic approach can be applied by playing a few scenarios with extreme values.



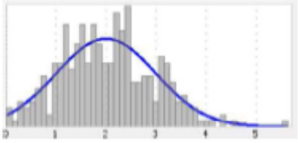
Most difficult variable to characterize = probe angle

- « Nominal » case (first guess) (-5°;+5°) => 2.7 mm
- Penalizing case (-10°;+10°) => 3.0 mm
- Worst (crazy) case (-15°;+15°) => 3.4 mm

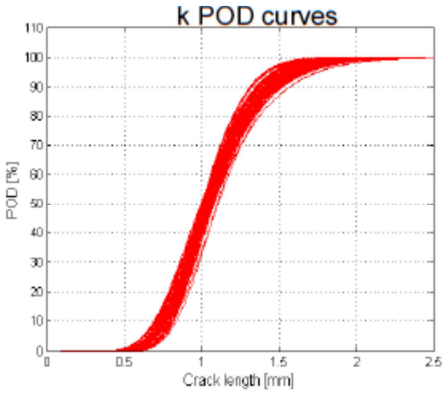
➡ Very stable NDT procedure (large beam, no noise)

CONFIDENCE IN POD USING SIMULATION

- The sensitivity study can greatly benefit from more scenarios to evaluate the robustness but also to calculate an associated confidence interval
- The basic idea is that the confidence band is there to cover for the lack of knowledge in the POD estimation process.
- In the study case of the present paper, the probe angle standard deviation would be subject to a variation scenario.



Distribution of σ



POD WITH CONFIDENCE

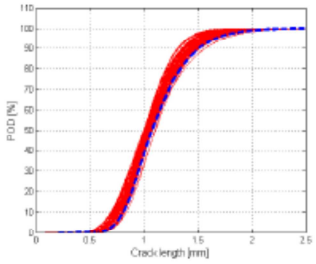
COMPUTATION OF THE POD CURVE WITH CONFIDENCE

- In practice the POD curve with confidence can be built pointwize, looping on POD values :

For p in [0.01;0.99]

- Find the POD curve leaving 95 % of the curves on the left at ordinate p
- Pick-up the corresponding flaw size a_p

End



- The POD curve with 95% confidence is the set of points (a_p, p)
- This approach requires a huge amount of computations (number of data per POD curve times the number of POD curves).

CONCLUSIONS

- A simulation supported POD evaluation has been performed on a complex geometry specimen inspection using phased-array probe
- It confirms the minimum detectable of the procedure
- The robustness of the results has been analyzed through a sensitivity study,
- The implementation of a promising approach for confidence interval calculation in such cases has been discussed.
- This approach is thought to be very promising but also challenges the computation performance of NDT simulation codes considering the very high number of runs to perform (use of surrogate-models…)

N. Dominguez, C. Reboud, A. Dubois, F. Jenson, « A new approach of confidence in POD determination using simulation », QNDE 2012