The relevance of Additive Manufacturing anomalies dimensions, amounts and locations.

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Nov 2021. WG2 Breakout sessions: F&DT and NDI of AM. (EASA-FAA Industry-Regulator AM Event.)

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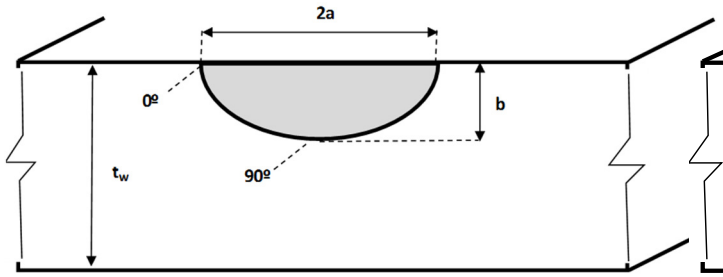
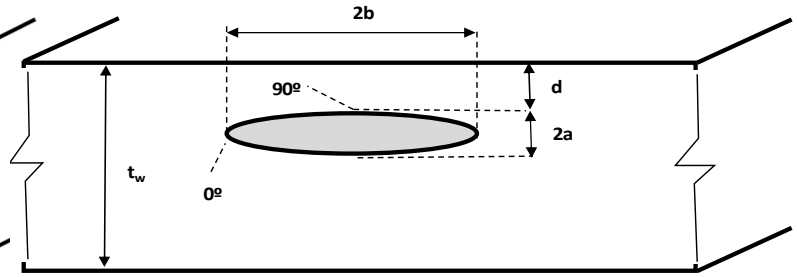
AM anomaly location relevance

Internal, superficial , and sub-superficial defects

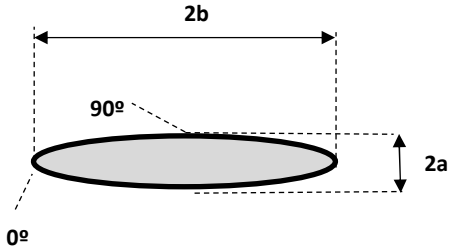
✓ Superficial



✓ Sub-superficial



✓ Internal



$$\Delta K = \frac{\lambda_\omega}{\Theta} \cdot \left(\lambda_t \cdot \sigma a + \lambda_b \cdot \sigma b\right) \cdot \sqrt{\pi \cdot a}$$

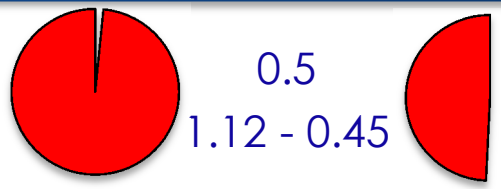
Newman, Raju & Picard.

$\sqrt{Area}$ 1.0

Stress Int. ΔK 1.12

$$\Delta K_w = \left(\frac{4}{5} + \frac{1}{5} \cdot \left(\frac{t_w}{t_w - 2a}\right)\right)\left(1 - \frac{0.23}{2b/2a}\right)\left(\frac{13}{15} + \frac{2}{15} \cdot \left(1 + \frac{a}{d}\right)\right) \cdot \left(\sigma a_w\right) \cdot \sqrt{\pi \cdot a}$$

Tada et al. & Coro et al., Sub-superficial



0.5

1.12 - 0.45

$$\Delta K_w = \left(\frac{2}{\pi} \cdot \sigma a_w\right) \cdot \sqrt{\pi \cdot a}$$

Tada et al.

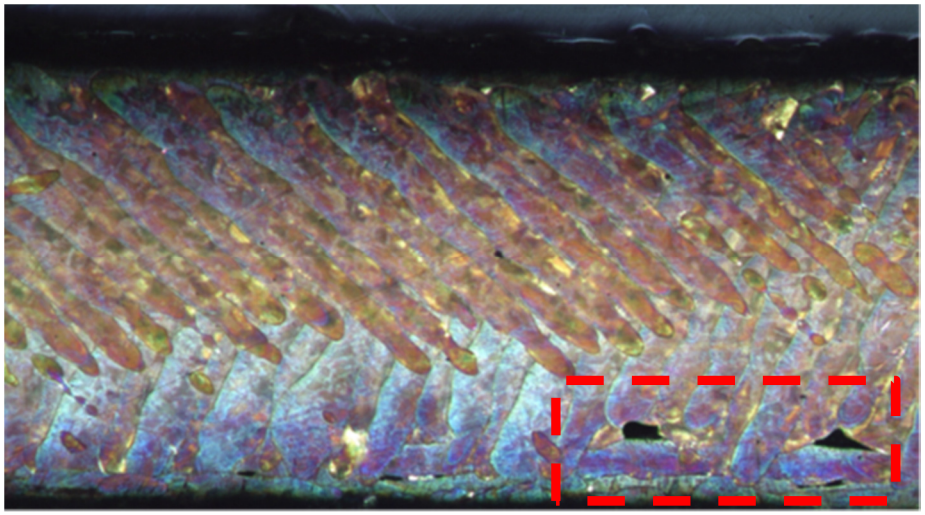
$\sqrt{Area}$ 0.5

Stress Int. ΔK 0.45

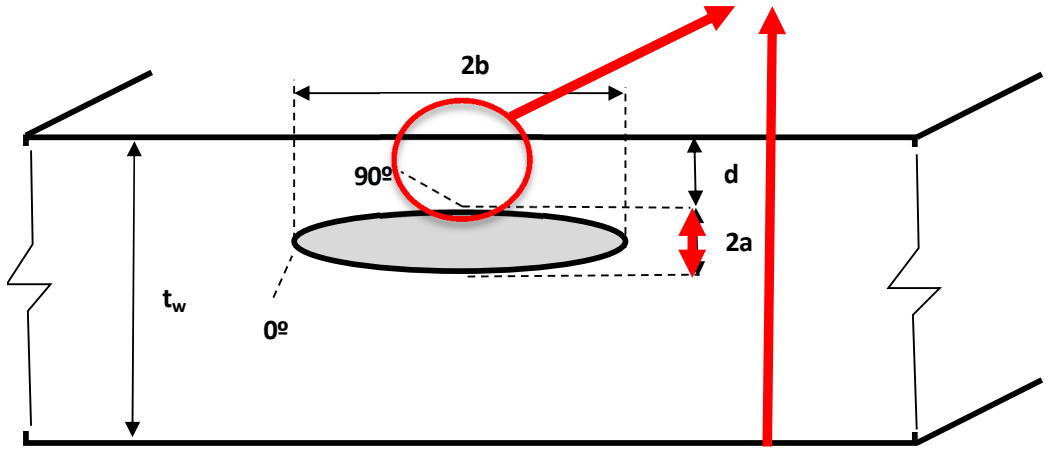
The defect area and the stress intensity factor approaches gives a similar defect size relevance. But, does it not work for the sub-superficial defects?

Anomaly size parameters relevance

Anomaly size and anomaly surface distance



High stressed area.



$$\Delta K_w = \left(\frac{4}{5}+\frac{1}{5}\cdot\left(\frac{t_w}{t_w-2a}\right)\right)\left(1-\frac{0.23}{2b/2a}\right)\left(\frac{13}{15}+\frac{2}{15}\cdot\left(1+\frac{a}{d}\right)\right)\cdot(\sigma a_w)\cdot\sqrt{\pi\cdot a}$$

The "a" defect dimension is the most relevant defect parameter

In addition, the sub-superficial defects behavior depend of the distance to the surface. The "d" distance need to be considered in the defect relevance evaluation.

Anomaly size parameters management

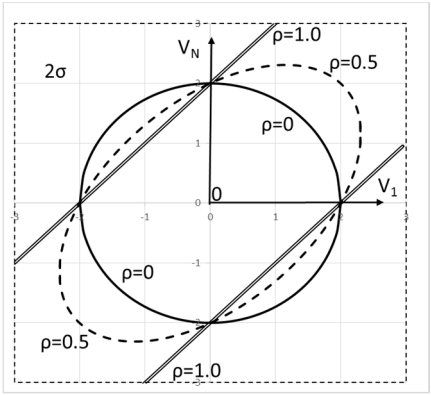
Anomalies dimensions correlation and principal component analysis

3 steps to evaluate a multi-parameter defect a,b,d:

1. Correlation matrix [C].
2. The use of the multivariable normal distribution (log-normal).
3. Principal component analysis.

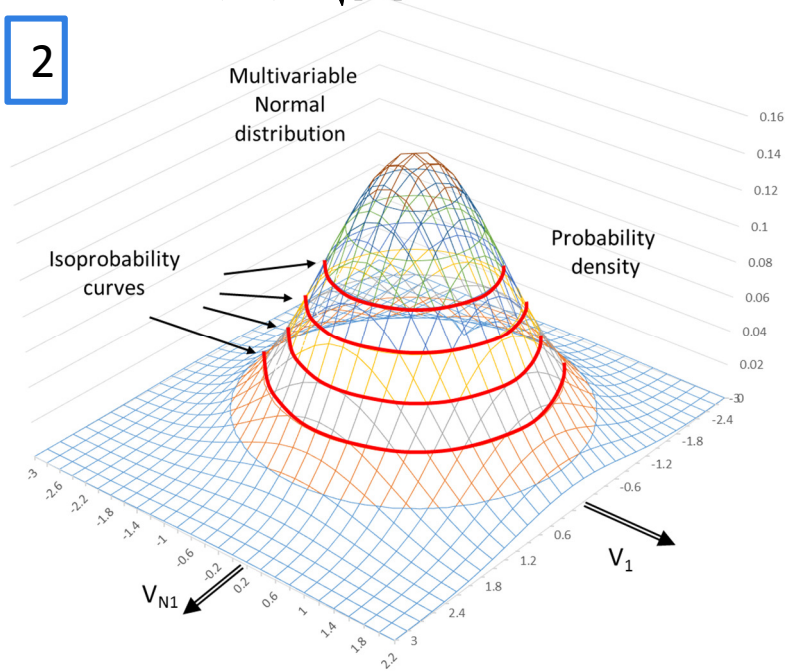
1

$$c_{i,j} = \sum_{k=1}^{n} \left((v_i)_k \cdot (v_i)_k \right)$$



2

$$f(v_1,\ldots,v_N) = \frac{1}{(2\pi)^{\frac{N}{2}} \cdot \sqrt{[C]}} \cdot e^{\left(-\frac{1}{2}\cdot(v_1,\ldots,v_N)^T \cdot [C]^{-1} \cdot (v_1,\ldots,v_N)\right)}$$



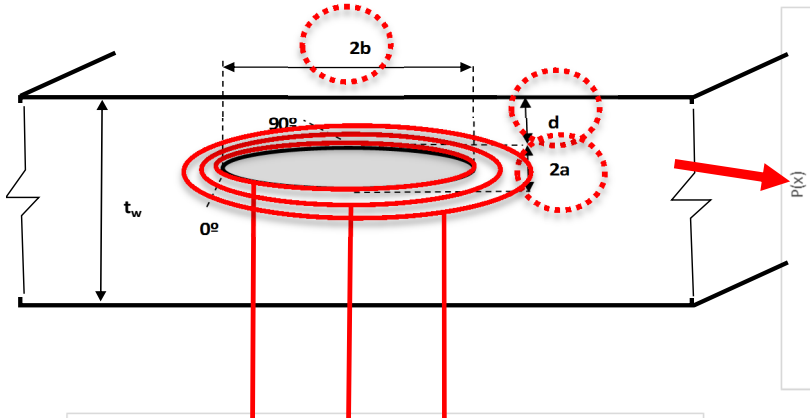
3

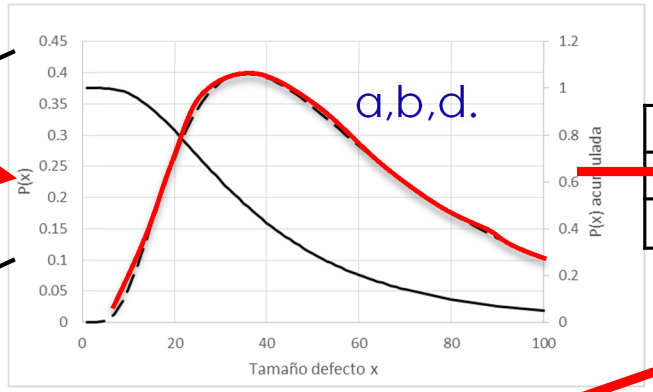
$$\begin{bmatrix} (\sigma_{vp_1})^2 & 0 & 0 \\ 0 & \ldots & 0 \\ 0 & 0 & (\sigma_{vp_n})^2 \end{bmatrix} = [Vp_1 \quad \ldots \quad Vp_n] \cdot [C] \cdot [Vp_1 \quad \ldots \quad Vp_n]^T$$

* Coro, A.(2021). PhD thesis. Planning the maintenance of gas turbine welded structures, by continuously updating of the reliability calculation. Department of Mechanical Engineering – Faculty of Engineering Bilbao. (TESEO Database).

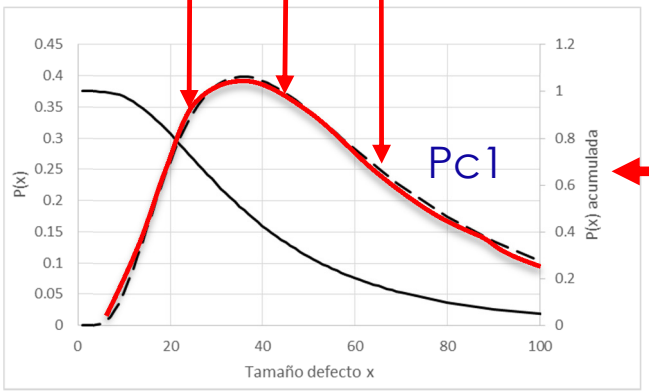
Example: anomaly size management

Anomalies dimensions correlation and principal component analysis example





	a	b	d
	1	0.8	-0.45
C=	0.8	1	-0.5
	-0.45	-0.5	1



	2.2
Eigen-values=	0.2
	0.6

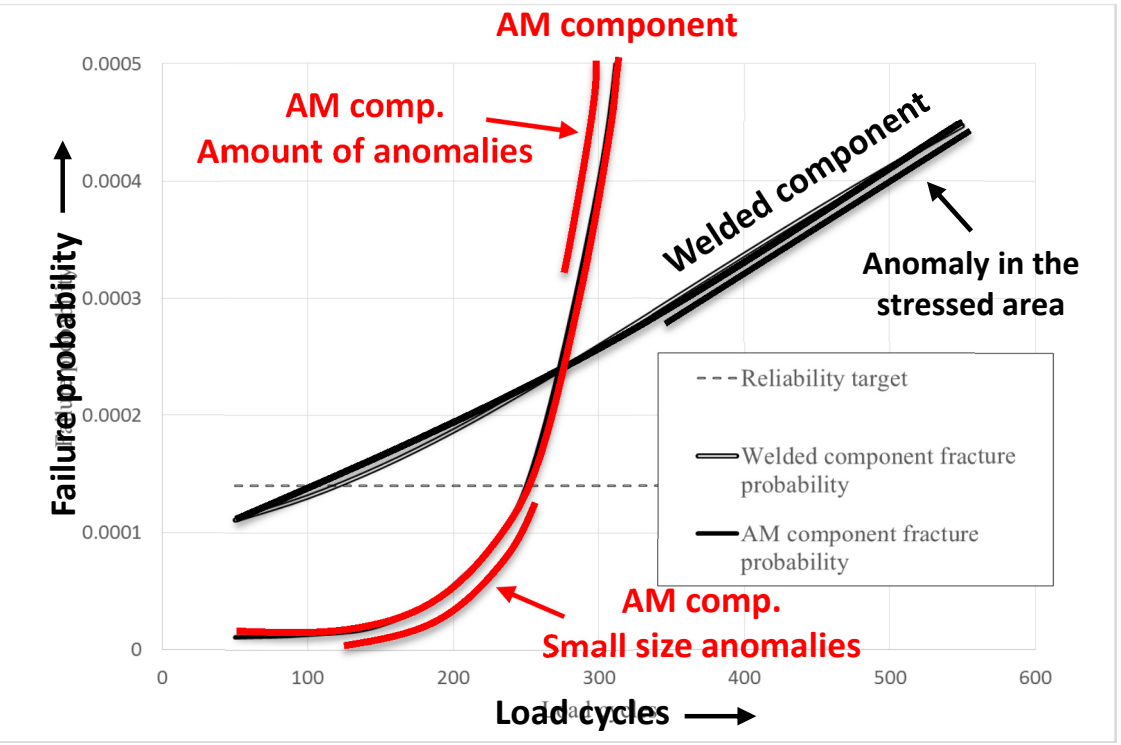
Scatter

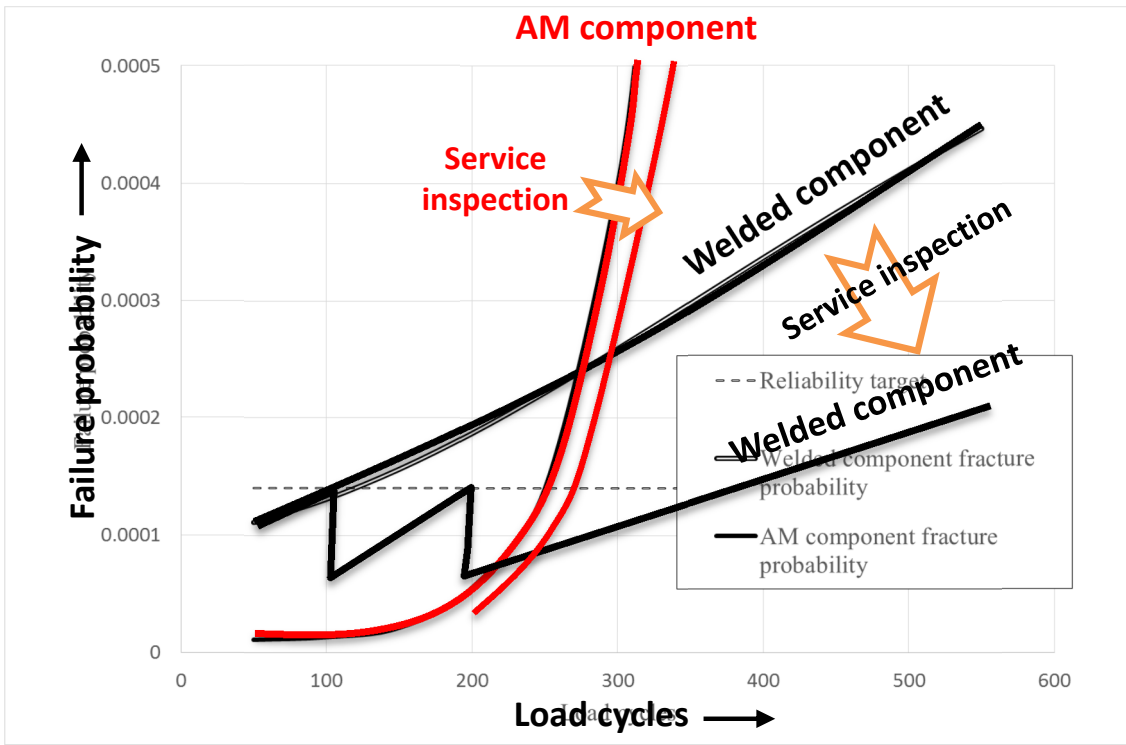
	a	b	d	
	-0.61	-0.70	0.36	Pc1
Eigen-vectors=	-0.61	0.70	0.36	Pc2
	0.50	0.0	0.86	Pc3

* Coro, A.(2021). PhD thesis. Planning the maintenance of gas turbine welded structures, by continuously updating of the reliability calculation. Department of Mechanical Engineering – Faculty of Engineering Bilbao. (TESEO Database).

AM anomaly size and amount impact

Example: Replacement of Welded Components by Additive Manufacturing Spare Parts





* Coro, A., Macareno, L.M., Aguirrebeitia, J., y López de Lacalle, L.N. (2019). A Methodology to Evaluate the Reliability Impact of the Replacement of Welded Components by Additive Manufacturing Spare Parts. Metals, 9(9), 932.

ITP Aero

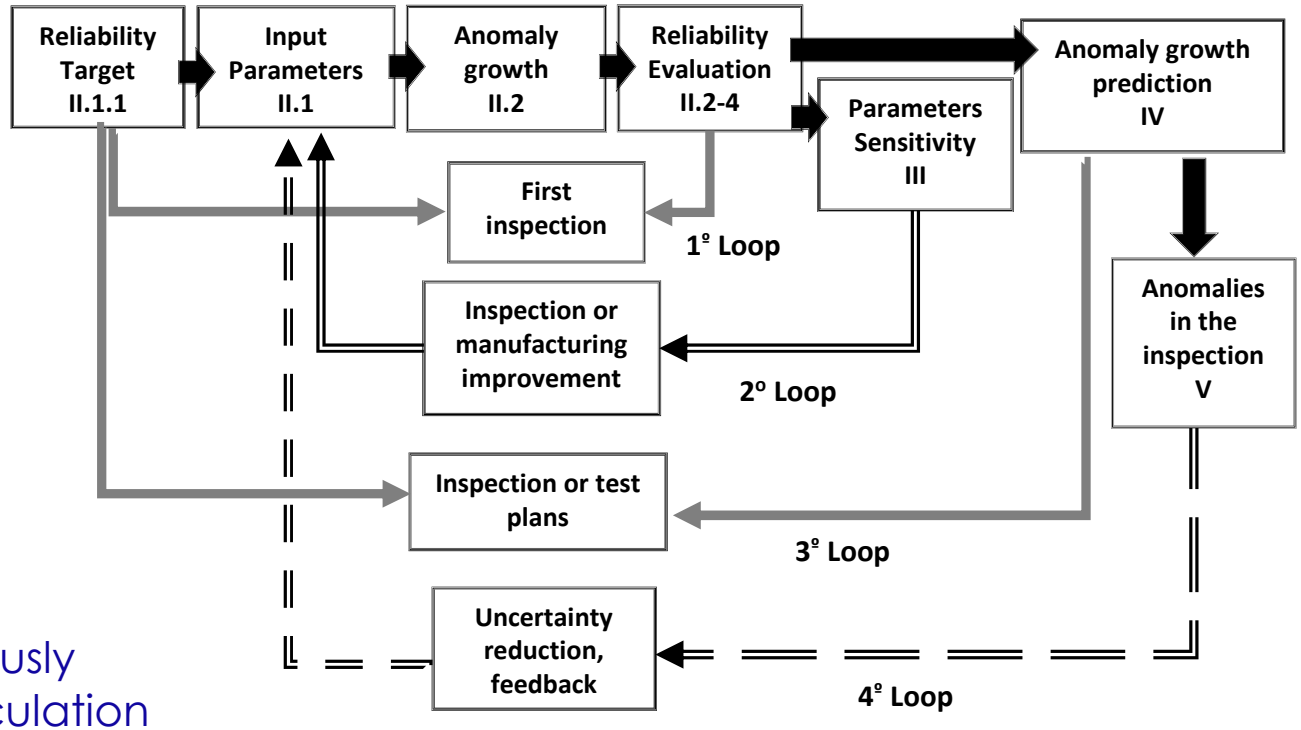
A Rolls-Royce company

AM anomaly assessment "calibration",…

Example: Inspection scheduling based on reliability updating. An anomaly size/amount based update.

Component reliability can be improve based in component test, inspection,..:

- 4 loops process have been developed.
  - Reliability evaluation.
  - Variable contribution.
  - Test and inspection prediction.
  - Mechanistic model and variables update.
- The process allow to continuously updating of the reliability calculation



* Coro, A., Abasolo, M., Aguirrebeitia, J., y López de Lacalle, L.N. (2019). Inspection scheduling based on reliability updating of gas turbine welded structures. *Adv. Mech. Eng.* 11, 1–20.