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Modelling of flawed riveted structure for EC inspection in aeronautics

Séverine Paillard, Yahya Choua, Grégoire Pichenot, Yann Le Bihan, Marc Lambert, Hubert Voillaume, Nicolas Dominguez

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Context and objective

- The industrial demand is to detect efficiently flaws located nearby a fastener
 - ✓ Need of Eddy Current inspection for flawed fastened structure



- Development of a semi-analytical model in CIVA
 - ✓ Based on the Volume Integral Method
 - ✓ Handles a multi-layer structure



The semi-analytical model

The state equation

$$\mathbf{E}_k(\mathbf{r}) = \mathbf{E}_k^{(0)}(\mathbf{r}) - j\omega\mu_0 \sum_{l=m}^n \int_{\Omega_l} \overline{\mathbf{G}}_{kl}^{(ee)}(\mathbf{r}, \mathbf{r}') [\sigma_l - \sigma(\mathbf{r}')] \mathbf{E}_l(\mathbf{r}') d\mathbf{r}'$$

Primary field in the layer k Dyadic Green's functions

Linear system from state equation (MoM) Solved by Matrix inversion or Iterative resolution

$$\begin{bmatrix} \mathbf{E}_m^{(0)} \\ \vdots \\ \mathbf{E}_n^{(0)} \end{bmatrix} = \left(\mathbf{I} - \begin{bmatrix} \mathcal{G}_{m,m} & \dots & \mathcal{G}_{m,n} \\ \vdots & \ddots & \vdots \\ \mathcal{G}_{n,m} & \dots & \mathcal{G}_{n,n} \end{bmatrix} \right) \begin{bmatrix} \mathbf{E}_m \\ \vdots \\ \mathbf{E}_n \end{bmatrix}$$

$\mathcal{G}_{i,i}$ electromagnetic self-coupling terms of the i^{th} region onto itself
 $\mathcal{G}_{i,j}$ mutual coupling terms of the j^{th} region over the i^{th}

Theoretical Formulation

The dyadic Green's functions are solution of

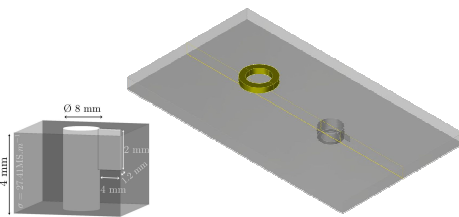
$$\nabla \times \nabla \times \overline{\mathbf{G}}_{kl}^{(ee)}(\mathbf{r}, \mathbf{r}') - k_k^2 \overline{\mathbf{G}}_{kl}^{(ee)}(\mathbf{r}, \mathbf{r}') = \delta_{kl} \overline{\mathbf{I}} \delta(\mathbf{r} - \mathbf{r}')$$

The response of the probe is obtained via the reciprocity theorem

$$I_0^2 \Delta Z = \sum_{l=m}^n \int_{\Omega_l} [\sigma_l - \sigma(\mathbf{r})] \mathbf{E}_i^{(0)}(\mathbf{r}) \cdot \mathbf{E}_l(\mathbf{r}) d\mathbf{r}$$

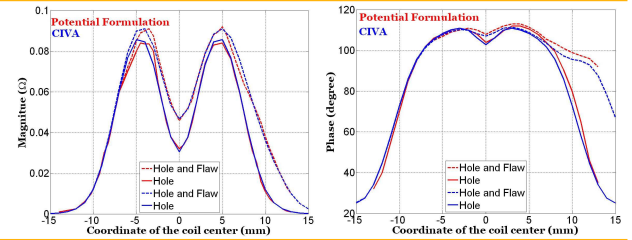
where I_0 is the feeding current of the probe, Ω the calculation volume and σ the conductivity

Configuration Zeng & al (ACES'07)



Good agreement with the data published in "Reduced Magnetic Vector Potential and Electric Scalar Potential Formulation for Eddy Current Modeling"

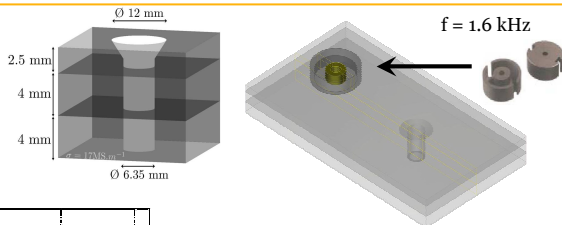
Z. Zeng & al



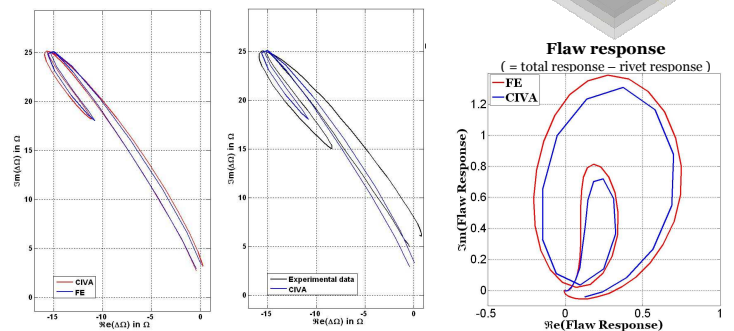
Validation on an aeronautical configuration

calibrated Rivet

Calibration
 CIVA : 1.3 +4°
 LGEP: 1.06 -1°



Flawed Rivet



Validation with experimental data is more difficult to achieve because of

Conclusion

- **Comparison with published data** (Zeng & al configuration)
 - Good agreement with the Potential Formulation
- **Validation with experimental data** (aeronautical configuration)
 - Good agreement with FE once calibrated, exhibiting Typical signature of the flaw in simulations

Perspectives

- **Optimization** of the discretization in order to improve the simulation of a flawed rivet
 - Best efficiency of the method
- **Simulation** of other rivet inspection techniques

The shape of the fastener structure