



Modelling of flawed riveted structure for EC inspection in aeronautics

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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

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

Primary field in the layer k Dyadic Green's functions

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

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

$\mathbf{G}_{i,i}$: electromagnetic self-coupling terms of the i^{th} region onto itself

$\mathbf{G}_{i,j}$: mutual coupling terms of the j^{th} region over the i^{th}

Theoretical Formulation

The dyadic Green's functions are solution of

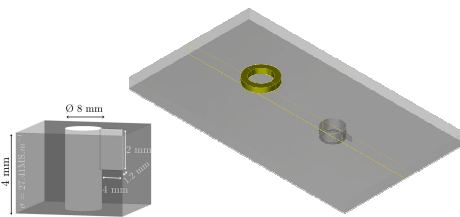
$$\nabla \times \nabla \times \bar{\mathbf{G}}_{kl}^{(ee)}(\mathbf{r}, \mathbf{r}') - k_k^2 \bar{\mathbf{G}}_{kl}^{(ee)}(\mathbf{r}, \mathbf{r}') = \delta_{kl} \bar{\mathbf{I}} \delta(\mathbf{r} - \mathbf{r}')$$

The response of the probe is obtained via the reciprocity theorem

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

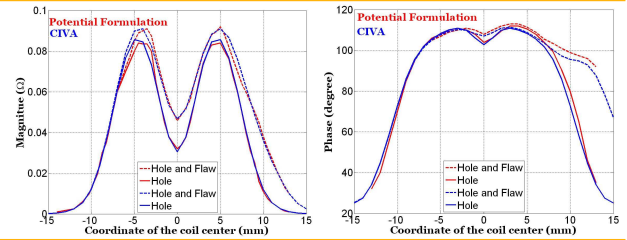
where I_0 is the feeding current of the probe, Ω the calculation volume and σ the conductivity

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"

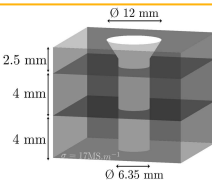
Z. Zeng & al



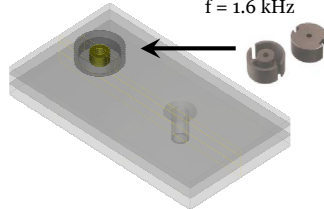
Validation on an aeronautical configuration

calibrated Rivet

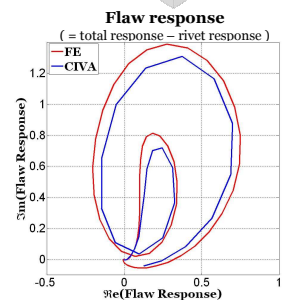
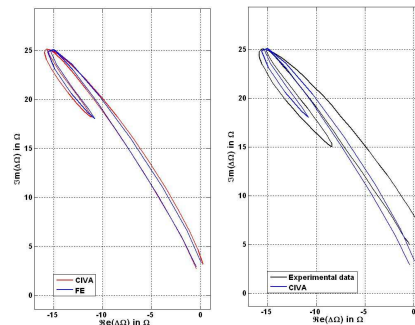
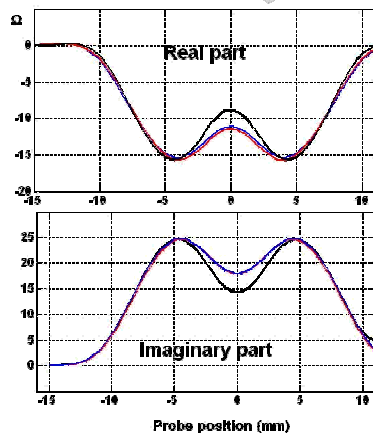
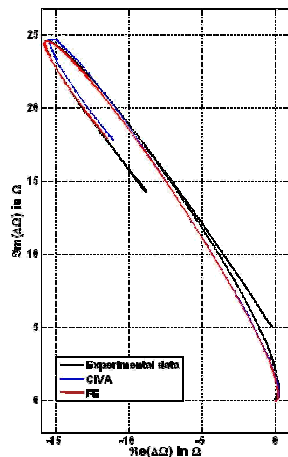
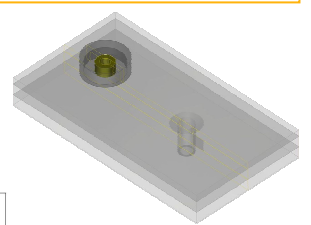
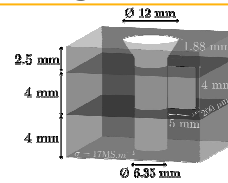
Calibration
CIVA: 1.3 +4°
LGEP: 1.06-1°



f = 1.6 kHz



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