

# Modelling of flawed riveted structure for EC inspection in aeronautics

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# MODELLING OF FLAWED RIVETED STRUCTURES 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

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

Primary field in the layer $k$ — Dyadic Green's functions

Linear system from state equation ($\mathcal{MoM}$) Solved by Matrix inversion or Iterative resolution

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

$\mathcal{G}_{i,i}$ 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

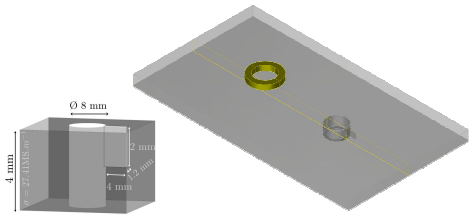
$$\nabla\times\nabla\times\overline{\mathbf{G}}_{kl}^{(ee)}(\mathbf{r},\mathbf{r}') - k_k^2\,\overline{\mathbf{G}}_{kl}^{(ee)}(\mathbf{r},\mathbf{r}') = \delta_{kl}\bar{\bar{\mathbf{I}}}\delta(\mathbf{r}-\mathbf{r}')$$

The response of the probe is obtained via the reciprocity theorem

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

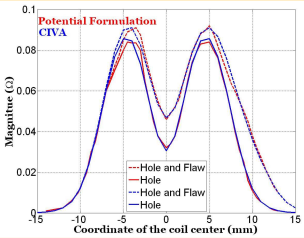
where $I_0$ is the feeding current of the probe, $\Omega$ the calculation volume and $\sigma$ the conductivity

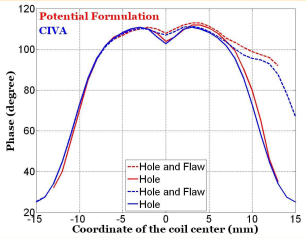
## Configuration Zeng & al (ACES'07)




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

Z. Zeng & al

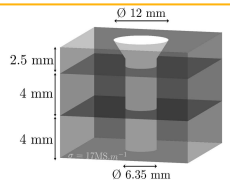


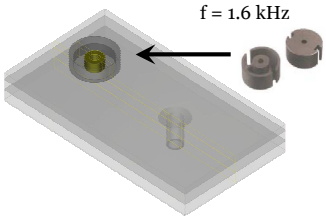



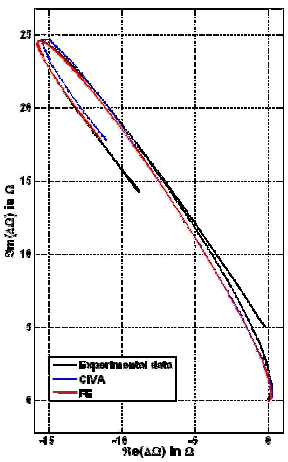

## Validation on an aeronautical configuration

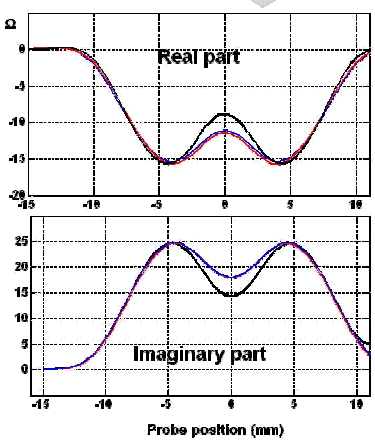
**calibrated Rivet**

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

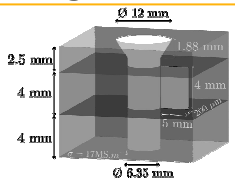


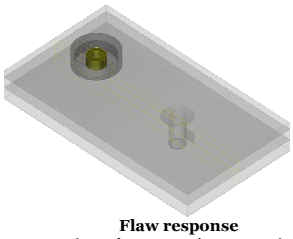



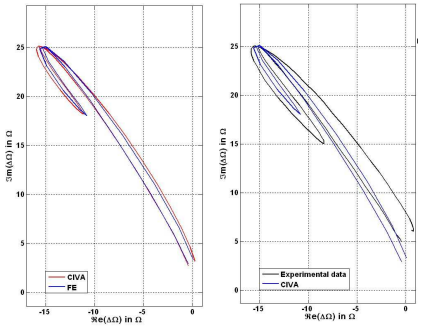



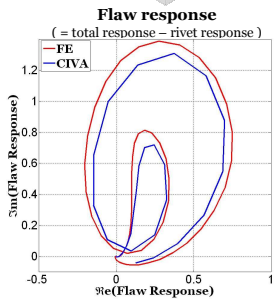




**Flawed Rivet**






**Validation with experimental data is more difficult to achieve because of**

➢ The shape of the fastened structure

## 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