



**HAL**  
open science

## **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

► **To cite this version:**

Séverine Paillard, Yahya Choua, Grégoire Pichenot, Yann Le Bihan, Marc Lambert, et al.. Modelling of flawed riveted structure for EC inspection in aeronautics. ENDE'07, Jun 2007, Cardiff, United Kingdom. <hal-01104131>

**HAL Id: hal-01104131**

**<https://centralesupelec.hal.science/hal-01104131v1>**

Submitted on 16 Jan 2015

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization

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

Theoretical Formulation

The dyadic Green's functions are solution of

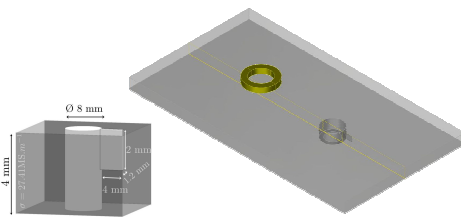
$$\nabla \times \nabla \times \overline{\mathbf{G}}_{kl}^{(ee)}(\mathbf{r}, \mathbf{r}') - k_k^2 \overline{\mathbf{G}}_{kl}^{(ee)}(\mathbf{r}, \mathbf{r}') = \delta_{kl} \overline{\mathbf{I}} \delta(\mathbf{r} - \mathbf{r}')$$

The response of the probe is obtained via the reciprocity theorem

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

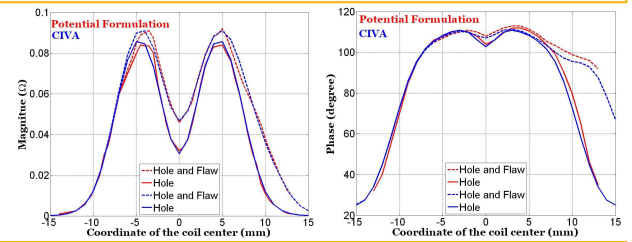
where  $I_0$  is the feeding current of the probe,  $\Omega$  the calculation volume and  $\sigma$  the conductivity

## 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"

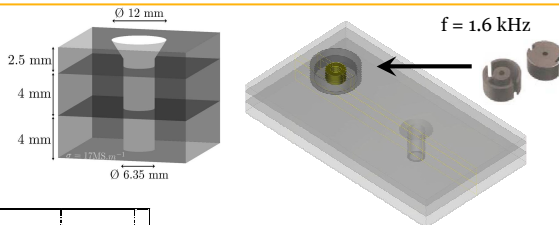
Z. Zeng & al



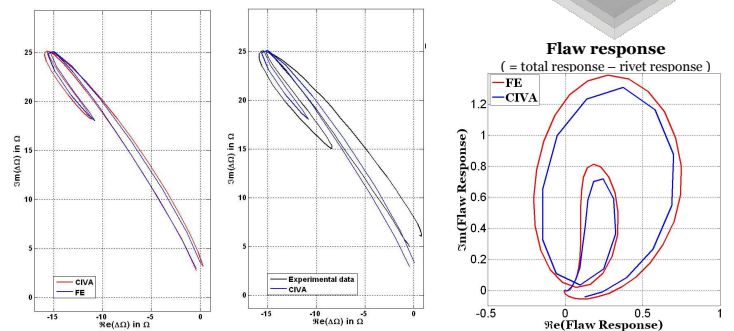
## Validation on an aeronautical configuration

calibrated Rivet

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



Flawed Rivet



Validation with experimental data is more difficult to achieve because of

## 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