Thermomechanical Design Of A Gas Turbine Reheat Combustor Experiment Using Finite Element Analysis

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Introduction and Outline

- Sequential combustion - framework for operationally flexible and low-emision gas turbines [1]
- Experimental research on lean premixed, auto-ignition stabilized flame dynamics
- **Thermomechanical design optimization** of a reheat combustor experiment

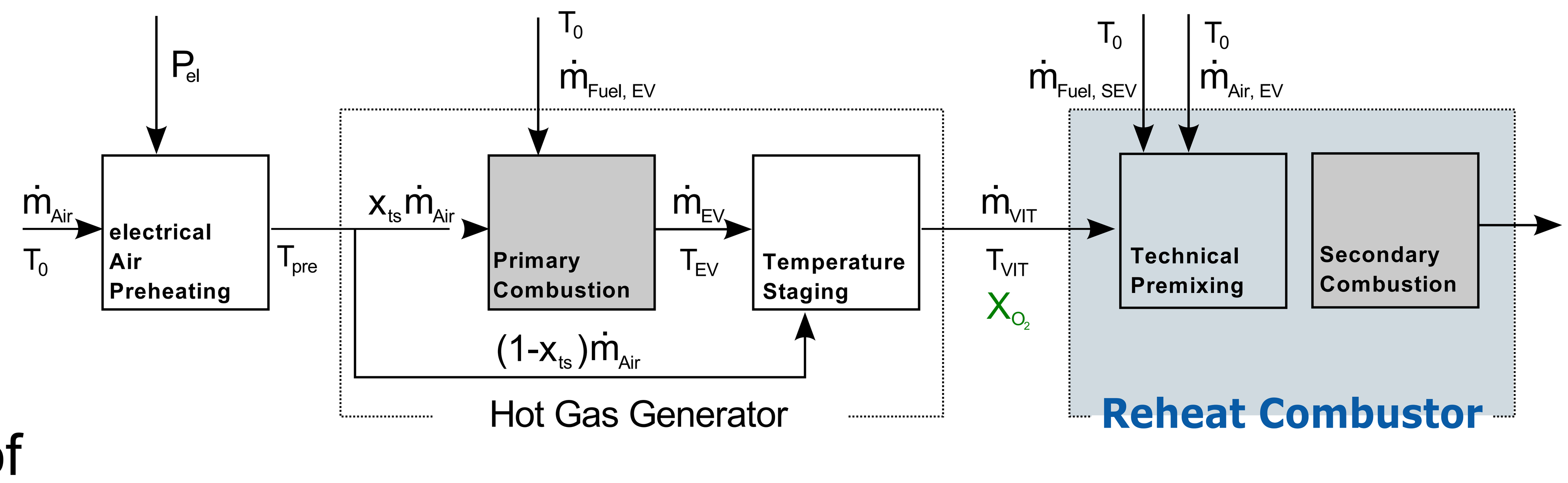

Figure 1. Schematic of the reheat combustor experiment

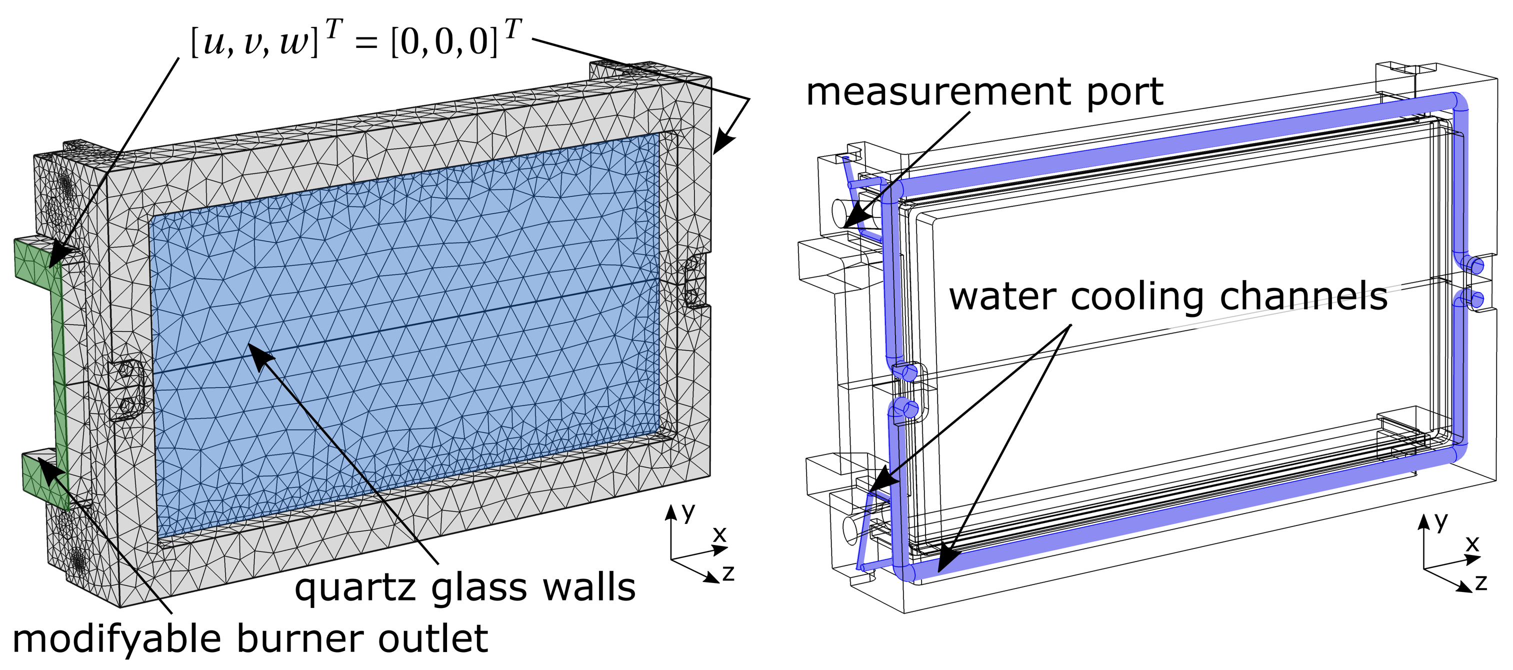

Figure 2. Combustion chamber geometry and FE analysis conditions

Thermomechanical Design/Requirements

- **High thermal loads** - 20 MW/m²bar, 1300-2200 K
- Application of high fidelity **conventional** and **optical diagnostic techniques**
- **Material coupling** with different thermal expansion - air-tight design of steel and quartz glass structure
- **Marginal heat loss** to sustain auto-ignition limits

Thermomechanical Finite Elemente Analysis

1. Thermal Analysis

- Heat conduction solution

$$\nabla (k \nabla T(\mathbf{x})) = 0, \text{ in } \Omega$$

- Dirichlet boundaries from CHT simulations

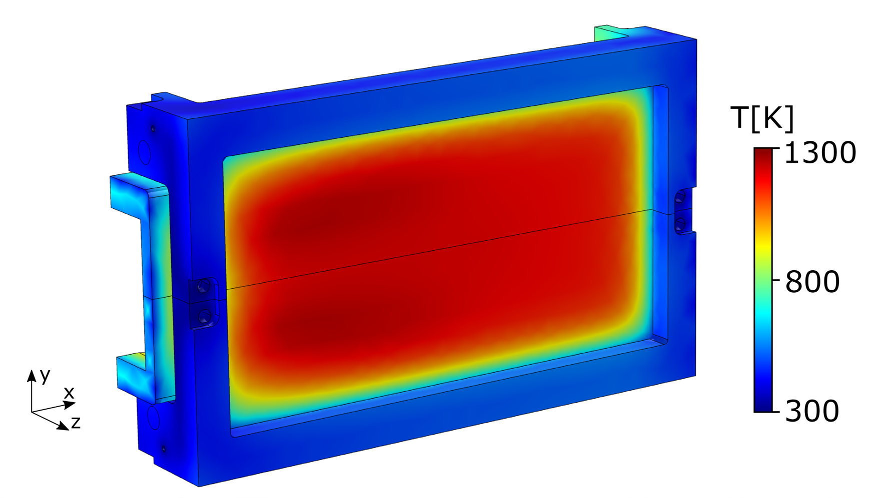

Figure 3. Temperature distribution

2. Structural Analysis

- Linear elastic, uncoupled, quasi-static thermomechanical solution [2,3]

$$\nabla \sigma = 0, \text{ on } \Omega$$ Equilibrium equation

$$\sigma = \mathrm{D}(\varepsilon - \varepsilon_0)$$ constitutive equations

$$\varepsilon = \frac{1}{2}\left[\nabla \mathbf{u} + (\nabla \mathbf{u})^T\right]$$ strain-displacement relations

COMSOL Multiphysics

- Implementation of weak form PDE formulation
- User-defined **I**nterpolation **F**unction to ascribe locally varying material propertiers

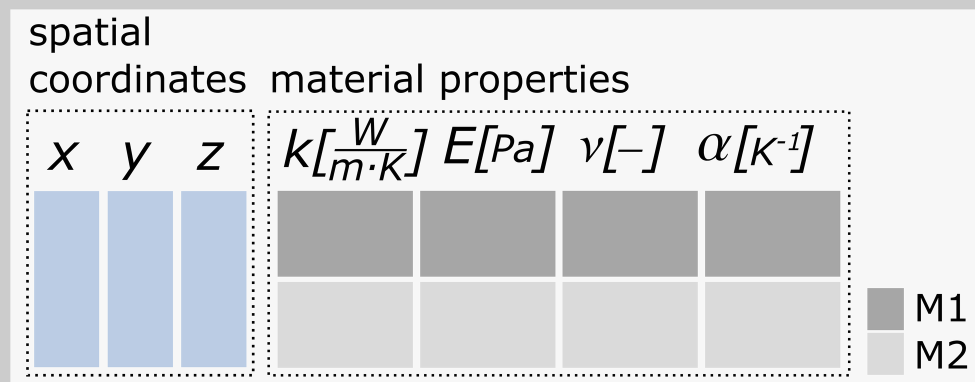

Figure 4. Material properties IF

Results

- Relative displacement and structural deformation
- Localization of critical thermally induced stresses
- Cooling optimization for instrumentation ports

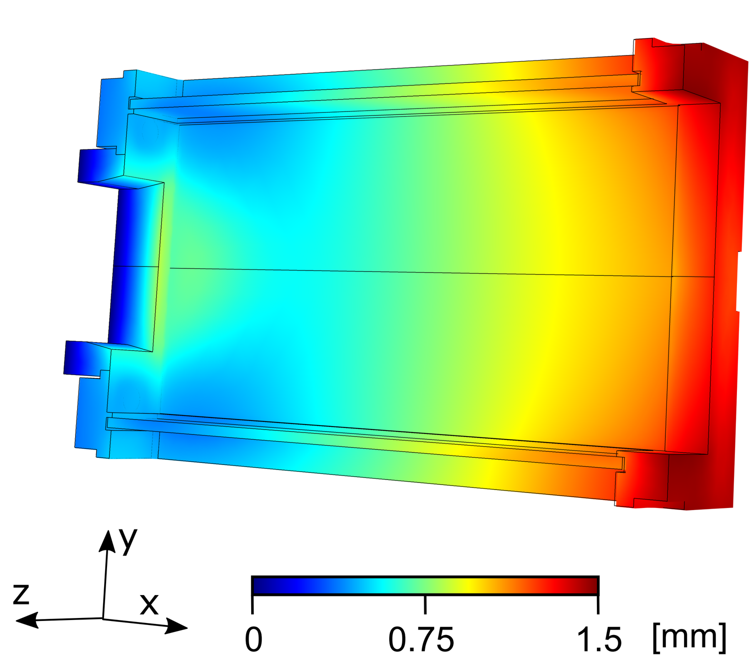

Figure 5. Global total displacement field

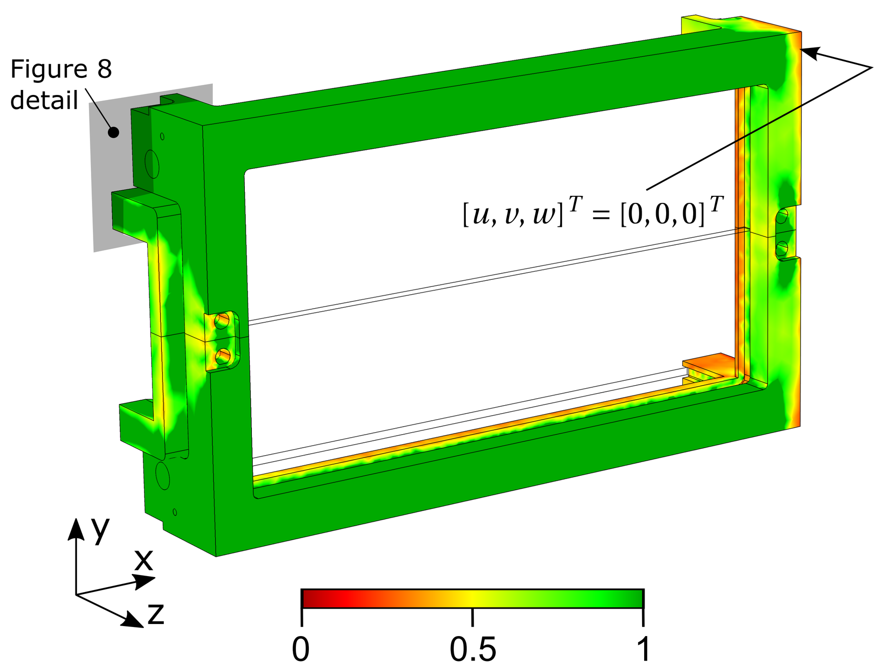

Figure 7. Linear elasticity stress ratio: $R_{p0.2}/\sigma_{Mises}$

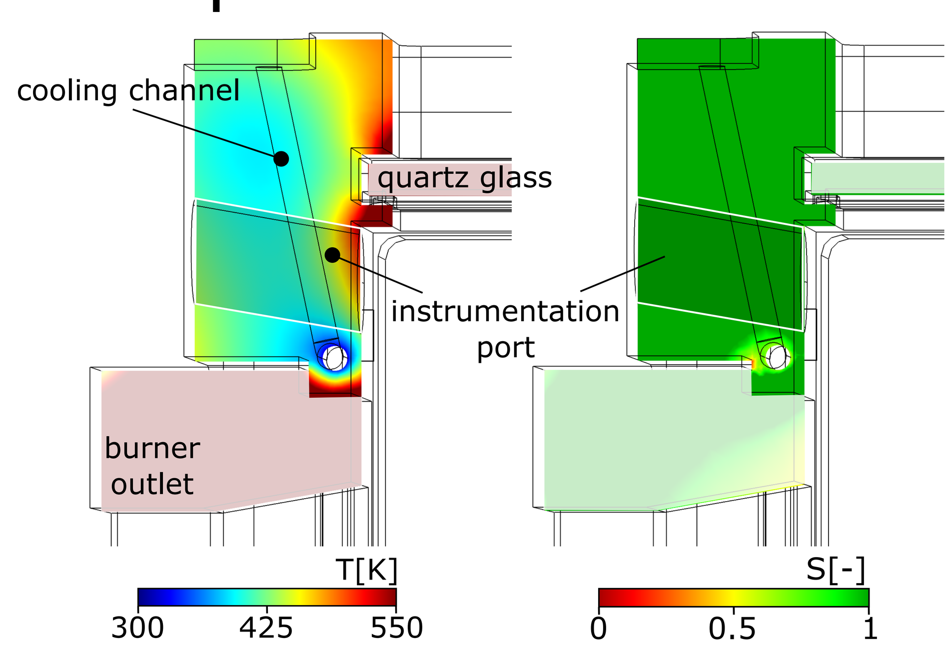

Figure 6. Instrumentation port detail

References

[1] Joos, F., Brunner, P., Schulte-Werning, B., Syed, K., and Eroglu, A., "Development of the Sequential Combustion System for the ABB GT24/26 Gas Turbine Family", *ASME Paper No 1996-GT-315*, (1996)

[2] Zienkiewicz, O., Taylor, R., Zhu, J., "The Finite Element Method - Its Basics and Fundamentals", Butterworth-Heinemann, (2013)

[3] Boley, B., Weiner, J., "Theory of Thermal Stresses", General Publishing Company Ltd., (1997)