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THERMAL-MECHANICAL COUPLED FSI-ANALYSIS OF ROCKET THRUST CHAMBERS WITH MULTIPLE LOAD CYCLES

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Cooled rocket thrust chambers are extremly loaded structures. Limited computer resources allowed in the past only the application of simplified models for transient coupled fluid-structure analyses to predict the thermal-mechanical loading and fatigue behaviour for design and sizing purposes. In order to enhance the life time prediction the careful modeling of the transient loading due to precooling, hotgas run and postcooling phase is important to capture the correct loading history.

This contribution begins with an overview of the implemented approach of the thermal-mechanical coupled analysis of rocket thrust chambers for life-time prediction. Building blocks are individual codes for the analysis of the hot gas flow in the thrust chamber respectively of the cooling fluid flow in the cooling channels and for the thermal and mechanical analysis of the structure. The basic coupling algorithm is the common Dirichlet-Neumann iteration in each time step for the transient analyses. Nonmatching grids are coupled via conservative projection methods to ensure a correct transfer of momentum and energy between the fluid and structural domains. A Lagrange multiplier (Mortar) method preserves the local smoothness of the continuity variables in case of spacing discrepancies of the fluid and structural grids. These algorithmical elements – thermal-mechanical load transfer (heat flux and forces), vice versa the temperature and displacement interpolation and the steering of the coupling iteration – are available in the coupling software environment ifls [1]. The object of interest is a regenerative cooled 40 kN LOX/H2 subscale rocket thrust chamber. It consists of 80 cooling channels in the combustion chamber and 160 cooling channels in the nozzle extension (Fig. 1) and is composed of a NARloyZ liner and an INCONEL 600 alloy jacket. The analysis uses RANS CFD for the hot gas and the cooling fluid flow and FEM for the thermal and mechanical behaviour of the structure [2].

The current developments subject is the efficient simulation of several precooling, hotgas run and postcooling loading cycles. The computing time of the CFD code predominates the overall simulation time and in each time step a couple of CFD analyses are needed for convergence. The effort of one loading cycle is considerable and an alternative approach is required for life-time simulations. In a first step an acceleration is introduced by using the Robin boundary condition which uses the heat flux description depending on the wall temperature instead of the Neumann condition. From the mathematical point of view this can be seen as a Schur complement or as a linearization of the heat flux and the thermal equilibrium is reached within a significant fewer number of iterations respectively of CFD analyses in each time step. A simplified model of the thrust chamber is used to demonstrate the acceleration and the impact, how the parameters of the Robin boundary condition are determined by the CFD code results.

Furthermore, first results of a second step will be presented: a surrogate model is built up to replace the CFD codes in thermally coupled analyses. It uses a nonlinear mapping (kriging or neuronal networks) between the surface temperature and the heat flux. Due to the high dimensionality of this mapping because a mapping for each surface grid point is required a reduction of dimensionality makes sense and is introduced with a proper orthognal decomposition (POD) for the temperature and the heat flux field. The methodology is borrowed from the aeroelastic domain [3]. It uses the method of snapshots to derive the POD bases and training sets calculated with the high fidelity model to construct the nonlinear mapping. Variations of the POD and mapping parameters show the applicability of this approach. With such a process chain the CFD codes can be replaced completely and a fast analysis of several load cycles is performed in a fraction of time compared with the usual CFD-CSM coupling.

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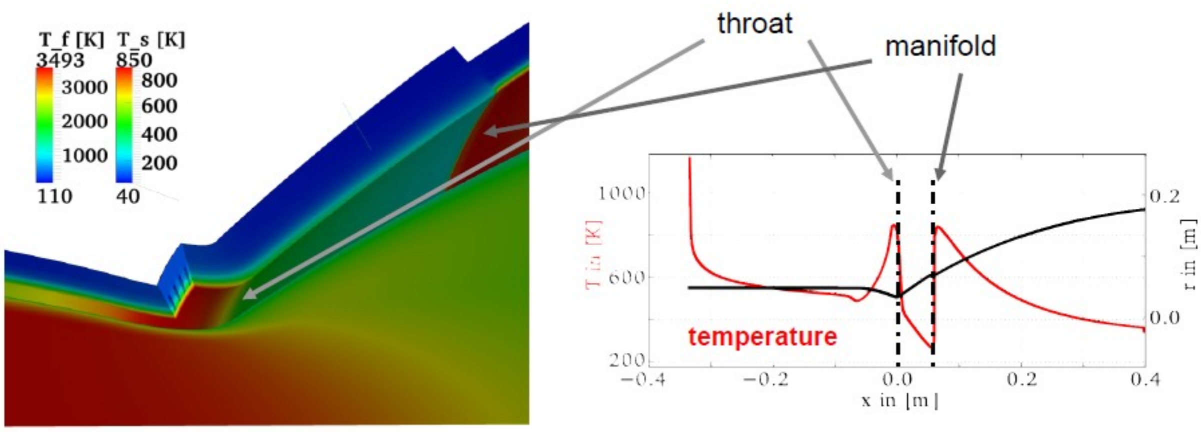

Fig. 1: Overview of the throat region of the subscale rocket thrust chamber.
left: temperature in structure and hot gas;
right: temperature and inner radius vs. axial coordinate x