SIMULATION OF LIQUID, TRANSCRITICAL AND GASEOUS COOLING FILMS IN ROCKET COMBUSTION CHAMBER

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Abstract

The prediction of heat loads and combustion efficiency is a crucial topic in the development of a rocket combustion chamber. Therefore EADS Astrium develops and enhances CFD-tools and conducts experiments both with fullscale and subscale rocket engines for tool validation. For numerical simulations Astrium uses amongst others the in-house CFD-tool Rocflam-II, which is a structured, finite volume, compressible and axisymmetric/2-D, multiphase and multi-species Navier-Stokes solver with a Lagrangian droplet tracking and evaporation module. This tool is validated against most current European launcher and satellite engines as well as many subscale rocket combustion chambers. Due to the fact that more and more rocket combustion chambers use film cooling for protecting the structure against the high heat loads and chemical attack, a film model is also incorporated in Rocflam-II. The big challenge for modeling cooling films in rocket combustion chambers is that the capability to simulate all kinds of film cooling applications is required. Consequently, the model has to treat different thermo dynamical states of the cooling fluid, different kinds of boundary conditions, different propellant combinations and different kinds of film injections.

The paper describes the film modeling in Rocflam-II and presents validation simulations for many different film applications. In detail, simulation results for sub-, trans- and supercritical thermo dynamical states and fluids as stated in Table 1 will be presented.

State	*Pressure*	*Temperature*	*Film fluids*
Liquid	$p < p_{crit}$	$T < T_{crit}$	MMH, NTO, kerosene and water
Transcritical	$p > p_{crit}$	$T < T_{crit}$	Kerosene and methane
Gaseous	$p > p_{crit}$	$T > T_{crit}$	Hydrogen

Table 1: Presented film fluids at different thermo dynamical states

The simulations also include different film build-up methods like droplet deposition or a dedicated film device and combinations of cooling techniques like combined film and radiative cooling or film cooling along with regeneratively cooled walls. In simulations with regenerative cooling the conjugate heat transfer is simulated via a coupling of Rocflam-II (hot-gas side) and the commercial 3D CFD Tool Ansys CFX (structure and cooling channel flows).

In Figure 1 an example of the validation for transcritical kerosene is shown. The test data used for transcritical kerosene are supported from the Institute for Flight Propulsion (LFA) at Technische Universität München (TUM). The top right side of Figure 1 shows the TUM-LFA water-cooled subscale rocket combustion chamber used for film cooling experiments. This rocket combustor uses gaseous oxygen and liquid or transcritical kerosene as propellants, which are injected through a single double swirl element. The liquid or transcritical kerosene film is injected via a film device (Yellow item between chamber segments 2 and 3 in Figure 1).

For film simulations a correct reproduction of the hot gas side including hot gas flow, combustion and heat transfer into the film and wall is mandatory. Therefore at first a setting anchoring of Rocflam-II on this combustion chamber for a reference configuration without cooling film was performed. The water cooling of this chamber is considered in the simulation via the calculation of the conjugate heat transfer between hot gas, structure and cooling circuit fluid. As one can see in the left side of Figure 1 the segment wise integrated wall heat flux from experimental film tests is well reproduced by simulation results of Rocflam-II.

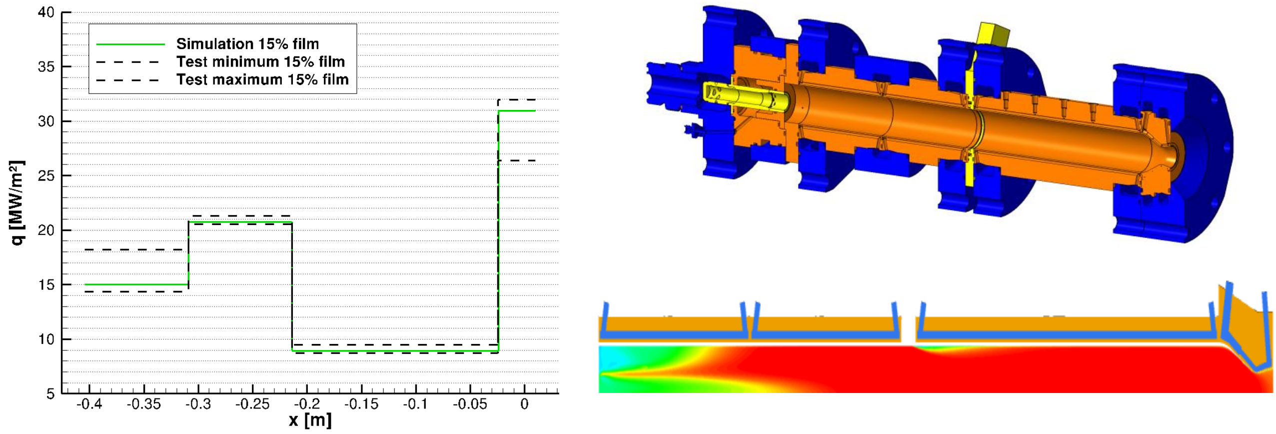

Figure 2. Left: Comparison of simulated and measured integral wall heat fluxes with 15% transcritical kerosene film injection (at x=-0.215 m); Right top: TUM-LFA subscale combustion chamber with film injector installed after second chamber segment; Right bottom: Exemplary temperature distribution and 3D structure grid with cooling channels