Abstract submitted to the 5th European Conference for Aeronautics and Space Science

Consideration of wall roughness effects in the prediction of heat transfer in rocket combustion chambers

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Experimental investigations of several rocket combustion chambers show a perceptible integral heat load increase with ongoing hot firing operation, which suggests an increase in wall surface roughness. This is confirmed by roughness measurements which additionally show that the increase can be locally very different. Besides the chamber wall material the wall temperature level is one of the main influencing parameters for the surface roughness development. Figure 1 exemplarily shows the wall temperature as well as the spatially measured wall roughness for three rocket combustion chambers. One can clearly see that depending on the wall temperature the roughness development presents itself very differently. As soon as a certain temperature limit is exceeded the surface roughness increase is strongly advanced. Below this temperature limit – as in case of the first engine - the roughness increase remains small.

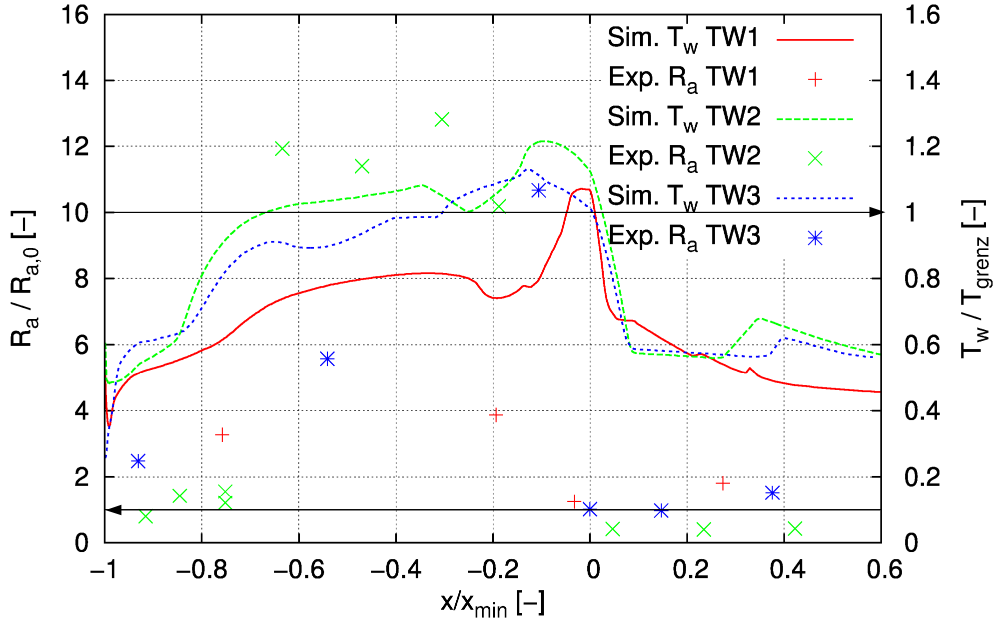

Figure 1: Relation between predicted wall temperature level and measured wall roughness for different combustion chambers

In order to determine the influence of different surface wall roughness strengths on the local wall heat flux and thus the combustion chamber wall temperature ASTRIUM Space Transportation applies the axisymmetric multi-phase Navier-Stokes solver Rocflam-II. Within this program an increased roughness is model by a non-dimensional quantity A_μ which reduces the damping function of the turbulent viscosity within the employed 2-layer k-ε turbulence model. The occurring temporally as well as spatially variable roughness development during operation is modelled by locally variable A_μ values. For the determination of these values the above mentioned roughness measurements are used. Their application in the frame of simulation of several combustion chambers shows substantially different wall temperature evolutions compared to former simulations without wall roughness consideration. In Figure 2 this is presented for the example rocket combustion chamber no. 3. Starting from the manufactured surface roughness its value in the simulation is increased according to the degree of operational aging. One can observe that the influence of surface roughness increase is mainly present in the convergent part of the chamber just upstream of the throat. Linked to this is a strong wall temperature increase in this region which anyway is the thermally most critical part of the chamber; this underlines the importance of the wall roughness development for the correct chamber wall temperature and thus life prediction.

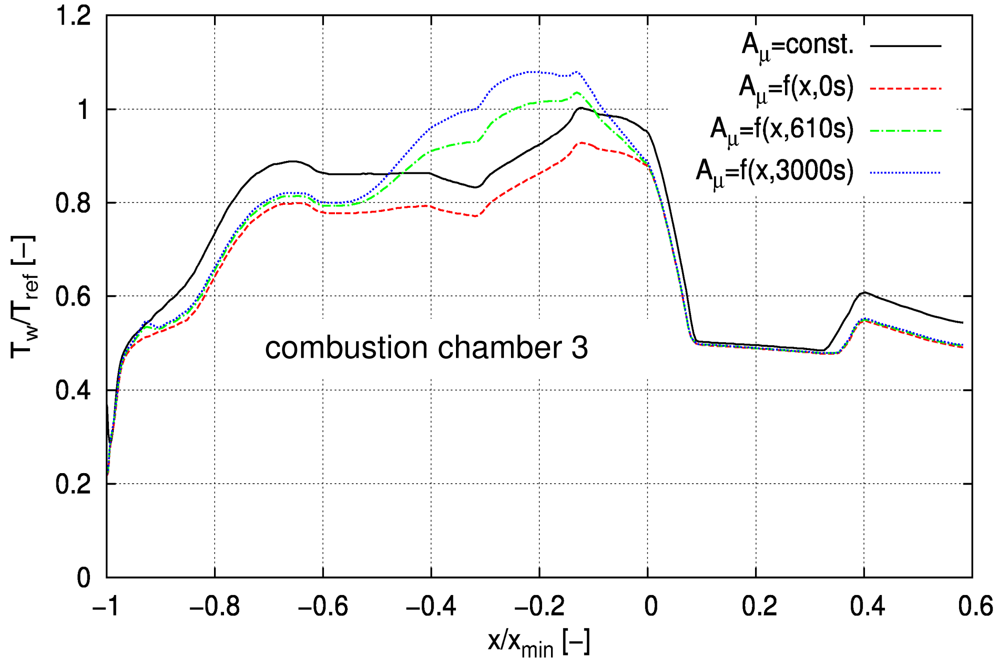

Figure 2: Temporal development of the wall temperature with local wall roughness evolution for combustion chamber 3

An important aspect for the development of new rocket combustion chambers is not only the possibility of considering a temporal and spatial wall roughness evolution of already operated chambers with measured surface roughness values but also the ability of predicting the level of roughness increase which can be expected for an engine in pre design phase where no measurement is available. For this purpose a simple roughness prediction model has been established, only based on the material and the wall temperature evolution of the non roughened combustion chamber. The verification of this model is discussed in detail in the paper.

References

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