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Radiative Heat Transfer Analysis in Modern Rocket Combustion Chambers

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Heat transfer analysis is crucial during the design process of rocket combustion chambers since the development of cooling systems and hence the life time of those chambers highly depend on the occurring heat loads.

The analysis of radiative heat transfer is a very complicated part of heat transfer calculations as it requires the solution of the Radiative Transfer Equation (RTE) which depends on spatial, directional and spectral variables. Analytical solutions for the RTE have been achieved only for simplified cases whereas for most other applications numerical approximations are used to solve the RTE. Within these approximations, radiation transfer models are responsible for the spatial propagation of radiation. In addition, spectral models deal with the spectral properties of the participating media.

Radiative heat loads depend on temperature's fourth power. Therefore, it is reasonable to assume that rocket combustion chambers with temperatures above 3000 K are influenced by radiative heat transfer. Former investigations of the Space Shuttle Main Engine (SSME) for H_2/O_2 combustion indicated that radiative heat loads to the wall have an integrated share of nearly 10 % on the Total Wall Heat Flux (TWHF) whilst the local ratio exceeds 30 % [1, 2, 3, 4]. Assuming thrust-identity for a fictitious CH_4/O_2 combustion in the SSME, radiation's share on the TWHF increased to nearly 15 % [3, 5]. One of the shortcomings of those investigations was that the flow field of the SSME has been predicted by commercial and research CFD codes [3, 4, 5], not taking into account the effect of propellant preparation on the heat load development.

The aim of this work is to assess radiative heat loads on the wall of various combustion chambers that are part of EADS Astrium's portfolio. As basis, more reliable flow field predictions by Astrium's in-house CFD code Rocflam-II are used, which are validated against numerous experiments [6, 7], taking into account propellant preparation effects such as propellant disintegration, evaporation and mixing. By using combustion chambers for H_2/O_2 and CH_4/O_2 combustion, the influence of a CO_2/H_2O mixture on the Radiative Wall Heat Flux (RWHF) in comparison to single H_2O systems is investigated.

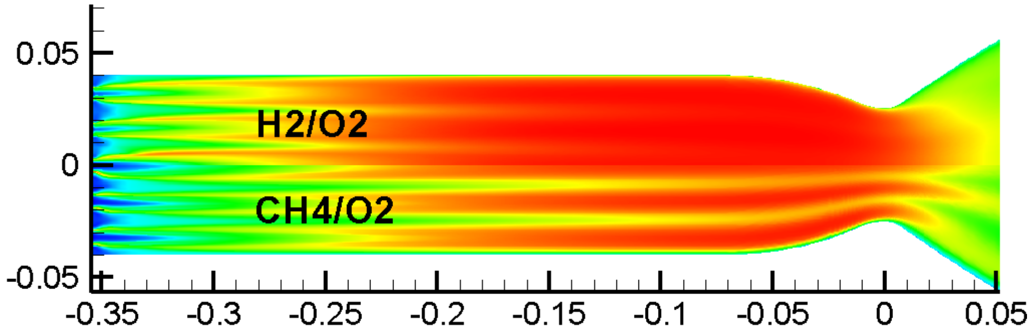

Figure 1: Temperature contours for H_2/O_2 and CH_4/O_2 combustion

The flow field of Rocflam-II, as shown in Fig. 1, is imported into the research CFD code NSMB [8] which has been extended to cope with radiative heat transfer analysis [3, 4]. Based on the temperature, pressure and molar fraction of radiating species, the P1 radiation transport model in NSMB [4] is used in conjunction with various Weighted Sum of Gray Gases Models (WSGGM) [9] as spectral models to predict the Radiative Wall Heat Flux (RWHF) and its share on the TWHF in an uncoupled simulation for different wall emissivities.
All simulation results reveal that the RWHF has a certain influence on the TWHF but it decreases compared to former investigations [1, 3, 4, 5]. With the more profound flow field simulations, accounting for propellant preparation effects, the temperature near the injector face plate decreases, predicting a smaller RWHF and reducing the total ratio of RWHF to TWHF. The final paper will outline these findings in detail.

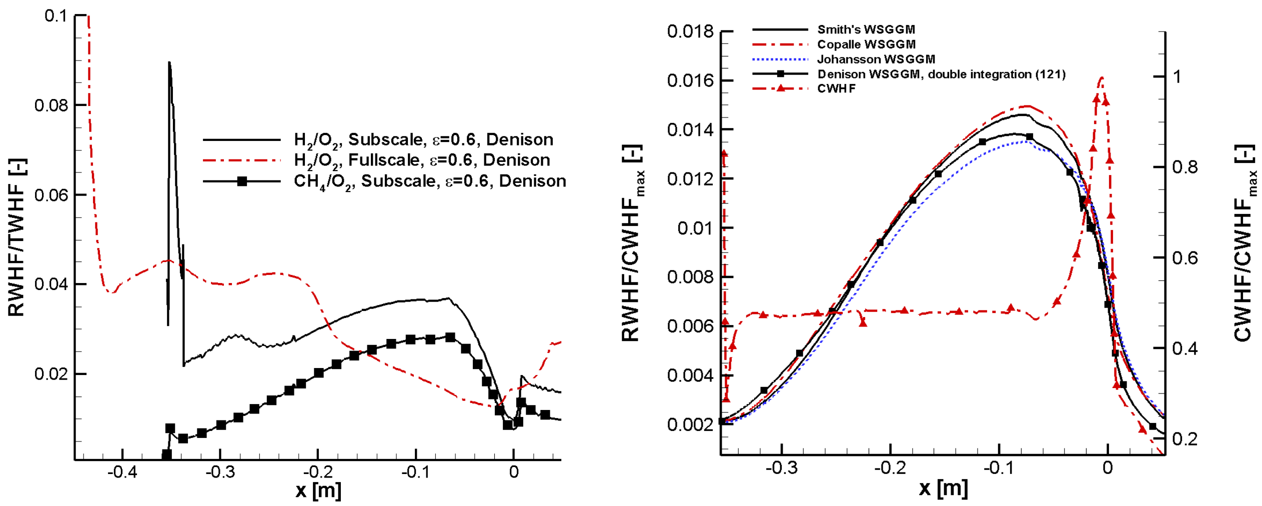

Figure 2: Ratio of Radiative Wall Heat Flux to Total Wall Heat Flux and Radiative Wall Heat Flux versus Convective Wall Heat Flux for CH_4/O_2 combustion

Furthermore, the results show that an improvement of the spectral modeling leads to a decrease in the prediction of the RWHF. However, within the family of WSGG models no significant difference could be observed in prediction of the RWHF between more sophisticated [10] and rather simple models [11] as Fig. 2 underlines. Nevertheless, one can see that for H_2/O_2 combustion the RWHF locally reaches up to 10 % of the TWHF. For CH_4/O_2 combustion this ratio does not exceed 4 %.
Concerning the mixture of CO_2 and H_2O as products of the CH_4/O_2 combustion the influence of RWHF on the total heat loads of the wall does not significantly change compared to the H_2/O_2 case, which is in contradiction to the former investigations. However, the question of comparable operational load point and thus pressure and mixture ratio plays an important role in this context. The final paper will investigate this in more detail.

An option for future investigations is the use of k-distributions instead of WSGG models, which have been utilized in former investigations at the Institute of Thermodynamics [12].

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