Investigation of different modeling approaches for CFD simulation of high pressure rocket combustors

B. Ivancic, H. Riedmann, M. Frey, O. Knab
ASTRIUM Space Transportation, D-81663 Munich, Germany
S. Karl, K. Hannemann
DLR Göttingen

This paper summarizes the main topics and highlights of the cooperation between DLR and ASTRIUM within the work package "CFD Modeling of Combustion Chamber Processes" conducted in the frame of the Propulsion 2020 Project. The main targets of this project are the strengthening of the knowledge and competence in the area of rocket propulsion combustion devices i.e. test, modeling and simulation capabilities. This is performed in narrow cooperation between several DLR institutes and ASTRIUM Space Transportation. Within the addressed work package, DLR Göttingen and ASTRIUM have defined several test cases (e.g. see Fig. 1) where adequate test data are available and which can be used for proper validation of the CFD tools (see Fig. 2). Several Modeling approaches, implemented in the DLR CFD solver TAU, ASTRIUM's in-house CFD tool-family Rocflam and the commercial solver CFX, adapted by ASTRIUM for rocket propulsion applications, have been compared and validated. Finally an assessment of the different modeling approaches and CFD tools is shown. Especially the PDF approach and the differences between TAU, Rocflam and CFX are presented. Furthermore the deficiencies and assumptions of the relevant models will be discussed.

Modern rocket thrust chambers as Vulcain 2 work at high pressure levels for efficiency and mass reasons. The propellants are injected in transcritical or supercritical and thus thermodynamically extreme conditions, making the physical and numerical description a very challenging task. The complexity of the dominant phenomena, i.e. mixing and combustion of the propellants determining the integral performance characteristics and the wall heat loading of propulsion systems, is discussed in this paper.

In earlier times the relevant processes, especially the wall heat flux distribution, were predicted by simple engineering tools based on 1D flow, chemical equilibrium and Nusselt-correlations. Further developments at ASTRIUM lead to the more sophisticated 2D spray combustion tool Rocflam-II. However, 3D-phenonema are existent and not negligible in some parts of the combustion chamber. The goal is hence the ability to resolve the major 3D phenomena inside combustion chambers and nozzles over various operating points and thrust chamber geometries. This includes explicitly the circumferential variation of heat loads on combustion chamber wall and face plate. Further inhomogenities can arise for example by asymmetries in the flow conditions or injector placement.

Therefore high effort has been put in the in-house development of Rocflam3 (3D), which is the successor of Rocflam-II (2D) and the adaptation of the commercial 3D-CFD solver CFX for the usage in these extreme thermodynamic conditions. The problems, especially for the rocket applications of the commercial CFD tool CFX are mainly, that this solver is developed for a broad range of application (e.g. turbo machinery) and not focused for rocket propulsion. The adaption process and the status of the ASTRIUM tool development are shown in [1]. The proposed paper describes the further development of the ASTRIUM 3D CFD simulation tools, but also the progress of the DLR in-house tool TAU and its 3D modeling capabilities. It is shown that the turbulent combustion model is one of the most important issues. Various combustion models (like Flamelet, Finite Rate, Chemical Equilibrium with PDF, etc.) have been investigated and evaluated with the available CFD tools.

The results are analyzed and compared using standard validation cases like the Mascotte Combustor [3] and the Penn State Single Element Combustor (see Fig. 1) [2].

[1] Ivancic B., Riedmann H., Frey M.: "**Validation of Turbulent Combustion Models for 3D-Simulations of Liquid H2/O2 Rocket Combustors**"; Space Propulsion Conference, Bordeaux 2012, SPC2012_2358097

[2] Marshall, Pal, Woodward, Santoro: **Benchmark Wall Heat Flux Data for a GO2/GH2 Single Element Combustor**; AIAA 2005-3572; 41st AIAA Joint Prop. Conference; 10-13. July, Tucson, Arizona

[3] French-German Research on Liquid Rocket Combustion: ***Test Case RCM-2. Mascotte Single Injector -10 Bar***; 2nd International Workshop on Rocket Combustion Modeling: Atomization, Combustion and Heat Transfer, Lampoldshausen, Germany, 2001

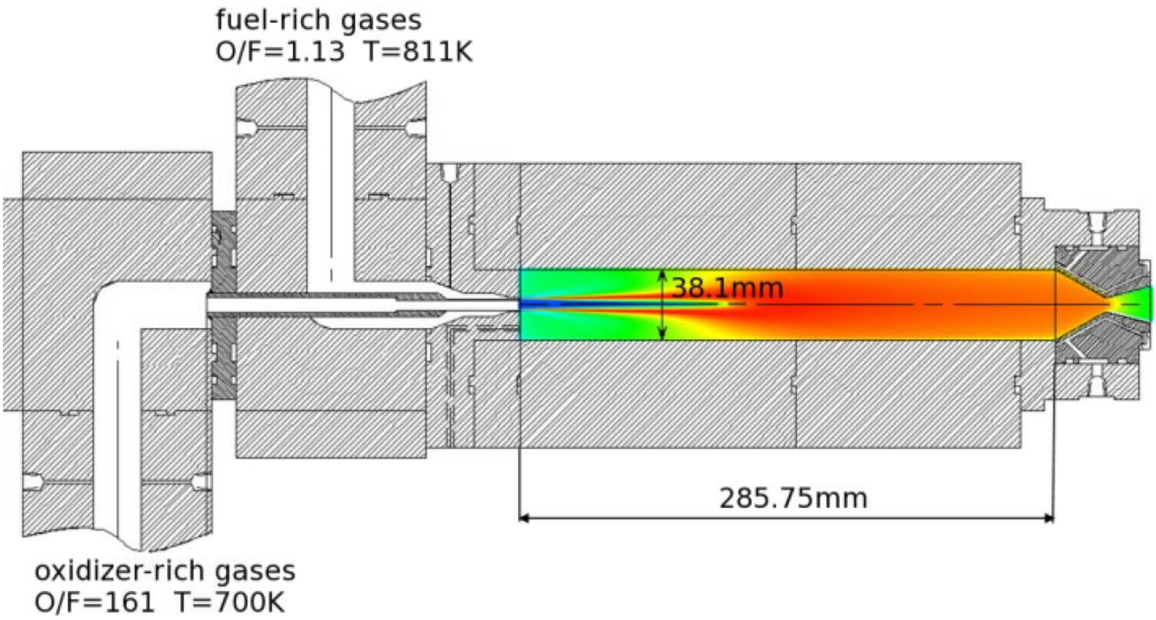

Fig. 1: Single-Injector Combustor (Penn State) with inlet conditions [2]

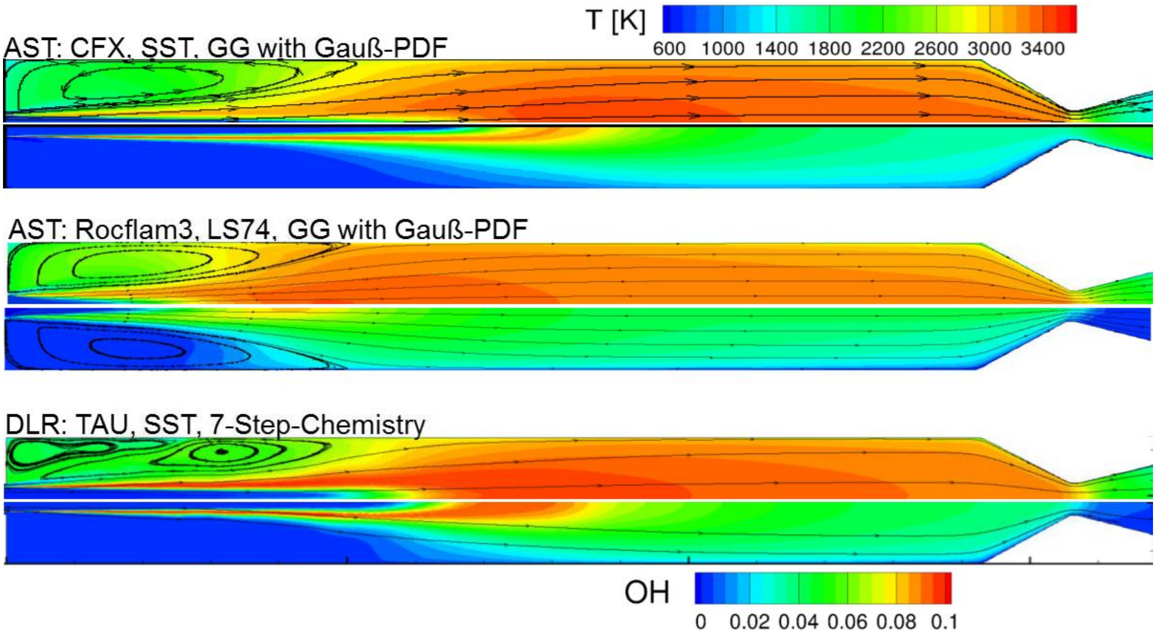

Fig.2: Comparison of thermal field and OH mass fraction distribution for the three CFD tools