Numerical Simulations of Flame of Single Co-Axial Injector

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Co-axial injector has a wide usage in rocketry. It is used practically in all hydrogen and kerosene rocket engines. Though operated engines use multi-injector systems which consists of hundreds of co-axial injectors, the flame even of a single injector is an actual problem, which is not solved yet [1].

All combustion processes can be represented in two stages: mixing and following chemical reacting. Combustion in rocket engine proceeds in different regimes which significantly obstruct the modelling, but most of the propellants burn in the flame where chemical reactions are faster than mixing. That is why mixing alongside with chemical reacting is important process in rocket-motor combustion. In the current work two both processes have been considered and modelled. Two test cases have been discussed: mixing in the jet of co-axial injector and its flame. In both test cases the CFD simulations of experiments have been done using ANSYS CFX 13.0 software.

In the first test case the experiments on the non-reacting coaxial jet mixing [2] have been simulated. In the experimental combustion chamber the study of the mixing in the coaxial jet was carried out using planar laser induced fluorescence (PLIF). Helium and air with admixture of acetone was used as the representative of rocket propellants (hydrogen and oxygen). The mixing occurred at temperature and atmospheric pressure. The numerical simulations have been carried out using Reynolds-averaged Navier-Stokes equations (RANS) and shear stress turbulence (SST) model on an ordinary desktop PC. The effect of numerical mesh and turbulent Schmidt number has been studied parametrically. At the optimal mesh and the Schmidt number the numerical simulations agree very well with experimental data.

The results of the first test case have been used in the second where the combustion in co-axial jet has been modelled. Hydrogen/oxygen flame was visualised using PLIF of OH in the experimental combustion chamber with a single co-axial injector at pressures from 10 to 53 bar in work [3]. The numerical simulations have been carried out using the same model as in the first test case. The agreement with experimental data is rather poor in the second test case in contrast to the first case. The simulated flame is long while in the experiments the flame is significantly shorter and the flame front is broken. To improve the agreement with experiments transient simulations have been done in 3D computational domain. The transient simulations have been performed using SAS (Scale-Adaptive Simulation) turbulence model on a small computer cluster. At the non-stationary solution the flame is relatively shorter and the flame front became similar to the observed in the experiments.

[1] P. K. Tucker, S. Menon, C. L. Merkle, J. C. Oefelein, and V. Yang. An approach to improved credibility of cfd simulations for rocket injector design. In 43rd AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, July 2007.

[2] S. A. Schumaker. An Experimental Investigation of Reacting and Nonreacting Coaxial Jet Mixing in a Laboratory Rocket Engine. PhD thesis, The University of Michigan, 2009.

[3] A. Vaidyanathan. OH-PLIF measurements and accuracy investigation in high pressure GH2/GO2 combustion. PhD thesis, University of Florida, 2008.