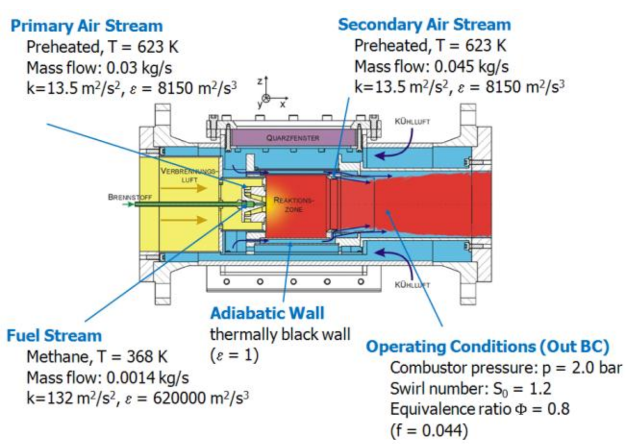
Generic Gas Turbine Combustor

Description of the combustor

This case study on combustion and radiative heat transfer in a generic gas turbine (GGT) combustor of TU Darmstadt illustrates the multi-physics modeling capabilities in FINE™/Open. Three test cases are simulated:

- Adiabatic non-premixed combustion
- Non-adiabatic non-premixed combustion with radiative heat losses
- Partially premixed combustion.

In the configuration shown below, the main air stream enters the combustion chamber via a swirler nozzle. The fuel enters the combustion chamber separately from the air via a pipe in the center of the swirler nozzle. The swirl of the air causes a recirculation zone, which stabilizes the flame. After the primary combustion zone a secondary air stream is injected to rapidly dilute the fuel/oxidizer mixture and to lower the temperature in the combustor [1].

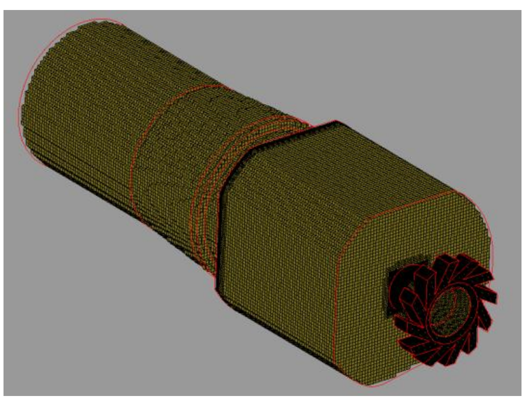


NUMECA has developed a software suite, or a Flow INtegrated Environment (FINE), for internal and external flows and geometries, which includes all the software tools required for a start-to-finish CFD project. This unstructured CFD package consists of the following:

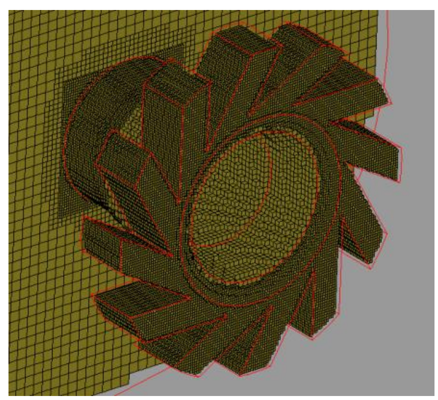
- HEXPRESS™, an automatic unstructured Hexahedral mesh generator software designed to automatically generate meshes for the discretization of complex 2D and 3D geometries;
- FINE™/Open flow solver, a state-of-the-art multi-domain unstructured code for the solution of the Euler and Navier-Stokes equations to compute laminar, transitional and turbulent flow;
- CFView™, a highly interactive flow visualization and post-processing software;
- FINE™ Graphical User Interface, a user-friendly environment that ties the FINE™/Open tools together and provides a smooth transition between each step of CFD analysis, from grid generation to flow visualization.

Grid generation

The mesh for the discretization of the combustor and the nozzle is generated by HEXPRESS™ and consists of 800,000 cells. The mesh is refined in the combustion chamber behind the swirler nozzle to capture the high gradients in this region.



Overall view of the mesh



View focusing on the swirler nozzle

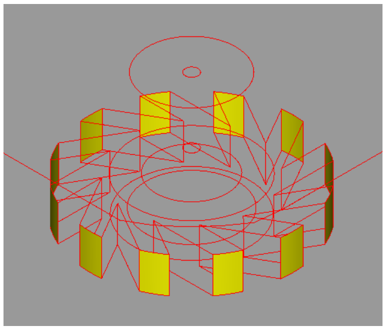
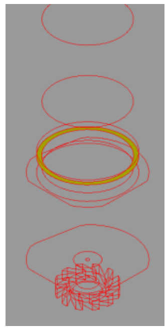
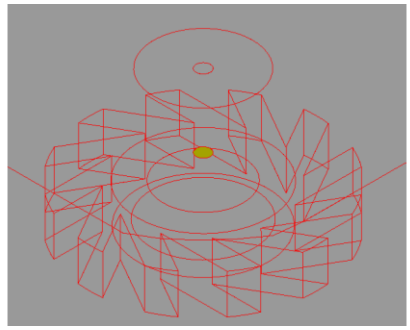
HEXPRESS™ uses a volume to surface approach to generate non-conformal, body-fitted, fully hexahedral meshes, applying sophisticated snapping and optimization algorithms to resolve lower dimensional geometric features such as corners and curves in the boundaries of the geometry. Optimization algorithms target poor quality cells, maximizing orthogonality and converting concave cells to convex ones by slightly displacing their vertices. Layers of additional cells (buffer insertion) are introduced at the mesh surface to create a body conformal mesh.

Modeling options and results

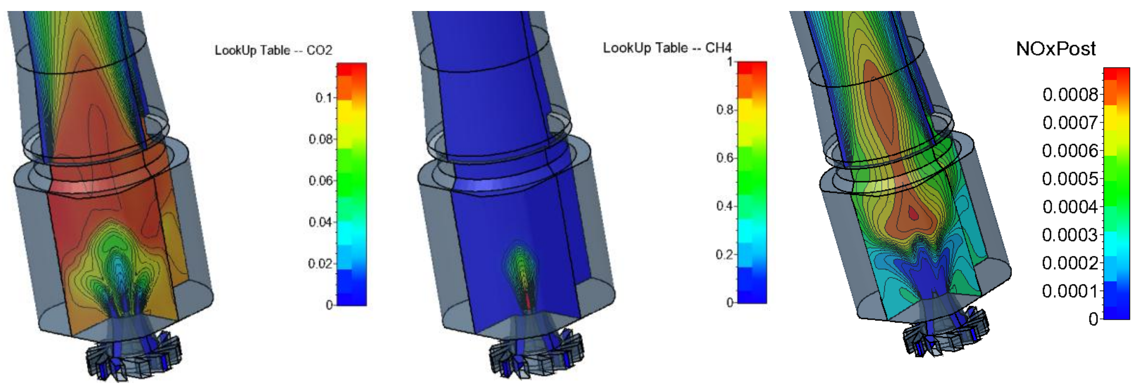
Case 1: Adiabatic Non-Premixed Combustion

In the first test case the reactive flow field in the combustor is simulated using the model for non-premixed combustion. The combustion process is assumed to be adiabatic, i.e., the heat transfer due to conduction and/or radiation will not be modeled. The flow model is steady state and the RANS equations are solved in conjunction with the standard k-ε turbulence model. The thermo-chemical properties of the fluid are defined via the use of a flamelet library generated using TABGen/Chemistry [2]. Both the density and the temperature are determined via combustion look-up tables, in which their values are tabulated as a function of the mixture fraction, its variance, the strain rate and/or the enthalpy defect. The turbulence-chemistry interaction is accounted for by using combustion look-up tables that have been pre-integrated over the mixture fraction variable using an assumed shape probability density function (Beta-PDF).

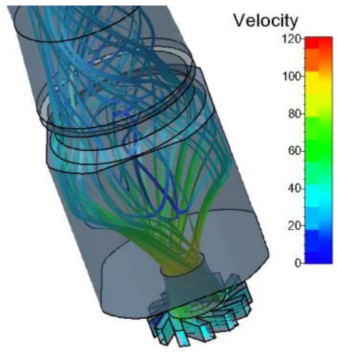
The mass flow rate is a) 0.03 kg/s for the primary air stream, b) 0.045 kg/s for the secondary air stream and c) 0.0014 kg/s for the fuel stream (see figure below). The static pressure at the outlet is set to 200000 Pa and the walls are defined to be adiabatic.

a)  b)  c) 

The convective fluxes of the RANS equations are discretized using a 2nd order central scheme. The combustion transport equations and the turbulent flow equations are discretized using an upwind scheme to ensure bounded and monotonous solutions for the combustion variables. The CFL number is set to 1.5 and a preconditioning technique is used with default values.



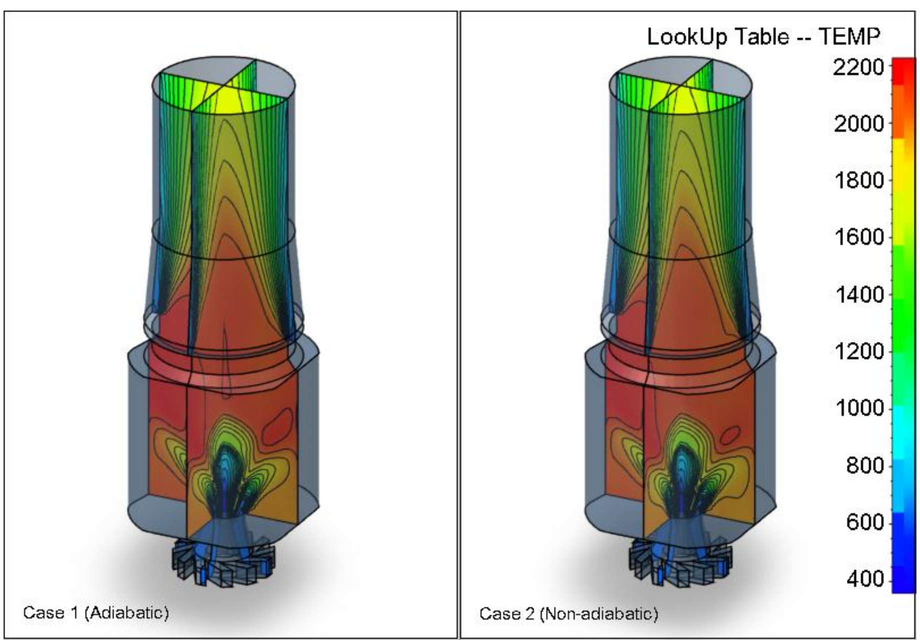
Reactive flow field in the combuster.



Stream lines in the combustion chamber show the swirl of the injected main air stream.

Case 2: Non-adiabatic non-premixed combustion with radiative heat losses

The model for this case is identical to Case 1 with the addition of radiative heat transfer in the model. The radiative heat transfer is modelled using the P1 radiation model and the Weigted-Sum-of-Gray-Gases (WSGG) approach for the determination of the optical properties. The emission coefficient of the solid walls is set to unity.

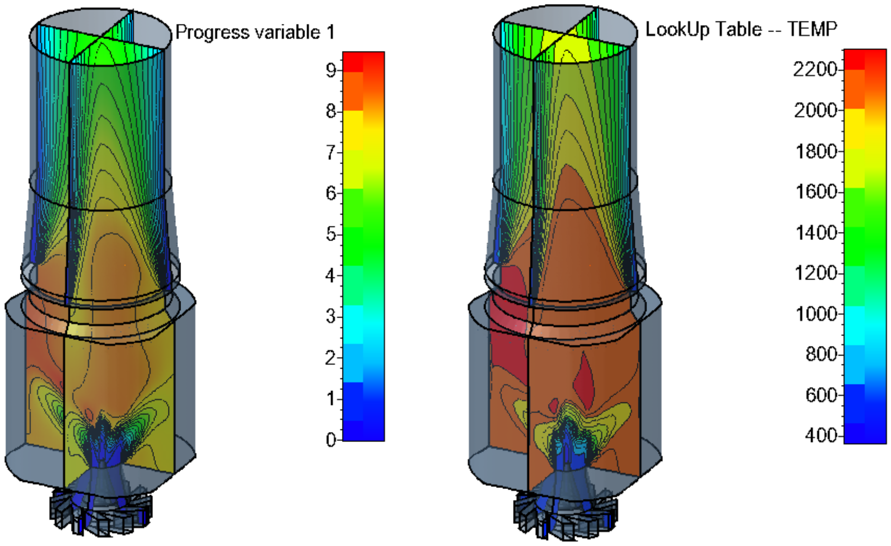


A comparison with the temperature field of case 1 (adiabatic simulation) shows that the radiative heat transfer slightly decreases the temperature in the system.

Case 3: Partially Premixed Combustion (FGM-Flamelet Generated Manifolds)

Here, the modelling approach for partially premixed combustion is demonstrated. Heat losses are not accounted for as the effect of the radiative heat transfer in this case is low. In this case the simulation uses the Partially premixed model and the Manifold technique as the chemistry model (FGM). The turbulence chemistry interaction is accounted for by using tables that have been pre-integrated over the mixture fraction.

In the FGM (Flamelet Generated Manifolds) approach, the combustion look-up tables are generated by remapping a flamelet library on the mixture fraction progress variable space which determines the progress of the reaction from unburnt (zero) to burnt (maximum value) [3]. The thermo-chemical states are tabulated as a function of the mixture fraction, mixture fraction variance and the progress variable (instead of the mixture fraction, mixture fraction variance, and strain rates as in the classical flamelet approach). The use of a progress variable in addition to the mixture fraction makes it possible to simulate combustion processes with partial premixing. The FGM approach can be used for both the simulation of non-premixed and partially premixed combustion processes, with the advantage over the classical flamelet approach that finite-rate effects and lifting of flames can be predicted.



The simulated progress variable and the temperature fields show that the (experimentally verified) lifting of the flame can be predicted using the module for partially premixed combustion.

References:

[1] Janus, B., Dreizler, A. and Janicka, J. (2004), "Experimental Study on Stabilization of Lifted Swirl Flames in a Model GT Combustor", Flow, Turbulence and Combustion, Vol. 75:293-315.

[2] Peters, N. (2000), "Turbulent Combustion", Cambridge University Press, Cambridge.

[3] van Oijen, J. and de Goey, P. (2000), "Modeling of premixed laminar flames using flamelet generated manifolds ", Combustion Science and Technology, Vol. 161:113-137. Generic Gas Turbine combustor (GGT).