Aerothermal investigations on turbine endwalls and blades

Project information

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Final Report Summary - AITEB-2 (Aerothermal investigations on turbine endwalls and blades)

The AITEB-2 project represented a new integrated approach to develop and assess advanced aerodynamic and aerothermal design concepts for highly loaded HP and LP turbines and interducts. To meet economic and environmental demands, future designs of aero engines and industrial gas turbines must strive for high performance, low noise and pollutant emissions, reduced weight and cost and shorter time to market.

The conjugate heat transfer is a key issue in combustion: the interaction of hot gases and reacting flows with colder walls is a key phenomenon in all chambers and is actually a main design constraint in gas turbines. For example, multi-perforated plates are commonly used in gas turbines combustion chambers to cool walls and they must be able to sustain the high fluxes produced in the chamber. After combustion, the interaction of the hot burnt gases with the high pressure stator and the first turbine blades conditions the temperature and pressure levels reached in the combustor, and therefore the engine efficiency.

Conjugate heat transfer is a difficult field and most existing tools are developed for chained (rather than coupled), steady (rather than transient) phenomena: the fluid flow is brought to convergence using a Reynolds averaged Navier-Stokes (RANS) solver for a given set of skin temperatures. The heat fluxes predicted by the RANS solver are then transferred to a heat transfer solver which produces a new set of skin temperatures. A few iterations are generally sufficient to reach convergence. There are circumstances, however, where this chaining method must be replaced by a full coupling approach. Flames interacting with walls for example, may require a simultaneous resolution of the temperature within the solid and around it. More generally, the introduction of LES to replace RANS leads to full coupling since LES provides the unsteady evolution of all flow variables.

Fully coupled conjugate heat transfer requires taking into account multiple questions. Among them, two issues were considered for the AITEB-2 project:
- The time scales of the flow and of the solid are generally very different. In a gas turbine, a blade submitted to the flow exiting from a combustion chamber has a thermal characteristic time scale of the order of a few seconds while the flow-through time along the blade...
is less than 1 ms. As a consequence, the frequency of the exchanges between the codes is critical for the precision, stability and restitution time of the computations.

- Coupling the two phenomena must be performed on massively parallel machines where the codes must be not only coupled but synchronised to exploit the power of the machines.

During this work, these two issues have been studied using two examples of conjugate heat transfer: a flame interacting with a wall in section II and a blade submitted to a flow of hot gases in section III. Both problems have considerable impact on the design of combustion devices. Section I deals with the codes used to this studies as well as the coupling strategies.

The AVBP code is used for the fluid. It solves the compressible reacting Navier-Stokes equations with a third-order scheme for spatial differencing and Runge-Kutta time advancement. Boundary conditions are handled with the NSCBC formulation.

For the resolution of the heat transfer equation within solids, a simplified version of AVBP, called AVTP, was developed. It uses the same data structure as AVBP. It is coupled to AVBP using software called PALM. For all present examples, the skin meshes are the same for the fluid and the solid so that no interpolation error is introduced at this level.

The interaction between flames and walls controls combustion, pollution and wall heat fluxes in a significant manner. It also determines the wall temperature and its life time. In most combustion devices, burnt gases reach temperatures between 1500 and 2500 K while walls temperatures remain between 400 and 850 K because of cooling. The temperature decrease from burnt gases levels to wall levels occurs in a near-wall layer which is less than 1 mm thick, creating large temperature gradients.

Studying the interaction between flames and walls is difficult from an experimental point of view because all interesting phenomena occur in a thin zone near the wall: in most cases, the only measurable quantity is the unsteady heat flux through the wall. Moreover, flames approaching walls are dominated by transient effects: they usually do not ‘touch’ walls and quench a few micrometers away from the cold wall because the low wall temperature inhibits chemical reactions. At the same time, the large near-wall temperature gradients lead to very high wall heat fluxes. These fluxes are maintained for short durations and their characterisation is also a difficult task in experiments.

The present study focuses on the interaction between a laminar flame and a wall. Except for a few studies using integral methods within the solid or catalytic walls, most studies dedicated to FWI were performed assuming an inert wall at constant wall temperature. Here, we will revisit the assumption of isothermicity of the wall during the interaction.

The second example studied during this work was the interaction between a high-speed flow and a cooled blade. This example is typical of one of the main problems encountered during the design of combustion chambers: the hot flow leaving the combustor must not burn the turbine blades or the vanes of the high pressure stator. Predicting the vanes temperature field (which are cooled from the inside by cold air) is a major research area. Here, an experimental set-up (T120D blade) developed within the AITEB-1 European project was used to evaluate the precision of the coupled simulations. The temperature difference between the mainstream (T2 = 333.15 K) and cooling (T1 = 303.15 K) airs is limited to 30 K to facilitate measurements. Experimental results include pressure data on the blade suction and pressure sides as well as temperature measurement on the pressure side.

Conjugate heat transfer calculations have been performed for two configurations of importance for the design of gas turbines with a recently developed massively parallel tool based on a LES solver. An unsteady flame / wall interaction problem was used to assess the precision of coupled solutions when varying the coupling period. It was shown that the maximum coupling period that allows well reproducing the temperature and the flux across the wall is of the order of the smallest time scale of the problem. Steady convective heat transfer computation of an experimental film-cooled turbine vane showed how thermal conduction in the blade tends to reduce wall temperature compared to an adiabatic case. Further studies on LES models, coupling strategy and experimental conditions are needed to improve quality of the results compared to the experimental cooling efficiency.

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