A CONJUGATE HEAT TRANSFER PROCEDURE FOR GAS TURBINE BLADES

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The temperature distribution in the blade metal is the result of the combined effects of convective internal heat transfer, external convection, and conduction through the metal itself. As a consequence, although stand-alone external flow heat transfer results yield important information for the designer, only a fully coupled conjugate heat transfer (CHT) computation allow the correct evaluation of metal temperature.

Such a fully coupled approach involves the solution of different physical problems: transonic flow in the blade passage, low Mach number flow in the cooling passages, conduction in the metal. It could be possible to use the same solver for all these problems, maybe using preconditioning schemes to handle the different Mach number regimes, and using the (modified) energy equation of the NS solver to get the conduction solution.

However as structural codes for conduction analysis are widely available in industry, the most rational approach for conjugate heat transfer requires the development of an interface between existing codes, rather then embedding a solid analysis capability in the flow solver. Furthermore, this can also allow the use of different codes optimised for the high and low Mach number domains.

An implicit Navier Stokes solver[1], whose accuracy in gas turbine heat transfer application has previously been assessed[2], was used for external flow computation. An ADI factorization, within an hybrid finite volume-finite difference frame, is adopted, while turbulence can be taken into account through a standard Baldwin-Lomax model or an algebraic RNG based one[1], and structured grids are used[3].

The conduction equation within the solid has been discretized with a finite volume formulation on an unstructured triangular grid[4] (or triangular prisms in 3D configurations). Neumann boundary conditions are easily implemented, due to the integral finite volume formulation. For 2D computation, an heat transfer rate coefficient is assumed for blade/coolant interface, allowing for a non-uniform temperature distribution along the internal surfaces; for 3D computation, internal flow is solved via an artificial compressibility algorithm.

The coupling between fluid and solid is obtained via an exchange of boundary conditions. Fluid solutions for both internal and external flow are obtained with a guessed temperature distribution along the wall; the heat flux computed by the two solvers is then used as a boundary condition for the solid conduction problem, which gives back a new temperature distribution along the walls. Consistent, conservative interpolation procedures can be used to handle mismatching grids.

Such an approach have been widely used in some simplified way in industrial environment: usually a few complete cycles are carried out, using converged or nearly solution for each domain problem. Here we use a stronger coupling, calling the interface procedure at each pseudo-time step. This approach, thus, corresponds to the Shur Complement algorithm for domain decomposition of partial differential equations described by Funaro et al.[5], where convergence properties of the methods are demonstrated for elliptic problems. In the same paper[5], some guidelines are given on the optimal choice of the relaxation parameter.

Using different equation on the two sides of the interface, as in the CHT case, the boundary condition choice is imposed by stability consideration. According to a simplified one dimensional finite differences analysis[6], in fact, the use of a heat flux b.c. for the solid and a temperature b.c. for the fluid provides stability for the global problem, while a Neumann condition for the fluid and Dirichlet for the solid lead to instabilities[6]. Similar algorithms have been used to couple fluid and solid energy equations in incompressible flow (where flow field is decoupled from thermal one), CHT[7,8].

As stated above, the whole procedure is not dependent on the details of the flow solver code: the same interfacial procedure has been successfully applied by the author to a finite-element codes for anti-icing problem analysis[9].

Advancing the solution at the same time as the flow solution allows the solution even if the solid is completely surrounded by flow domain (i.e. Neumann condition on all solid boundaries), as we are actually solving on a single domain spanning the fluid and the solid, and the correct flow b.c. ensures the convergence to the steady-state solution. Furthermore, the strong coupling implies that the number of time steps required for the CHT computation is of the same order of magnitude of the time required for a stand alone computation. However, as we use an implicit algorithm for the fluid and conduction solver the global convergence rate is slightly reduced, in comparison to the stand-alone computation, as the coupling is not linearized[9].

A useful feature of the outlined procedure is the ability to deal with non-matching grids. This can be obtained using interpolation techniques consistent with a conservative FVM formulation in order to transfer the temperature and heat fluxes from one side of the interface to the other.

The procedure was tested on the gas turbine blade shown in fig.1. Grid nodes don’t match exactly at the interface, and a suitable (and conservative) interpolation and integration routine is used to handle the mismatch. Sample results are given in fig.2.

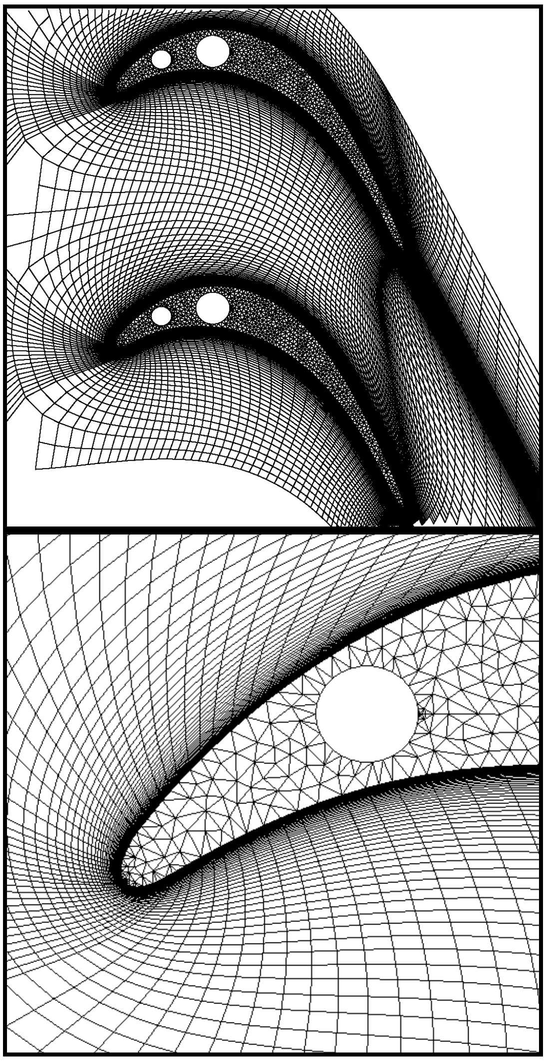

Fig.1 Computational grids

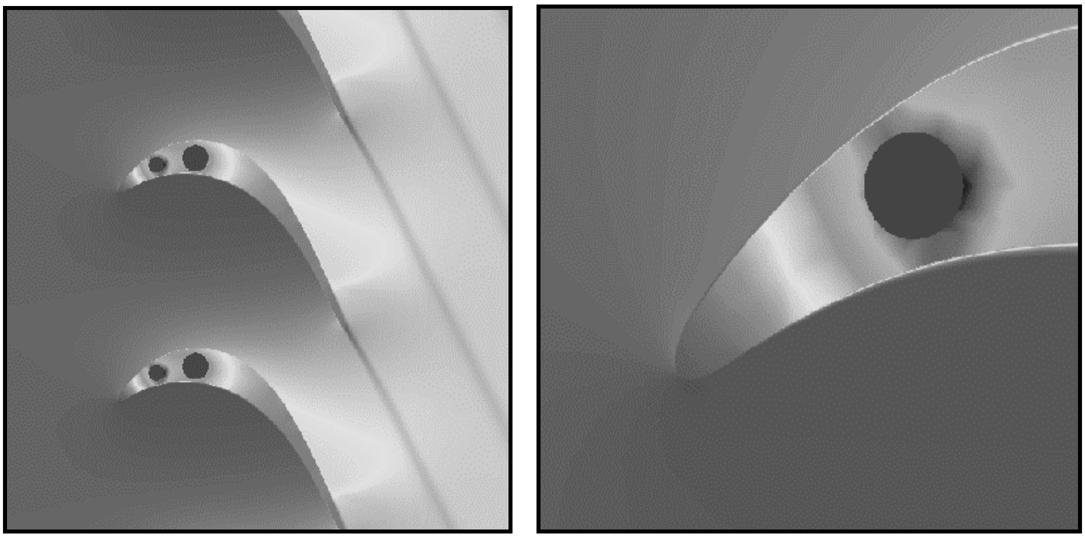

Fig.2 - Temperature field

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