Numerical Interface Treatments for Weak and Strong Interaction in Conjugate Heat Transfer Problems

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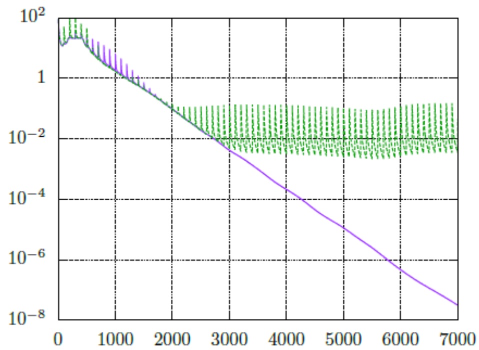
Conjugate heat transfer (CHT) is employed to study thermal interaction processes at a fluid-solid interface. It is an important procedure in many fluid dynamics applications in which accurate heat transfer predictions are needed, including heat conduction in the solid body via a coupled aerothermal modeling.

Our goal in this paper is to present the main numerical characteristics, in weak and strong thermal interaction, derived from a normal mode stability analysis based on the theory of Godunov-Ryabenkii. On the basis of this model problem, two fundamental parameters are introduced : a "numerical" Biot number Bi_{ν} controlling the stability process and an optimal coefficient that ensures unconditional stability. This numerical Biot number is a combination of the ratio of the thermal resistances and takes into account the time step. This number is a key factor that defines the nature of the interaction : a low thermal interaction when $Bi_{\nu} \leq 1$ and a strong thermal interaction when $Bi_{\nu} \geq 1$.

In the first case, unconditional stability of the coupling procedure, with no relaxation, can easily be ensured. The second case is inherently prone to instability, and a relaxation coupling coefficient is thus necessary. This is illustrated and confirmed via a test case, simple from a geometric point of view, but exhibiting complex thermal fluid-structure interactions. A CFD computation only, serves as a reference for establishing the performance of the CHT solutions.

An example of the convergence history is plotted in Figure 1 in terms of the coupling iterations for two relaxation parameters, in the case of a strong thermal interaction. An oscillatory behavior is observed when the convective heat transfer coefficient is employed. On the contrary, a fast convergence process is obtained with the optimal coefficient derived from the stability analysis.



This study shows that an interface treatment based on optimal coupling coefficients leads to the fastest convergence, both in the weak and strong interactions. Moreover, convergence is always oscillation-free. The theoretical results proposed in this paper can have the widest practicable effect in reducing the CPU time and in ensuring unconditional stability.

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