V International Conference on Computational Methods for Coupled Problems in Science and Engineering
COUPLED PROBLEMS 2013
S. Idelsohn, M. Papadrakakis and B. Schrefler (Eds)

STABILITY OF COUPLING METHODS FOR CONJUGATE HEAT TRANSFER

SEBASTIAN T. SCHOLL*, BART JANSSENS† AND TOM VERSTRAETE‡

* ‡Von Kármán Institute for Fluid Dynamics
Chaussée de Waterloo 72
1640 Rhode-St-Genèse, Belgium
* e-mail: sebastian.scholl@vki.ac.be, web page: www.vki.ac.be
‡ e-mail: tom.verstraete@vki.ac.be, web page: www.vki.ac.be

†Royal Military Academy
Renaissancelaan 30
1000 Brussels, Belgium
e-mail: bart.janssens@rma.ac.be - web page: www.rma.ac.be

Key words: Conjugate Heat Transfer, Coupled Problems, Computing Methods, Stability

Abstract. We suggest a novel approach for coupled computations of conjugate heat transfer, considering the exchange of the boundary conditions between fluid and solid solver. Within the multi-physics environment COOLFluiD 3, developed at the von Kármán Institute for Fluid Dynamics, we included four different coupling strategies. In all methods, boundary conditions are exchanged until equal temperatures and heat fluxes at the interface from the solid to the fluid domain. The first method sets a temperature distribution to the fluid solver that predicts a heat flux distribution imposed to the solid solver [2]. The second method sets a heat flux distribution to the fluid solver computing a temperature field for the solid [3]. A third method imposes a temperature field to the fluid returning a Robin boundary condition to the solid using the wall heat transfer equation [4]. Based on a stability analysis for the existing coupling procedures [5], we postulated a new method, imposing a heat flux distribution to the fluid solver that returns a Robin boundary condition to the solid solver [6]. The stability of all methods only depend on the dimensionless Biot number, the ratio of conductive to convective thermal resistance. For flat plate computations, the result of each method is in good agreement with an analytical solution. We compare the novel coupling strategy with the established methods. Considering the stability, the new approach is advantageous, especially for high Biot numbers. Further, it converges faster concluding that it can improve efficiency and accuracy of conjugate heat transfer computations.

1 INTRODUCTION

Many engineering design processes require to predict temperature distributions, e.g. the life of a turbine blade reduces by half with an increased metal temperature of 30 Kelvin [1]. In case of a complex flow field, the temperature prediction is improved if the fluid and solid temperature computations are coupled. Besides the need for two different solvers, the challenge arises through the different time scales in the solid and the fluid that can vary by orders of magnitude and increase the computational cost.

2 NUMERICAL METHOD AND COUPLING PROCEDURES

The flow equations are solved by means of the second order accurate Pressure Stabilized Petrov Galerkin Finite Element method with the Streamline Upwind Petrov Galerkin stabilization. The time is integrated with the Crank-Nicholson scheme, of second order accuracy. The convective terms are linearized in time. The solid conduction is solved with the steady state Finite Element Method.

2.1 EQUATIONS

The following example is a single line equation:

$$Ax = b \tag{1}$$

The next example is a multi-line equation:

$$\begin{aligned} Ax &= b \\ Ax &= b \end{aligned} \tag{2}$$

3 STABILITY

4 RESULTS AND DISCUSSION

5 CONCLUSIONS

6 ACKNOWLEDGEMENTS

The research leading to this results has received funding from the European's Comunnity's Seventh Framework Programme (FP7, 2007-2013), PEOPLE programme, under the grant agreement No. FP7-290042 (COPA-GT project).

REFERENCES

[1] J.-C. Han, S. Dutta and S. Ekkad, *Gas turbine heat transfer and cooling technology.* Taylor and Francis, 2001.

[2] J.A. Verdicchio, J.W. Chew and N.J. Hills, Coupled Fluid/Solid Heat Transfer Computation for Turbine Discs, ASME Paper No. 2001-GT-0205.

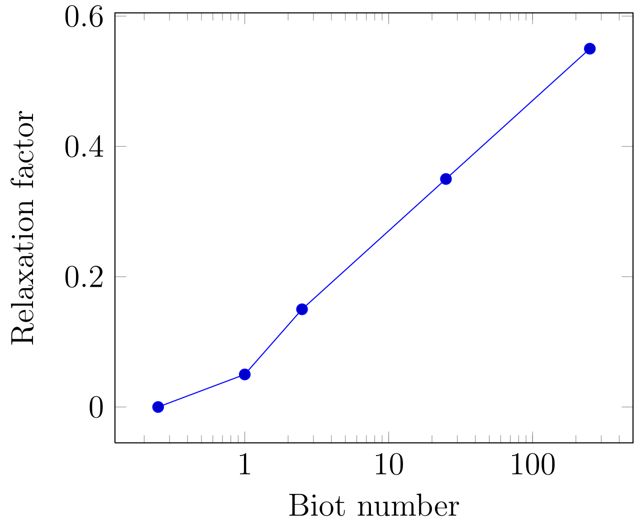

Figure 1: Relaxation needed as a function of the Biot number for the FFTB method and one Navier-Stokes solve per iteration. Biot number varied by means of the plate thickness.

[3] J.D. Heidemann, A.J. Kassab, E.A. Divo, F. Rodriguez and E. Steinthorsson, Conjugate Heat Transfer Effects on a Realistic Film-Cooled Turbine Vane. ASME TURBO EXPO, No.GT2033-38553.

[4] A. Montenay, L. Pat and J. Dubou, Conjugate Heat Transfer Analysis of an Engine Internal Cavity ASME Paper No. 2000-GT-282.

[5] T. Verstraete, Multidisciplinary Turbomachinery Component Optimization Considering Performance, Stress, and Internal Heat Transfer, PhD-Thesis, Universiteit Gent, 2008.

[6] T. Verstraete, Z. Alsalihi and R. A. Van den Braembussche, Numerical Study of the Heat Transfer in Micro Gas Turbines, J. of Turbomachinery, Vol. 129, pp. 835-841, 2007.

[7] Zienkiewicz, O.C. and Taylor, R.L. *The finite element method.* McGraw Hill, Vol. I., (1989), Vol. II., (1991).

[8] Idelsohn, S.R. and Oñate, E. Finite element and finite volumes. Two good friends. *Int. J. Num. Meth. Engng.* (1994) **37**:3323–3341.