An efficient finite-volume algorithm for fluid-structure thermo-mechanical analysis

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Abstract

It is a common practice to apply the finite volume method (FV) for the fluid flow computations and the finite element (FE) method for the structural analysis. Such traditional division of computational fields has been also kept by leading commercial software companies. Consequently, different industries are using STAR CD, Ansys Fluent, AVL FIRE™ etc., all finite volume codes, for the fluid flow and others like Abaqus, Nastran etc. are used for thermo-mechanical deformation and stress analysis (note also that some of these codes have FV-FE options for fluid-solid problems but this is still not in the widespread use). However, there are many attempts to apply the same methods for both, fluids and solids. This should be also beneficial for the industry as costs for different software licenses could be decreased and building users' knowhow in both fields could be avoided. Many companies assign fluid and solid calculation tasks even to different simulation teams and then the work between these teams must be coordinated as well. For example, after finishing fluid side, data is exchanged with another team that performs structural analysis and vice versa. Usually, such project workflow provides high quality results, but a project time needed to complete all tasks is often too long. Note that changing calculation setup on the fluid side would require repetitive calculations on the solid side etc. Therefore, this paper focuses on the finite volume method for both, fluid and solid, and proposes the practical and fast problem-solving approach for industrial fluid-solid applications.

There are number of papers which present applications of the finite volume method to structural analysis (Demirdzic and his co-authors 1993-1995, Jasak and Weller 2000, etc., the list of all relevant references will be given in the full paper). To identify possible advantages over the standard FV-FE approach for industrial applications, one should start by analyzing the meshing requirements. The tasks that should be preferably fulfilled on the meshing side are: a) the same meshing procedure / pre-processor on fluid and solid domains; b) no arbitrary interfaces between two domains (this means that cells are merged sharing the same faces) to obtain conserved and accurate energy calculations; c) an easy control of wall mesh layers on the fluid side in order to predict the heat transfer with the best available models; d) a high quality mesh cells especially on the solid side. We adopt here the polyhedral mesh which could satisfy all mentioned prerequisites (the same is also possible with tetrahedral meshes but having more cells than with poly meshes), see Figure 1a (calculation domains for the cooling of the cylinder head).

A basic discretization for all equations is done following the same principles (all will be provided in the full paper). Each equation is solved over separate domains depending if fluid or solid domains are considered, except the energy equation, which is calculated with the single common matrix for all domains. Some of the convergence acceleration steps made for fluid flow calculations are adopted for the solid as well (Basara, 2004). In addition, the gradients of all variables on the solid side are calculated following the recent work of Hahn et al. (2016) which provides more accurate solution. Calculations with the present algorithm can

be performed either in a steady-state or in a transient mode. The standard procedure would be that after some time steps or iterations, depending on the pre-defined setup, solid calculations are performed based on the calculated temperature fields (see Figure 1b for predicted streamlines). To make such kind of a 'snapshot' procedure, thermal effects on the solid are introduced with two additional forces, namely volumetric source and a surface force normal to the external boundary (following Duhamel's theorem). Figures 2a-b show predicted displacements and von Mises stress.

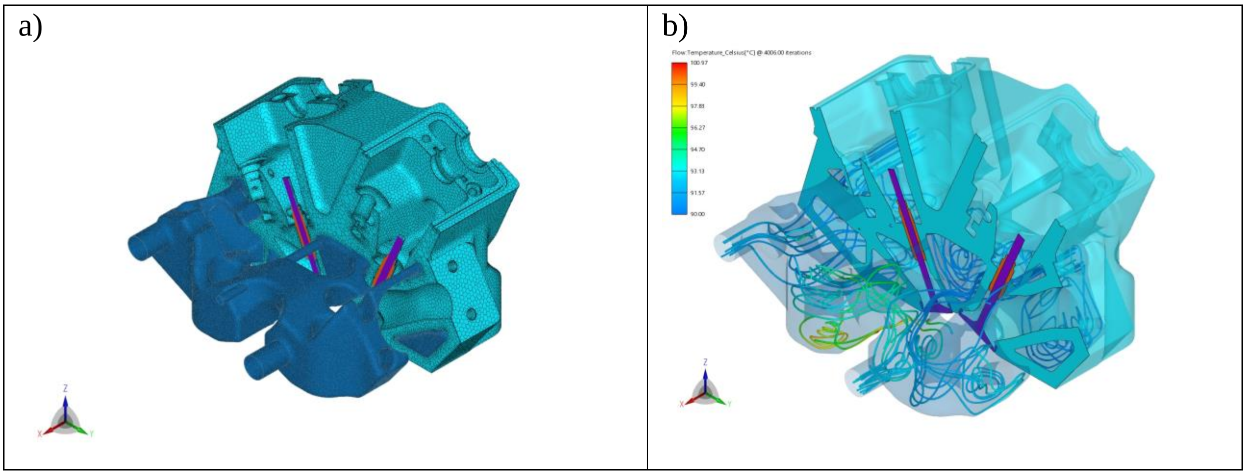

Figure 1. Parts of fluid domain (dark blue) and solid domain (light blue) (a) and predicted streamlines (b).

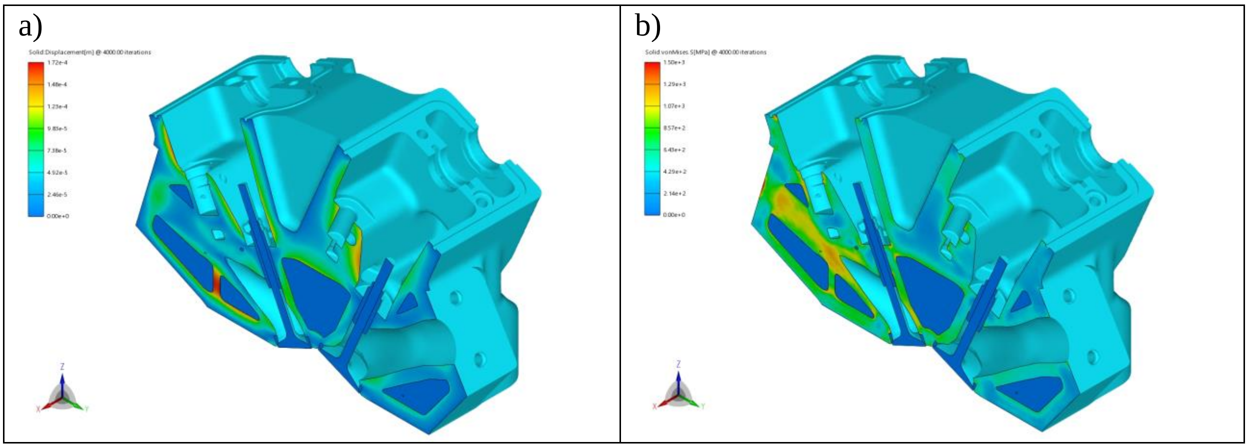

Figure 2. Predicted displacement and von Miss stress fields.

Present results for the industrial real-life case will demonstrate that the FV method for fluid-solid calculations can be successfully employed as a very simple tool, especially for CFD engineers that have no experience with structural analysis. After having performed parametric studies, the final project results can be always cross-checked with FE calculations, but the overall project time can be largely reduced.

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