Problem specification: Research project "Dimension-Coupling"

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Abstract

Coupling of one- and three-dimensional barotrop Euler equations with focus on inhomogeneous three-dimensional two-phase (liquid and vapor) flow in technical applications.

Keywords: 1D-/3D-Coupling, Euler-equations, three dimensional two-phase flow.

1 Introduction

For the computation of inhomogeneous three-dimensional two-phase (liquid and vapor) flow in technical applications, appropriate boundary conditions for 3D-CFD are needed. The common used boundary conditions are often simplified and thus insufficient to reproduce the dynamics of the fluid flow at the boundary. Another negative feature is the reflection of pressure waves at the outlet (and inlet) of the application, which superpose the fluid flow within the three-dimensional domain.

A Co-Simulation of 3D-CFD with 1D-hydraulic simulation, which is descripted by a one-dimensional model, has the aim to

- provide physical boundary conditions for 3D-CFD and
- not generate artificial pressure waves at boundaries of the three-dimensional domain, which are equal to Co-Simulation interfaces.

2 Codes to be coupled

The barotrop three-dimensional Euler-equations should be coupled with the barotrop one-dimensional Euler-equations by a Co-Simulation interface model. In this context barotop (isentopic flow) means the assumption that the entropy s is constant, the pressure is given by a function $p(\rho, T_0)$ with density ρ and temperature T_0, thus the energy-equation is negligible. The equations of the one-dimensional model are a restriction of the equations of the three-dimensional model. Therefore these homogeneous equilibrium models have the same father-model, equation of state and numerics and are deployed on structured hexahedral grids.

The three-dimensional barotop Euler equations

$$\frac{\partial \underline{u}_3}{\partial t} + \frac{\partial F_1\left(\underline{u}_3\right)}{\partial x} + \frac{\partial F_2\left(\underline{u}_3\right)}{\partial y} + \frac{\partial F_3\left(\underline{u}_3\right)}{\partial z} = 0 \tag{1}$$

with

$$\underline{u}_3 = \left(\rho, \rho u, \rho v, \rho w\right), \tag{2}$$

$$F_1(\underline{u}_3) = \left(\rho u, \rho u^2 + p(\rho, T_0), \rho uv, \rho uw\right), \tag{3}$$

$$F_2(\underline{u}_3) = \left(\rho v, \rho uv, \rho v^2 + p(\rho, T_0), \rho vw\right), \tag{4}$$

$$F_3(\underline{u}_3) = \left(\rho w, \rho uw, \rho uv, \rho w^2 + p(\rho, T_0)\right), \tag{5}$$

where u, v, w, ρ and $p(\rho, T_0)$ stands for the velocity in x, y and z-direction, density ρ and pressure $p(\rho, T_0)$. These variables depends on the space variables x, y and z and the time t, $\underline{u}_3 = \underline{u}_3(x, y, z, t)$.

The one-dimensional barotop Euler model is an restriction of the three dimensional Euler model

$$\frac{\partial \underline{u}_1}{\partial t} + \frac{\partial F\left(\underline{u}_1\right)}{\partial x} = 0 \tag{6}$$

with

$$\underline{u}_1 = \left(\rho, \rho u\right), \ F(\underline{u}_1) = \left(\rho u, \rho u^2 + p(\rho, T_0)\right). \tag{7}$$

These variables only depends on the one dimension in space x and the time t, $\underline{u}_1 = \underline{u}_1(x, t)$.

3 3D-1D-Interface model

An interface model for the Co-Simulation of the 1D- and 3D-Euler model (details of the models see section 2) must fulfill the following requirements:

- guarantee energy- and momentum- balance in the x-direction (if possible: mass-balance).
- provide suitable data to be exchanged through the interface,
- both codes stay unchanged in the coupling procedure, only different values at the Co-Simulation interface are used,
- transfer of inhomogeneous three-dimensional two-phase flow from a 3D- to a 1D-geometry and vice versa, without the generation of waves,
- stable numerics.

4 Reference-cases

In this section two reference-cases will be specified.

4.1 One-phase fluid flow with inhomogeneous inflow

A pipe is streamed from the left to the right with liquid fluid as depicted on the left of figure 1. As boundary conditions (BCs) at the inlet one-/two-/three-dimensional profiles of the velocities u, v and w and the pressure p are imposed (details see figure 1 on the right). The fluid lefts the pipe on the outlet. These profiles of the inhomogeneous inflow should completely be transferred over the interface.

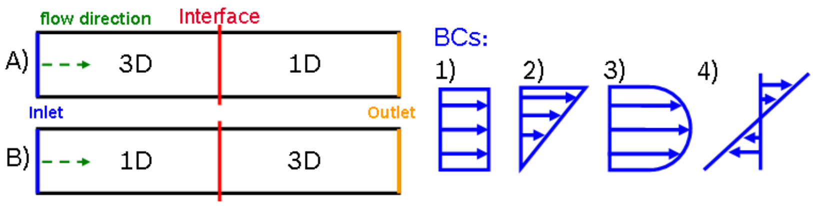

Figure 1: Geometry and boundary conditions for A) 3D-1D-Co-Simulation, B) 1D-3D-Co-Simulation with boundary conditions 1)-4) at the inlet.

4.2 Two-phase fluid flow: PREVERO

The PREVERO-Case (details see: [1] and on the left of figure 2) consists of a pipe as conduction (In), a 2D-planar throttle and a pipe (Out) which guides the fluid flow back to the reservoir. In the throttle, depending on the pressure p_{in} at the inlet and p_{out} at the outlet, inhomogeneous three-dimensional two-phase flow occure and pressure waves are omitted by the collapse of vapor bubbles. In the Co-Simulation model (details see on the right of figure 2) these pressure waves travel especially up- and downstream over the two Co-Simulation interfaces and should correctly be transferred by the interface model. Additionally the vapor bubbles must not condensate when passing the interfaces.

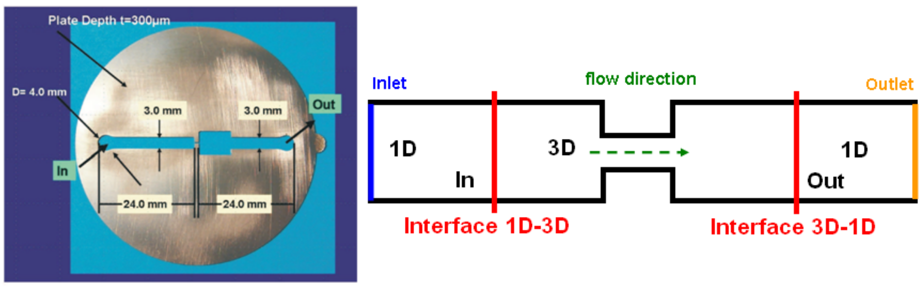

Figure 2: left: PREVERO-geometry[1]; right: PREVERO: setup of Co-Simulation

References

[1] Morozov A., Iben U.: Experimental Analysis and Simulation of Cavitating Throttle Flow, HEFAT2008, MA1.