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Large Eddy Simulation for high pressure flows: Model extension for compressible liquids

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ABSTRACT

The present study gives a general outline for the fluid-dynamical calculation of flows at high pressure conditions. The main idea is to present a mathematical description of high pressure processes in liquids at compressible conditions, quantifying the effect of density variations on the flow pattern due to those pressure variations. The improved mathematical approach is coupled to a Large Eddy Simulation (LES) solver. The main code was developed by OpenSource Ltd. for OpenFOAM, and the authors have introduced the additional expressions in order to calculate particular variables. For validating the code improvement, the LES solver is applied to a modern common-rail nozzle injector used in diesel engines. Results have been compared against other calculations that assumed constant properties and simultaneously validated with experimental data.

1. Introduction

The numerical approaches for solving the simplified Navier–Stokes equations for liquid flows are numerous. Most of the time, in the modelling of liquid flows at any pressure condition the density is considered as a constant. So far, this assumption was applicable for the majority of liquid flows present in the industry, where pressure and velocity values were moderate. Nevertheless, thanks to technical improvements, nowadays, it is possible to achieve very high pressure conditions that produce flows with increased velocity profiles [1]; in some cases the speed is so elevated that Mach numbers could reach values higher than 0.3, so the liquid flow could become compressible, depending on pressure and density changes relative to the local speed of sound [2]. Usually, this kind of flow involves significant changes in density. Moreover, many authors have confirmed that density is a property that increases with pressure, therefore, density will increase when pressure is higher [3].

Besides, the high velocity values of the flow induce turbulent regimes, complicating the physics and the mathematical description of these processes. Many problems of practical engineering interest, such as aerodynamics, combustion and acoustics demand the modelling of turbulent compressible flows, so it is becoming an important aspect for calculations enhancement.

So far, the modeling technique available for solving turbulent flows with a reasonable accuracy — cost ratio is the Large Eddy Simulation (LES). However, they are developed mainly for incompressible flows (ρ = constant). Current LES softwares are not able to resolve the aforementioned problem for turbulent liquids at compressible conditions (for moderate Mach numbers), for this reason, the aim of this work is to improve an LES solver, extending the mathematical description of high pressure processes in liquids, considering density as a variable. An existent incompressible LES code for liquids has been modified in order to consider the influence of variable liquid density in the solved conservation equations.

For validating the code improvement, the modified LES solver is applied to a specific industrial process, such as a modern common-rail nozzle injector used in diesel engines. Flow in diesel injection nozzles is characterized by high pressure drops

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