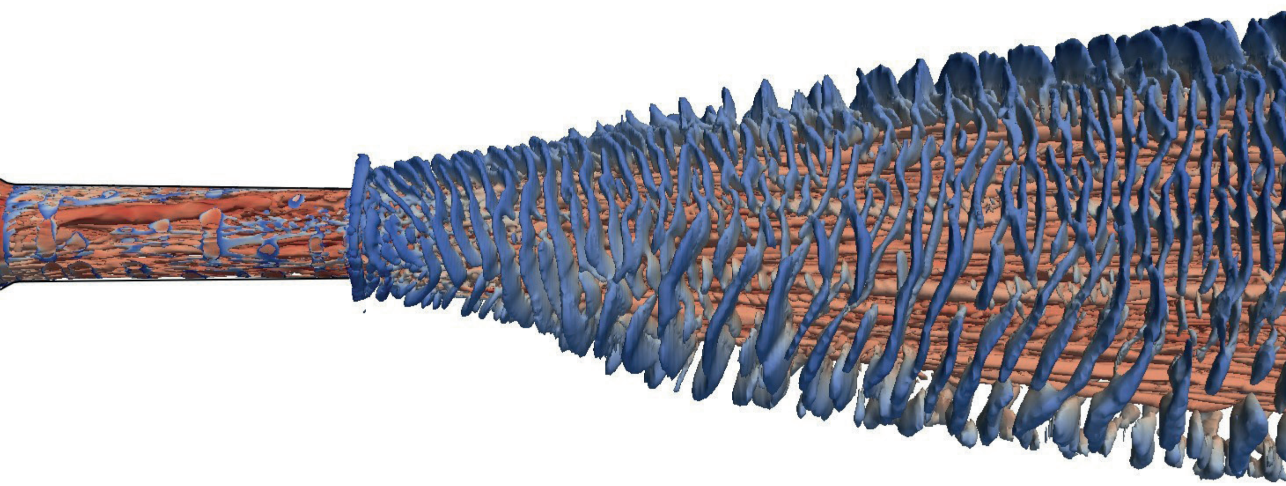
3D Flow Simulation for the Investigation of Cavitation and Its Relationship To Erosion, Turbulence and Primary Breakup in Hydraulic Components by Single-Fluid Multi-Phase Methods

Martin Blume



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Berichte aus der Strömungstechnik

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Abstract

3D single-fluid volume of fluid (VoF) CFD methods are assessed for cloud and string cavitation in hydraulic components. These aggressive cavitation types often induce erosion and are associated with turbulent structures, so that for high-pressure injection, they determine primary breakup behavior of the jet. Two single-fluid VoF methods, based on the homogeneous mixture approach, are tailored to investigate erosion and primary breakup in *OpenFOAM* and applied to three example test cases. A density-based flow solver with a thermodynamic equilibrium cavitation model captures shock wave dynamics in order to study erosion-sensitive wall zones. A pressure-based, three-phase flow solver has been developed for scale resolving turbulence simulation and direct resolution of primary ligaments, modeling cavitation and free surfaces in a single simulation with the VoF method by distinct numerical schemes and interface treatments. Erosion is analyzed either by a statistical evaluation of a multitude of single collapsing voids or by condensation rate statistics at wall cell faces, yielding an erosion probability.

Erosion-sensitive wall zones are investigated for cloud cavitation on a hydrofoil with circular leading edge. The shedding frequency is well predicted for different Reynolds and cavitation numbers. Erosion zones are identified in good agreement with experimental data and viscosity is shown to play a minor role for this application. A relationship between cavitation structures and erosion zones is demonstrated that enables a simple and approximate erosion assessment by 3D flow simulation without any erosion model.

The internal flow of heavy fuel oil (HFO) in two maritime high-pressure injector nozzles is studied for the assessment of erosion zones. Due to the high viscosity of real fuels, a viscosity variation is performed, yielding a higher flow aggressiveness for lower viscosity, while the location of erosion zones is barely affected. Erosion zones are evaluated separately for distinct sub-phases of the injection cycle, which enables the assignment of experimentally measured erosion zones to particular sub-phases.

Finally, cavitating in-nozzle flow and primary breakup are investigated for a ballistic injection cycle of a close-to-production, 9-hole Diesel injector. An agreement with the spray shape of experiments is obtained in the range of the cyclic fluctuations. By analysis of cavitation and turbulence structures, the highly unsteady flow field generated during the opening phase is revealed, which persists far into the closing phase.

The single-fluid VoF approach is efficient and capable of investigating a plethora of cavitating flow problems in hydraulic components as demonstrated by the three example test cases. However, possible enhancements of these methods are pointed out; e.g., more accurate turbulence and cavitation modeling by easing of the made assumptions.

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