

Abstract

The increasing interest in cryogenic centrifugal pumps for aerospace and aeronautical applications has intensified the need for reliable and computationally efficient modeling and optimization methodologies. In the space sector, electrically driven turbopump systems are enabling simplified feed architectures for small launchers, while in aeronautics the transition toward hydrogen-powered aircraft requires dedicated cryogenic pumping solutions. In this context, the present thesis addresses the modeling and optimization of cryogenic centrifugal pumps through numerical approaches characterized by different levels of fidelity. A first low-fidelity model, based on the Euler turbomachinery equation combined with empirical loss correlations, is applied to the preliminary optimization of an electrically driven liquid-oxygen pump for a hybrid rocket upper stage using a particle swarm optimization algorithm. This approach enables rapid exploration of the design space at negligible computational cost. Subsequently, CFD models with different spatial resolutions are developed and validated against experimental data for a two-stage submerged cryogenic pump provided by Vanzetti Engineering. A reduced-cost CFD model is then adopted as a design-oriented tool to guide the redesign of the pump diffuser. The resulting radial diffuser is experimentally tested on a cryogenic test rig using liquid nitrogen, confirming the performance improvement anticipated by the numerical analyses. Finally, the limitations of trial-and-error design strategies in guaranteeing global optimality are addressed through the development of a data-driven reduced-order modeling framework based on Proper Orthogonal Decomposition. Using high-fidelity CFD data, this approach is applied to the optimization of a cryogenic hydrogen pump for aeronautical applications, employing both gradient-based and genetic algorithms. This strategy enables the systematic identification of optimal geometric configurations with a reduced computational effort, while retaining the level of fidelity provided by CFD simulations.