DISSERTATION
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Efficient, stable, and reliable solvers for the steady incompressible Navier-Stokes equations in computational hemodynamics

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Abstract: In recent years, improvements in medical imaging and image-reconstruction algorithms have led to increased interest in the use of Computational Fluid Dynamics (CFD) as a clinical tool in hemodynamics. While such methods have long been employed in the design of medical devices and in basic medical research, many of the techniques commonly employed in these contexts are not ideal in the clinical setting. In particular, in clinical settings typically one is faced with more demanding turnaround times for simulations, less powerful computational resources, and noisy, incomplete, or missing data.

In this thesis, we discuss these challenges and introduce CFD methods which are more practical for direct clinical application. Frequently in these settings, the variable of interest is the temporal average of some time-periodic quantity, such as wall shear-stress, over a cardiac cycle. In these cases, the standard procedure is to perform an unsteady simulation over several cardiac cycles and then to take the time average of the last one. Here, we propose to instead surrogate the unsteady time-averaged solution with the solution of a steady-state problem, allowing us to compute it directly. This approach, if properly applied, can dramatically lower computational cost as we show here; however in many respects the steady problem is arguably more difficult numerically than its unsteady counterpart.

We will address these difficulties and propose effective workarounds. In particular, we aim to develop methods for steady solvers that are *efficient*, *stable*, and *reliable*. Roughly speaking, this work is divided into three parts, with each part focusing on one of these aspects. Concerning efficiency, we extend the inexact algebraic factorization approach popular for the unsteady problem into the steady setting. We will address the issue of stability by taking inspiration from nonlinear filtering techniques used in turbulence modeling to develop stabilization techniques for the steady problem. Finally, we will develop and validate methods for assigning boundary conditions in data-deficient settings while maintaining reliability. Throughout each section, we will provide both theoretical and numerical justification for our methods.

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