Preface

In the 70+ year history of control theory and engineering, few applications have stirred as much excitement as flow control. The same can probably be said for the general area of fluid mechanics with its much longer history of several centuries. This excitement is understandable and justified. Turbulence in fluid flows has been recognized as the last great unsolved problem of classical physics[1] and has driven the careers of many leading mathematicians of the 20th century.[2] Likewise, control theorists have hardly ever come across a problem this challenging.

The emergence of flow control as an attractive new field is owed to the breakthroughs in micro-electro-mechanical systems (MEMS) and other technologies for instrumenting fluid flows on extremely short length and time scales. The remaining missing ingredient for turning flow control into a practical tool is control algorithms with provable performance guarantees. This research monograph is the first book dedicated to this problem—systematic *feedback* design for fluid flows.

We are aware of the great interest in the topic among both control theorists, fluid mechanicists, and even mathematicians and physicists. This is why the book contains preliminaries to make its content accessible to graduate student level readers from all these fields. For the benefit of controls students we have included a self contained introduction on Navier-Stokes equations. To assist fluid dynamicists with control concepts, we have added an overview of some of the basics in linear and nonlinear control. To help non-engineers we have provided some elementary information on the current sensor/actuator/MEMS technology.

[1] A statement attributed to, among others, Einstein and Feynman, albeit undocumented [68].

[2] Well posedness of 3D Navier-Stokes partial differential equations with large initial data and high Reynolds number remains an open problem.

The scope of efforts in flow control is extremely broad. Control engineers are typically used to stabilization/regulation/tracking/disturbance attenuation problems where the quantity being minimized is well defined. In flow control one finds both such problems and the problems that are exactly opposite—where one has the task of destabilizing the system. Mixing of fluids is such a problem. Mixing is achieved by generating turbulence and is beneficial in several applications: fuel/air mixing in combustion, noise and infrared signature reduction at jet engine exhaust, and mixing of reactants in chemical process industry. This monograph dedicates a substantial portion to control of mixing and pioneers feedback concepts in this traditionally open-loop area. Both stabilization and destabilization, i.e., both relaminarization and turbulence enhancement, are treated in the book in a unified way.

While we give our own results in more detail than the results that precede them, the book is fairly complete in surveying the principal feedback algorithms for flow control available at present time.[3] An instructor can therefore use the book as a text in a stand-alone course on flow control, or as a supplemental text in courses on fluid dynamics or control of infinite dimensional systems.

The core of the book are Chapters 4 and 5. The lengthy Chapter 4 covers stabilization techniques, including linear optimal control results for discretized models, Lyapunov results for full Navier-Stokes models, and some backstepping results. Chapter 5 covers mixing control techniques, including approaches inspired by dynamical systems theory and Lyapunov-based inverse optimal approaches. The range of geometries covered includes 2D and 3D channel flow, pipe flow, and bluff body (cylinder) flow.

The material based on the first author's dissertation work are Section 4.3 (except Sections 4.3.2 and 4.3.3), Section 4.4, and Sections 5.2–5.4.

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[3] We specifically do not cover the results on controllability of Navier-Stokes equations (Fursikov, Imanuvilov, Coron, etc.). These are open-loop mathematical existence results of great significance but are not in a form implementable numerically or experimentally.

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