Research strategy for
Flow control and optimization

Introduction

A new challenge for fluid dynamics research is to take the step from analyzing and predicting the flow field to actively controlling it. In many fluid-mechanics systems, significant variations of global flow parameters may be achieved by local perturbations using devices sensing and acting on some critically chosen parts of the flow, the process often requiring small amounts of energy. Such control devices can be used to obtain drag reduction on bodies, increased lift on wings, increased propulsion efficiency, heat- and mass transfer reduction or enhancement, control of combustion instabilities, and control of the generation of sound. The activity within flow control is focusing in three different directions: feedback control of boundary layer instabilities, optimization with applications for hybrid and laminar flow control and passive control.

Feedback Control. Our group has been among the first to pursue the combination of large-scale computations and control theory, thus going past early attempts of flow control based on a trial-and-error basis. A linear model-based feedback control approach, that minimizes an objective function that measures the perturbation energy, can be formulated based on the linearized perturbation. Currently, focus is put on model reduction in order to extend the control to more complex configurations.

Optimization. Relevant efforts worldwide aim to develop tools to identify disturbances the flow is most sensitive to and to use this knowledge to manipulate the flow to our advantage. While developing new theoretical tools, we apply our knowledge to establish a laminar boundary layer on the surface of a wing. In Natural Laminar Flow (NLF) design, the shape of a wing is designed such that the growth of disturbances inside the boundary layer is reduced. In Hybrid Laminar Flow Control (HLFC) the boundary layer is instead stabilized by means of suction at the wall. We have been the first group to apply optimal control ideas to this problem.

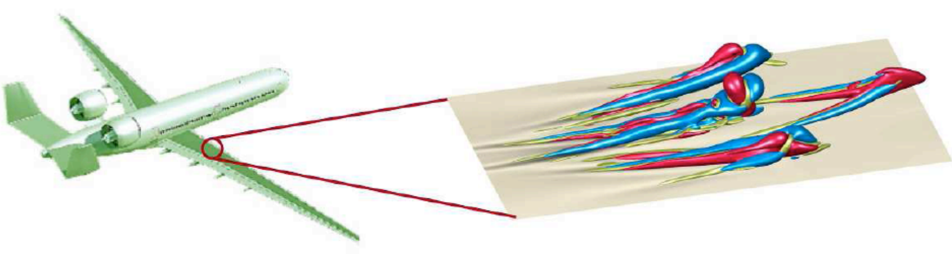

Figure 1. Left: Airbus led FP6 EU-project NACRE (New Aircraft Concepts REsearch) PROGreen environmental concept aircraft. Right: typical transitional flow structures inside boundary layer with suction.

Open-loop control. Strategies for efficient open-loop control based on physical understanding of flow phenomena are also developed. Separation of the boundary layer forming around bluff bodies is one of the most complicated problems in fluid mechanics. From a control viewpoint, it is of interest to reduce or suppress the region of separated flow in order to reduce drag. Passive, e.g. open-loop approaches not requiring any energy input, and active control have been shown to work since the sixties by increasing the mixing in the flow. However, the progresses in numerical and experimental techniques enable now to understand and further develop such methods. Open-loop control of transition to turbulence is also investigated.

Research environment

The activity in flow control at FLOW is still closely related to the research on stability and transition, even though new directions are also taken. Initially, the control studies have been aimed at the instabilities and transition scenarios successfully investigated in the last decade, whereas current efforts also include turbulent and separating flows. A list of the people currently involved in the control research is as follows.

Project titles	PhD stud. Postdoc	Senior researcher	Proj. Start	Sponsor
Feed-back control				
Feedback control of spatially developing flows 2	Semeraro	Henningson Brandt	10/2008	VR
Using global modes for transition analysis and control	Bagheri	Henningson	2/2006	VR
Reduced-order models for flow control	Ilak	Henningson	11/2009	FLOW
Optimization and Laminar flow control				
OPTLAM: optimization for laminar wings	Amoignon Pralits	Henningson Hanifi	1/2010	EU, KTH
Control and Optimization of transitional flows	Monokrousos	Henningson Brandt	2/2007	FLOW
Sensitivity and optimization for passive control		Brandt	2006	KTH
Open-loop control				
Transition delay by passive mechanisms		Fransson Talamelli/Brandt	2006	KTH
Vortex generators and control of turbulence	von Stillfried	Wallin Johansson	2007	Airbus
Vortex Generators and turbulent boundary layer separation control	Lögdberg	Alfredsson Fransson	9/2004	Scania

A list of the projects concluded reads as follows.

Project titles	PhD stud. Postdoc	Senior researcher	Proj. end	Sponsor
Feedback control of spatially developing flows	Åkervik	Henningson Brandt	12/2008	VR
SUPERTRAC	Pralits Chevalier	Henningson Hanifi	2009	EU, KTH
NACRE		Hanifi	2009	EU, KTH

Overall Research Goals

The long term goals of the Flow centre within flow control are

- To apply successful feedback control laws calculated from reduced-order models, e.g. in order to extend laminar flow regions in transition experiments.
- To apply optimal flow design in a wide variety of areas, enabling new innovative designs in aerodynamics and aero-acoustics, e.g. aimed at noise reduction.
- Examine efficiency of open-loop control for transition and turbulent separation. Develop tools to reliably investigate the implication of active control in turbulent flows of industrial interest.

In the roadmap below, a detailed description of the short-term work is reported for the three areas identified above.

Roadmap

Feedback control. To develop the theory and tools to apply feedback control for flows in complex geometries, we plan

- To improve model reduction to significantly decrease the cost of the estimation and thus of the computation of online control. Different approaches based on global modes are investigated, e.g. balanced truncation. The feasibility of the approach is investigated for nonlinear problems.
- Apply control based on localized arrays of sensors and actuators, in order to better reproduce feasible experiments.
- Use global modes, e.g. Koopman modes, to investigate transition in complex geometries.

International collaborators in this area are Prof. Peter Schmid in LadHyX, Ecole Polytechnique and Prof. Rowley in Princeton.

Optimization. The short-term goals in this area are
- Apply optimization theory for flow and shape design in aeronautics. Our knowledge in is used in several EU-projects to design suction distributions and wing shapes for the new environmental concept aircraft.

Flow Control and Optimization

- Use tools from optimization and control theory to determine optimal (most dangerous) disturbances for flows in complex geometries, e.g. vortical disturbances impinging on leading edge of a wing.
- Analyze different types of unstable flows (bluff-body wakes and boundary layers) and use sensitivity analysis to determine the type of disturbance that has larger impact on the flow stability via modifications of the base flow.

Coworkers in optimization and laminar flow control are Prof. Sipp and Dr. Marquet at ONERA, France; Prof. Luchini, Dr. Pralits and Dr. Giannetti, University of Salerno.

Separation Control. The short-term goals in this area are

- The aim is to find efficient and robust active vortex generators that minimize the penalty drag.
- To model the effect of vortex generators and synthetic jets into CFD computations.
- To experimentally study active and passive control in order to suppress vortex shedding downstream of bluff bodies.
- To carry out new experiments and computations on laminar-turbulent transition delay by means of passive mechanisms. The study will consider both the generation of the spanwise modulations responsible for the observed delay and extensions of the proposed approach.

International collaborator in this area is Prof. Talamelli, University of Bologna.