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PROPOSITION DE SUJET DE THESE

Intitulé : Drag reduction of a supersonic turbulent boundary layer through reactive control

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(à rappeler dans toute correspondance)

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Mots clés

Supersonic, reactive control, turbulence, drag reduction, DNS

Profil et compétences recherchées

CFD, Automatic, Turbulence, Compressible Fluid Dynamics

Présentation du projet doctoral, contexte et objectif

Turbulent boundary layer leads to important wall friction penalizing aircraft drag. At high speeds, the generated heat is significant and becomes a major concern for the design of supersonic/hypersonic vehicles. Hence, limiting both skin friction and heat flux via control action appears to be a pivotal aspect for new supersonic/hypersonic vehicle design.

Friction reduction strategies in supersonic regimes have often relied on passive control methods [1] or predetermined active strategies [2], which may be less effective and robust in response to changing operating conditions compared to reactive control strategies that continuously adjust control actions based on real-time measurements. The few supersonic studies using reactive control aim to reduce friction by delaying the transition to turbulence in the boundary layer [3,4].

However, detecting the instabilities that lead to turbulence can be challenging in experimental or flight conditions, since these instabilities have very low amplitudes compared to the upstream flow (less than 1%). To overcome this difficulty, one solution is to reduce the friction of an already turbulent boundary layer (where fluctuations around the mean flow are on the order of several tens of percent).

Reducing the friction of a turbulent boundary layer has already been achieved in incompressible flows [5,6,7,8] using classical linear tools from reactive control theory, even though the dynamics of a turbulent boundary layer are inherently nonlinear. Indeed, by manipulating only the near-wall turbulent structures—whose key self-sustaining processes are linear [9,10]—it is possible to achieve drag reduction. However, these studies relied on approaches such as inverse feedforward controllers [7], proportional derivatives [5,6], or LQG [11], which are far from optimal in terms of performance or robustness. Modern multi-criteria and multi-objective synthesis methods [3,4], which appear promising for cases like turbulent boundary layers, do not seem to have been used.

The goal of this exclusively numerical thesis, at the intersection of fluid mechanics and reactive control theory, is to use a network of sensors and actuators controlled by a controller designed with multicriteria synthesis methods to mitigate the turbulent structures developing in a supersonic turbulent boundary layer, thereby reducing friction.

Implementing closed-loop control of the supersonic turbulent boundary layer, based on a MIMO (Multiple Input Multiple Output) architecture, will first involve determining wall-mounted sensors capable of providing information strongly correlated with the turbulent structures we aim to mitigate [12]. We will also study the response that actuators must produce within the flow (such as generating streamwise vortices) to ensure optimal control. Once the control system is defined, reduced-order models of the flow will be identified using data-driven methods to synthesize control laws. The energy efficiency, robustness of the method (against uncertainties and changes in Re_τ), and the impact of control actions on turbulent structures will be analysed. To prevent a drop-in drag reduction performance with increasing Re_τ [13,14]—linked to the growing influence of large-scale outer structures in the logarithmic layer on near-wall turbulence [15,16]—multiple sensor/actuator/controller triplets could be considered to address both small-scale near-wall turbulent structures and large-scale, low-frequency vortices [17].

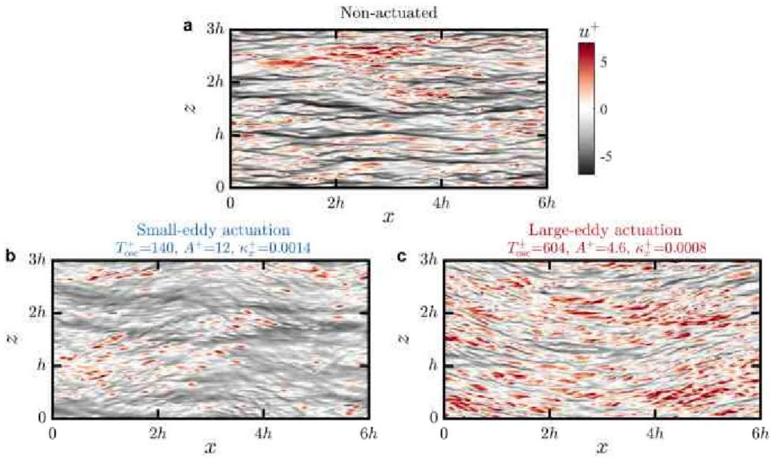

Figure 1: Visualizations of near-wall turbulence illustrating the effects of actuation at low Re_τ [17].

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Collaborations envisagées

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