Flow Instability and Control Group: Introduction

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Background:

- Flow instability is good...
  - Seeds new possibilities
  - Enhances mixing (efficient combustion, washes away pollution)
  - Promotes turbulence (robust macroscopic outcomes)
- But, some times laminar flow is desired...
  - Lower friction drag
  - Lower convective heat-transfer
  - Controlled kinetics (nano-synthesis, coatings, ..)

Research Issues:

- Instabilities in complex flows (multi-physics)
  - Stability of 2D/3D base flows--very large linear/nonlinear Eigenvalue problems
  - Low-order dynamics in complex/turbulent flows
  - Transition prediction including receptivity pathways (free-stream turbulence, roughness, ...)
  - Theory - nonlinear dynamics (open flows)
- Control of Instability
  - Reshape the flow properties (mixing, separation, noise, ...)
  - Preserve laminar flow (control of transition)
  - Model reduction for prediction and control

Laminar flow wing for supersonic transport  Aerodynamic heating in hypersonic vehicle  Biomimetic drag reduction
Flow Instability and Control Group: Introduction

At present: 4 projects

**Reduced-order model of near-wall dynamics with implications to wall-models**
Taraneh Sayadi, Peter Schmid
Curtis Hamman (host)
Data analysis, control-oriented modeling
Enable simulation of high-Re flows

**Structural Changes to a Turbulent Boundary Layer Grazing a Compliant Panel**
Daniel Bodony
Data analysis and flow physics
Technology for high-speed vehicles

**DNS of Laminar-Turbulent Transition in Swept-Wing Boundary Layers**
Lian Duan, Meelan Choudhari
Sanjiva Lele (host)
Data analysis, flow physics, transition pathways
Technology for low drag high-speed vehicles

**Passive Flow Control in Transonic Turbulent Boundary Layers with Impedance Boundary Conditions**
Carlo Scalo, Julien Bodart, Sanjiva Lele and Laurent Joly
Data analysis, flow physics, instability modeling
Separation control - increased operability
Reduced-order model for near-wall dynamics with implications to wall models
T. Sayadi (Imperial College London), P.J. Schmid (Imperial College London), Curtis W. Hamman

Background
- DNS/LES limited applicability for high Reynolds number flow
- Wall-modeled LES
  - TBLE near the wall (e.g. LES/RANS)
  - …

Research Issue
- Link between bulk quantities and Reynolds stresses at a virtual layer near the wall
- Formulation of a low-dimensional model based on coherent structures
- Relation of coherent structures to dominant resolvent and dynamic modes
- Use of Re-dependencies to accomplish validity across Re-ranges
- Revisit of LES near-wall models in light of this approach

Research Approach and Methods
- DNS of compressible boundary layer to identify and extract relevant near-wall structures
- Sparsity-promoting dynamic mode and triple decomposition to design low-dimensional representation of near-wall dynamics
- Transfer-function framework between first- and second moments (model-based)
- System identification techniques (data-based)

Expected Outcome
- New insight into reduced-order near-wall dynamics
- Basis for the design and improvement of wall models for LES
- Validation across a range of wall-bounded high-Reynolds number shear flows
DNS of Laminar-Turbulent Transition in Swept-Wing Boundary Layers
Lian Duan, Missouri University of Science and Technology
Meelan Choudhari, NASA Langley Research Center
CTR-Host: Sanjiva Lele

Background

- Laminar flow technology for swept wings can yield significant reductions in net fuel burn.
- Crossflow instability and subsequent onset of high frequency secondary instabilities provides an important mechanism for swept wing transition.

Research Issue

- Which of the multiple families of secondary instability modes can lead to transition?
- What are the associated laminar breakdown mechanisms?
- What is the effect of the remnants of crossflow vortices on turbulent skin friction?

Research Approach and Methods

- DNS of laminar breakdown due to secondary instability of stationary crossflow vortices in a realistic swept-airfoil configuration
- Comparison of predictions based on secondary instability theory, nonlinear parabolized stability equations, and the DNS.

Expected Outcome

- Refined DNS dataset of crossflow induced transition including 3D turbulent boundary layer
- Deeper understanding of transition scenarios for swept-wing boundary layers, including the issues of mode selection from competing instability mechanisms, nonlinear interactions between primary and secondary instabilities of different types, and the resulting laminar breakdown mechanisms.
- Guidance for other ongoing investigations related to crossflow transition over high-speed configurations (cones and other slender body configurations).
Structural Changes to a Turbulent BL Grazing a Compliant Panel
Daniel J. Bodony, University of Illinois at Urbana-Champaign.

Background
- Future reusable hypersonic vehicles will severely weight-constrained and cannot be assumed to be rigid.
- Current aircraft design methods do not account for fluid-structural coupling, leading to increased design conservatism and weight.
- There is insufficient experimental capability to reliably measure transition and turbulence over fully compliant surfaces.

Research Issue
- Question: how and why does a turbulent boundary layer change when flowing over a dynamically-compliant surface?

Research Approach and Methods
- Analysis of existing DNS databases of Mach 2.25 ZPGTBL with rigid and compliant surfaces
- Develop “predictive” models using
  - RDT on transversely sheared mean flow
  - Driven acoustic problem about uniform mean flow

Expected Outcome
- Quantification of ZPGTBL modification by a compliant surface, primarily through Reynolds stresses
- Develop a predictive model that explains and quantifies the modification, if possible
- Identify refined objectives for planned future DNS of high-speed transitional and turbulent ZPG boundary layers
Passive flow control in compressible turbulent boundary layers with impedance boundary conditions

Carlo Scalo (Stanford), Julien Bodart, Laurent Joly (ISAE, France), Sanjiva K. Lele (Stanford)

Background
- Low-speed TBL interacting with porous walls, wavy walls, roughness (Jimenez, von Rohr, Henn)
- Modeling of acoustic liners well established via Impedance Boundary Conditions (IBC)

Research Issue
- Develop passive flow control strategies for compressible TBLs
- Coupling between Navier-Stokes solvers (time-domain) and IBC (frequency domain)

Research Approach and Methods
- Fundamental setup: turbulent channel flow
- High-fidelity simulations (LES/DNS) using CharLES

Expected Outcome
- Reproduce semi-analytical solutions for broadband signals interacting with IBCs
- Identify set of dimensionless parameters (multiple d.f. in IBCs & flow) for scaling study
- Identify physical processes involved in the interaction of TBL with IBCs