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PhD THESIS PROPOSAL

Title: Numerical study of hypersonic laminar boundary layers over smooth and porous walls

Reference: **MFE-DMPE-2021-03**
(to be included in any correspondence)

Thesis start: October 2021	**Deadline for application:** open until filled

Keywords

Laminar-turbulent transition, hypersonic flows, direct numerical simulations, stability analysis.

Applicant profile

Applications are invited from candidates with (or who expect to gain) a degree in physical sciences, engineering or applied mathematics. A first-hand experience with numerical methods and fluid mechanics is required. Applicants should have an interest in modeling and in physical understanding of complex flow phenomena.

Project description

Vehicles traveling at hypersonic speeds, *i.e.* above Mach 5, have received increasing attention over the last few years. Strategic reasons drive several nations towards tackling key challenges related to this flow regime. Modeling transition from laminar to turbulent flow over smooth and porous walls is one of them. Indeed, since laminar and turbulent boundary layers cause drastically different momentum and heat transfer rates, an accurate prediction of the transition onset entails high performance gains compared to conservative designs based on all-turbulent flow. Inherent to the hypersonic regime is the fact that additional mechanisms trigger - or delay - transition, while the high temperatures encountered call for a precise design of thermal shields. On the modeling side, real gas effects need to be accounted for.

When the flow speed at the boundary layer edge reaches approximately Mach 4, the transition to turbulence is governed by the spatio-temporal amplification of acoustic instabilities. The latter are trapped between the wall and the sonic line within the boundary layer, making them highly sensitive to the wall acoustic impedance. Experiments have shown that a porous coating on the wall can stabilize the predominant wave - the secondary Mack instability - and shift the transition onset further downstream. This stabilizing effect has also been reported in studies based on direct numerical simulations (DNS). One such study was carried out in our team at ONERA, using the compressible flow solver JAGUAR: a spectral-difference code developed jointly with the CERFACS laboratory for running on high-performance computing platforms. A special type of boundary condition was used to reproduce the presence of the porous coating, the so-called time-domain impedance boundary condition. Stability analyses have also been applied to the flow fields obtained by DNS, confirming the stabilizing effect of the porous coating against the secondary Mack instability.

The PhD project will follow up on these recent efforts. Two aspects will be considered for further study by means of numerical and theoretical work. First, studying the impact of wall temperature on the transition process with and without a porous coating. The expected results, obtained by combining numerical simulations and stability analyses, will be complementary to ongoing work at ONERA on transition models calibrated with high-fidelity simulations of hypersonic flows. Second, recent work on automatic differentiation applied to JAGUAR has shown the feasibility of accurate gradient computations of generic outputs from the DNS code. The approach will be explored to find optimal acoustic parameters defining a porous coating aimed at stabilizing target disturbance frequencies.

Expected interactions

The project will benefit from ongoing collaborative work between ONERA and members from the NATO AVT-346 group working on hypersonic transition. JAGUAR is developed jointly with the CERFACS lab.

Host laboratory at ONERA	**Thesis advisor**
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