Effect of the Acoustic Black Hole on the turbulence transition of a laminar boundary layer flow over a compliant panel

The boundary layer flow transition to turbulence in a low-noise environment takes place through the linear development of the fluid based on the 2D Tollmien-Schlichting waves (TSWs). This first stage of the transition is significantly longer than the later stages of the nonlinear development of the 2D and 3D waves and turbulent spots. The use of a compliant wall with proper structural properties can significantly extend the linear development of the convectively unstable 2D TSWs before entering to the next stage of the transition by reducing their spatial amplification rate [1,2]. In this way, the laminar boundary layer flow can be extended for a larger total length relative to the rigid wall with the concomitant significant reduction of the skin-friction drag. However, the compliant wall as a bear wave medium supports wall based instabilities as the Static Divergence (SD) [3] and the traveling wave flutter (TWF) [4] which diminish the compliant wall effectiveness to maintain laminar boundary layer, advancing the transition to turbulence. For an infinite length compliant wall, the TWF is a convective instability with a wave amplifying only as it propagates away from the initiating source of disturbance and can be stabilized by both the structural damping and stiffness. However, the excessive increase of the structural damping must be avoided because it has a destabilizing effect on the TSW instabilities, increasing their spatial amplification rate [4]. The SD is considered an absolute instability because the wave grows in time at all spatial locations of the domain. It can be effectively stabilized by an increase of the compliant wall stiffness [3].

Recently, it was demonstrated that for a finite length compliant wall the TWF and TSW instabilities become globally unstable and the flexural waves travel and grow along the whole finite length of the compliant wall because of their reflection at the compliant wall ends [5,6]. This could have a deleterious effect on the delay of the turbulence transition which could take place earlier than the rigid wall case. This project will investigate the Acoustic Black Hole (ABH) as means for diminishing the amplification and reflection of the TWF and TS waves at the compliant wall ends, maintaining their convecting nature and contributing to the optimization of the compliant wall for transition delay. The project will involve the analytical modeling of the ABH combined with the compliant wall properties tailored for boundary layer transition delay, the global stability analysis of the FSI system and numerical simulations with Ansys Fluent.

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2. Carpenter, P. W., Davies, C. & Lucey, A. D. 2001 Does the dolphin have a secret? Current Science 79, 758–765.
3. Lucey, A. D. & Carpenter, P. W. 1992 A numerical simulation of the interaction of a compliant wall and inviscid flow. Journal of Fluid Mechanics 234, 121–146
4. Carpenter, P. W. & Garrad, A. D. 1986 The hydrodynamics stability of flow over kramer-type compliant surfaces. part 2. flow-induced surface instabilities. Journal of Fluid Mechanics 170, 199–232.

5. Tsigklifis, K. & Lucey, A. D. 2017 The interaction of Blasius boundary-layer flow with a compliant panel: global, local and transient analyses. J. Fluid Mech. 827, 155–193.
6. Pfister, J. L., Fabbiane, N. & Marquet, O. 2022 Global stability and resolvent analyses of laminar boundary-layer flow interacting with viscoelastic patches J. Fluid Mech. 937, 1–41.

Project Milestones

Milestone 1

The candidate will develop a theoretical and a numerical model to investigate the effect of the ABH concept on the wall and flow-based instabilities of a finite length compliant wall.

Milestone 2

The optimisation of the properties of the compliant wall and of the ABH will be attempted to maximise the drag reduction. The compliant wall-ABH (panel) system could be extended to multi-panels in a row, each panel tailored to the local properties of the boundary layer.

Milestone 3

The experimental study of an optimized scaled model will prove the efficiency of the proposed FSI system(compliant wall - ABH) in reducing the platform/lifting surface drag.

Milestone 4

A theoretical and experimental study should also be conducted to quantify the reduction of acoustic radiation from the proposed FSI system.