Stability of cavity flows at high Reynolds numbers

Department: Aerodynamics, Energetics and Propulsion Department

JOB DESCRIPTION:

The control of cavity flows has been a topic of interest for many years as evidenced by review articles published in the early 2000s (Cattafesta et al, 2003; Rowley & Williams, 2006). Recently published work shows that the interest is still relevant (Prudhomme et al, 2021; Luo et al, 2018; Liu & Gómez, 2019; Ohmichi & Yamada, 2021). The recent test campaign by Prudhomme et al (2021) to characterise the response of the cavity flow to passive control systems (rod perpendicular to the main flow direction or sawtooth spoiler) in transonic flight conditions (M = 0.9 and M = 1.1) clearly indicates the need to characterise the flow dynamics for these high speed regimes. This type of passive control is still preferred because of its simplicity of implementation for aeronautical applications compared to active systems for which the need for a power source is often a difficulty for an on-board solution. Beyond the classical passive control systems tested by Prudhomme et al (2021), the modification of the rear shape of the cavity is a promising avenue for the suppression of oscillations via the modification of the aeroacoustic properties of the cavity (Luo et al, 2018; Liu & Gómez, 2019).

The design of these control systems requires a preliminary characterisation of the flow dynamics to quantify its receptivity to external perturbations and to identify the regions of sensitivity where the positioning of a control system will be most effective (Ohmichi & Yamada, 2021). The global stability analysis of the adjoint Navier–Stokes system allows this characterisation and the application of this type of approach to cavity flow is still largely confined to two-dimensional cavity configurations for which the three-dimensional perturbations are assumed to be periodic in the transverse direction (Brès & Colonius, 2008; , Sun et al(2017; Theofilis, 2017). This limitation to bi-global stability analyses is often dictated by the prohibitive numerical cost of fully three-dimensional configurations, especially when the linearised equations are solved explicitly by the solver. The recent study by Ohmichi & Yamada (2021) is the first and only three-global stability analysis of cavity flow to date. The approach used is based on time-stepping methods which allow to get rid of the explicit calculation of the linear operator and are thus well adapted to very large problems (Tesuka & Suski, 2006; Rolandi et al, 2021). Nevertheless, this study is conducted on a low Reynolds number flow regime (Re = 1500) in a compressible subsonic regime (M = 0.6). The need to extend this type of analysis to higher Reynolds numbers and in the transonic regime therefore remains.

The extension of this stability analysis to higher Reynolds numbers implies to take into account the turbulent nature of the upstream boundary layer flow and to carefully consider the response of the cavity to these continuous external perturbations. Recent studies based on numerical simulations of the LES type (Boujo et al, 2018; Liu & Gaitonde, 2021) have addressed this problem of forcing the cavity by the turbulent boundary layer at high Reynolds numbers (Re = 150 000 and Re = 10 000 respectively) but they only consider a two-dimensional approach.

MISSION:

The present Postdoctoral study therefore aims to address the problem of characterising the linear dynamics of cavities in response to external perturbations in a three-dimensional configuration for turbulent flow regimes at high Reynolds numbers and for Mach numbers up to the transonic regime. The study will be carried out by means of a linear stability analysis based on direct and adjoint Navier–Stokes systems to characterise the receptivity and sensitivity of the cavity flow with a view to controlling the oscillations of the sheared layer, whether self-sustained or forced directly by the turbulent boundary layer. In particular, the influence of the geometry of the rear face of the cavity (slanted rear wall, rounded rear edge…) will be considered in order to modify its aeroacoustic properties and suppress the acoustic excitation leading to the oscillations of the sheared layer. This work will be performed with the numerical solver IC3, a high-order compact compressible code developed at ISAE-SUPAERO.

The project is scheduled as follow:

1. Implementation and validation of the linearised adjoint equations in IC3.

2. Stability analysis of the cavity flow in weakly compressible regime (up to M = 0.5): 3D laminar flow, 2D and 3D turbulent regime. 2

3. Stability analysis of the cavity flow in transonic and low supersonic regimes (M ∈ [0.8; 1.2]): 3D laminar flow, 2D and 3D turbulent regime.

REQUIRED PROFILE:

This project is funded by the French Ministry of Defence through financial support of the Agence Innovation Défense and therefore only candidate with European citizenship can apply. The candidate has a PhD with a strong background in stability analysis of fluid flows and/or CFD. Coding skills (Python and C++) are expected. Oral and writing skill in English is mandatory.

DURATION: 12 to 24 months

LOCATION: : ISAE-SUPAERO, 10 avenue Edouard Belin – BP 54032, 31055 Toulouse Cedex 4, France

RESPONSIBLE OF THE SUBJECT:

Dr J. Fontane, jerome.fontane@isae-supaero.fr
Dr J. Gressier, jeremie.gressier@isae-supaero.fr
Dr T. Jardin, thierry.jardin@isae-supaero.fr

APPLICATION PROCESS:

Please send a cover letter, a CV, a list of relevant publications as well as recommendation letters to jerome.fontane@isae-supaero.fr.

REFERENCES:

Brès, G. & Colonius, T. 2008 Three-dimensional instabilities in compressible flow over open cavities. Journal of Fluid Mechanics 599, 309–339.

Boujo, E., Bauerheim, M. & Noiray, N. 2018 Saturation of a turbulent mixing layer over a cavity: response to harmonic forcing around mean flows. Journal of Fluid Mechanics 853, 386–418.

Cattafesta, L., Rowley, C.W., Williams, D.R. & Alvi, F. 2003 Review of active control of flow-induced cavity resonance. AIAA Paper, 2003–3567.

Liu, Q. & D. Gaitonde, D. 2021 Acoustic response of turbulent cavity flow using resolvent analysis. Physics of Fluids 33 (5), 056102.

Liu, Q. & Gómez, F. 2019 Role of trailing-edge geometry in open cavity flow control. AIAA Journal 57 (2), 876–878.

Luo, K., Zhu, W., Xiao, Z., Weng, Z., Deng, L., Yang, D. & Liu, J. 2018 Investigation of spectral characteristics by passive control methods past a supersonic cavity. AIAA Journal 56 (7), 2669-2686.

Ohmichi,Y. & Yamada, K. 2021 Matrix-free TriGlobal adjoint stability analysis of compressible Navier–Stokes equations. Journal of Computational Physics 437, 110332–110350.

Prudhomme, D., Chin, D., Reeder, M.F., Schmit, R., Maatz, I. & Johnson, R. 2021 Flight Tests of Passive Flow Control for Suppression of Cavity Aeroacoustics. Journal of Aircraft 0, 1–10.

Rolandi, L.V., Jardin, T., Fontane, J. Gressier, J. & Joly, L. 2021 Global stability analysis of the compressible flow past a NACA0012 airfoil at low Reynolds numbers. AIAA Journal 60 (2), 1052–1066.

Rowley, C.W. & Williams, D.R. 2006 Dynamics and Control of High-Reynolds-Number Flow over Open Cavities. Annual Review of Fluid Mechanics 38, 251–276.

Sun, Y., Taira, K., Cattafesta, L.N., & Ukeiley, L.S. 2017 Spanwise effects on instabilities of compressible flow over a long rectangular cavity. Theoretical and Computational Fluid Dynamics 31, 555–565.

Tezuka, A. & Suzuki, K. 2006 Three-Dimensional Global Linear Stability Analysis of Flow Around a Spheroid. AIAA Journal 44 (8), 1697–1708.

Theofilis, V. 2017 The linearized pressure Poisson equation for global instability analysis of incompressible flows. Theoretical and Computational Fluid Dynamics 31, 623–642.