Stall cells identification through global stability of turbulent mean-flows: a data-assimilation approach

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Stall cells are three-dimensional turbulent coherent structures that often appear on wings close to the stall angle, forming transverse cellular patterns on the suction side of the profile. Such structures were recently observed experimentally on a NACA4412 profile in a transitional flow regime with Reynolds number Re=350000. In this paper, we explain their formation through the global stability of turbulent mean-flows computed in the framework of the Reynolds-Averaged Navier Stokes equations, coupled with a Spalart-Allmaras turbulence model. Such analysis was recently performed by Plante et al[1], but the onset of stall cells occurs at a critical angle of attack larger than in the experiments. Such discrepancy is mainly due to the inaccuracy of the turbulence model, which we propose to correct based on an adjoint data-assimilation algorithm (Franceschini et al[2]), using turbulent velocity and flow statistics from the Direct Numerical Simulations by Gleize et al[3]. Global stability analysis of the assimilated mean-flows, based on the linearization of the RANS and turbulence models, reveals the existence of a three-dimensional stationary global mode linked to the formation of stall cells that gets unstable for an angle of attack and transverse wavenumber in agreement with the experimental results. The structure of the mode is shown in figure 1, using the streamwise and transverse velocity components. We finally compare these results with methods based on frozen eddy-viscosity approaches and eddy-viscosity fields estimated from DNS mean-flows, as recently proposed in the literature. We show that the stability of the fully-linearized equations predicts the wavelengths of the coherent structures with much more accuracy.

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[1] Plante et al, *J. Fluid Mech.* **908**, A16 (2021).

[2] Franceschini et al, *Phys. Rev. Fluids.* **8**, 094603 (2020).

[3] Gleize et al, *Int. Jour. of Num. Meth. for Heat & Fluid Flow.* **32**, 1375 (2022).

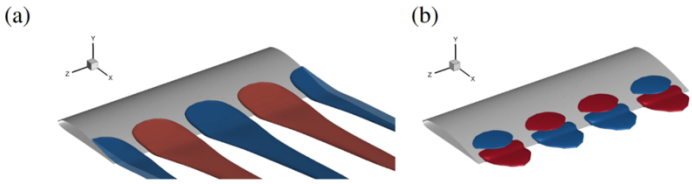

Figure 1: (a) Streamwise and (b) transverse velocity component of the unstable stationary global mode explaining the onset of stall cells