UK Fluids Network (UKFN)
Special Interest Group (SIG) on
Flow Instability, Modelling & Control

2nd ONLINE SIG EVENT
15/09/2020

ABSTRACTS

(1) Speaker: Prof. Steve Tobias (School of Mathematics, University of Leeds).
Title: Generalised Quasilinear Modelling of the interaction of shear and convection.
Abstract: The interaction of turbulence with mean flows is complicated, but an understanding is crucial for our modelling not only of wall-bounded flows but also those of geophysics and astrophysics. Two types of interaction can be envisaged. In the first, a large-scale mean flow feeds energy into the turbulence that acts itself so as to modify the mean. In the second the turbulence is driven on a moderate scale and correlations in this turbulence lead to the driving of the mean flow. Here I shall discuss the modelling of such interactions within the quasilinear and generalised quasilinear approximations, and the implications for statistical modelling of the flows.

(2) Speaker: Prof. Francois Gallaire (Laboratory of Fluid Mechanics and Instabilities, EPFL).
Title: Too big to grow: saturation mechanisms in open flows.
Abstract: In this lecture, I will discuss the derivation and limitations of Stuart–Landau amplitude equations to capture nonlinear saturation in unstable flows. In particular, I will discuss the limitations of this approach as one pushes the control parameter as far as possible from threshold, proposing an interpretation based on the progressive loss of the non-resonant compatibility condition, which is the cornerstone of Stuart's multiple-scale expansion method. I will then briefly review a self-consistent model recently introduced in the literature and demonstrate a link between its properties and the above-mentioned failure. Finally, I will consider convectively unstable flows which are globally stable but exhibit strong non-normal amplification potential when forced in a rather broad range of excitation frequencies. I will show that the self-consistent approach is equivalent to the harmonic balance method and provides a precise prediction of the saturation of the response with increasing forcing amplitude.

(3) Speaker: Yacine Bengana and Laurette S. Tuckerman (CNRS ESPCI Sorbonne).
Title: Frequency prediction from exact or self-consistent mean flows in thermosolutal convection
Abstract **link**.

(4) Speaker: Sean Symon (University of Southampton).

Title: A nonlinear energy transfer perspective on reduced-order modelling tools.

Abstract: In this talk, we characterise the energy transfer mechanisms in the cylinder wake at low Reynolds number. The beauty of this example is that only three temporal Fourier modes are energetic, allowing us to explicitly characterise all the relevant nonlinear interactions in the flow. We also compare the energy balance in the true flow to predictions from resolvent analysis, which can be interpreted as a quasi-linear method that models energy exchange between the mean and fluctuations. We find that the mean flow is the main source of energy for the fundamental mode only while higher harmonics receive most of their energy from the fundamental mode. Since quasi-linear methods, e.g. resolvent analysis, only model interactions between the mean and fluctuations, they fail to predict the structure of higher harmonics. They also neglect to model energy transfer out of the fundamental mode, resulting in a structure that is too energetic in the far wake. In the spirit of a generalised quasi-linear analysis (Marston et al. 2016), we investigate all "eddy-eddy" interactions that comprise the net nonlinear transfer for each harmonic and discuss implications for reduced-order modelling of more complex flows.

(5) Speaker: Georgios Rigas (Dept. of Aeronautics, Imperial College London).

Title: Nonlinear input/output analysis: application to boundary layer transition.

Abstract: We extend linear input/output (resolvent) analysis to take into account nonlinear triadic interactions by considering a finite number of harmonics in the frequency domain using the harmonic balance method. Forcing mechanisms that maximize the drag are calculated using a gradient-based ascent algorithm. By including nonlinearity in the analysis, the proposed frequency-domain framework identifies the worst-case disturbances for laminar-turbulent transition. We demonstrate the framework on a flat-plate boundary layer by considering three-dimensional spanwise-periodic perturbations triggered by a few optimal forcing modes of finite amplitude. We show that nonlinearity plays a critical role in optimizing growth by combining and redistributing energy between the linear mechanisms and the higher perturbation harmonics. With a very limited range of frequencies and wavenumbers, the calculations appear to reach the early stages of the turbulent regime through the generation and breakdown of hairpin and quasi-streamwise staggered vortices.

(6) Speaker: Edouard Boujo (Laboratory of Fluid Mechanics and Instabilities, EPFL).

Title: Second-order adjoint-based sensitivity for hydrodynamic stability and control.

Abstract: Adjoint-based sensitivity analysis is routinely used today to assess efficiently the effect of flow control on the linear stability properties of globally unstable flows. Sensitivity maps identify regions where small-amplitude control is the most effective, i.e. yields the largest first-order (linear) eigenvalue variation. In this study an adjoint method is proposed for computing a second-order (quadratic) sensitivity operator. The method is applied to the flow past a circular cylinder, controlled with a steady body force or with a model of passive control device. Maps of second-order eigenvalue variations are obtained, without computing controlled base flows and eigenmodes. For finite control amplitudes, the second-order analysis improves the accuracy of the first-order prediction, informs about its range of validity, and about whether it under/overestimates the actual eigenvalue variation. The second-order variation can be decomposed into two mechanisms: second-order base flow

modification, and interaction between first-order base flow and eigenmode modifications. Finally, the optimal control for second-order stabilisation is computed via a quadratic eigenvalue problem.

(7) Speaker: Giovanni Fantuzzi (Dept. of Aeronautics, Imperial College London).

Title: Bounding nonlinear amplification of energy and other quantities with convex optimization

Abstract: Determining the maximum nonlinear amplification of energy or enstrophy in fluid flows is a fundamental problem in the study of stability and transition, and also has implications for the well-posedness of the incompressible Navier-Stokes equations. Direct methods such as adjoint optimization can be used to construct particular flows that exhibit large growth of energy or enstrophy, which in turn yield lower bounds on the maximum possible amplification. Complementary upper bounds are of equal interest, but they are significantly harder to obtain because they must apply to all possible flow states. In this talk, I will show that the search for such upper bounds can be posed as a convex optimization problem over auxiliary functions, which resemble (but are not the same as) the Lyapunov functions used in nonlinear stability analysis. For low-dimensional ODE models, polynomial auxiliary functions can be optimized numerically and, under mild technical conditions, the corresponding bounds provably converge to the true maximum amplification as the polynomial degree is raised. I will demonstrate that these techniques indeed produce arbitrarily sharp bounds on a range of low-dimensional ODE models. The challenges posed by high-dimensional ODE models and the full Navier-Stokes PDEs will also be discussed along with possible strategies to overcome them.