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Jet noise modelling and control / Modélisation et contrôle du bruit de jet

Foreword

This thematic issue contains invited contributions from participants in the 2016 "Jet Noise Modelling and Control" colloquium. All papers herein are original research articles that have been peer-reviewed according to the standards of the journal. They are intended to give a representative picture of current approaches to the jet noise problem, as they emerged during the colloquium.

1. The "Jet Noise Modelling and Control" colloquium

The colloquium was held on 28–30 September 2016, at École polytechnique, in France. It was sponsored jointly as a Euromech Colloquium and an IUTAM Symposium, with additional support from the European Commission through the EC-Aero2 programme, from LaSIPS, École polytechnique, and ERCOFTAC SIG-39. The scientific programme of the colloquium is provided as supplementary material to this foreword.

Forty researchers from institutions in eight different countries participated, among them 18 graduate students, and a large number of leading experts in the field were present. There were 32 oral presentations in total, spread over the three days of the colloquium, and open-discussion sessions were held at the end of each day. The keynote lecture, "*Why large scales are the dominating source of jet noise*", was given by Ulf Michel. The colloquium was preceded by a two-day lecture series on "Measurement, simulation and control of subsonic and supersonic jet noise", organised by the Von Karman Institute, near the Polytechnique campus.

The colloquium marked the end of the first period of the *Cool Jazz* programme ("Control-oriented linear modelling of jet aeroacousticzz"), funded over three years by the 'Agence Nationale de la Recherche'. The *Cool Jazz* logo embellishes the front cover of this volume.

2. Current approaches to the jet-noise problem

Recent progress in jet-noise research has seen hydrodynamic stability theory occupy an increasingly central place. This is largely due to developments in modern numerical and experimental tools, and a closer association of these that has clarified the extent to which linear theory can describe wavepackets in turbulent jets. The colloquium succeeded in presenting a broad and rather complete overview of the state of the art, both from physical and technical viewpoints. A certain consensus is apparent regarding linear input–output analysis as an appropriate theoretical framework for the modelling of wavepackets in turbulent jets.

The majority of the work presented at the colloquium as well as in this thematic issue involves association of data from either high-fidelity numerical simulation or experiment (or both) with theory-based modelling techniques. The acoustic analogy, in its various forms, continues to be used: as a diagnostic tool, as for example by Margnat et al. [1] and Nichols & Kreitzman [2]; for simplified kinematic modelling, as per Piantanida et al. [3,4]; or for the acoustic extrapolation of high-fidelity numerical solutions of the near field of turbulent jet, as by Semilitov & Karabasov [5] and Cetin et al. [6] — as opposed to the use of Ffowcs Williams–Hawkings surfaces, as in the work of Markesteijn & Karabasov [7] and Wang et al. [8]. While the acoustic-analogy approaches may provide insight regarding sound-generation mechanisms, a limitation is the difficulty of inferring anything about the dynamics that underpin the source terms.

It is here that a dynamic modelling framework grounded in linear stability theory can provide further insight. Such approaches are underpinned by the assumption that wavepackets are the dominant noise-producing features of the turbulent jet [9], as argued also in Ulf Michel's keynote lecture. Wavepackets were broadly discussed during the colloquium. It was shown, for instance, by Agarwal et al. [10], using Schlieren imaging of a rectangular jet, that these appear as relatively coherent, intermittent ('jittering') structures. The importance of this intermittency for the radiated sound levels [11–13] was underlined in the analyses of Schmidt & Colonius [14] and Jeun & Nichols [15]. Mancinelli & Camussi [16] discussed the use

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of wavelet transform for the eduction of jittering wavepackets, and they apply that technique in their study of jet-surface interaction in the present volume [17].

Until recently, the use of stability theory to model wavepackets has generally been based on the homogeneous linearised Navier–Stokes system, where linearisation is performed about the turbulent mean. Such mean-flow analysis is *ad hoc* and only justified, *a posteriori*, by comparison with data. Arguments for the *a priori* justification of mean-flow analysis can be made by identifying the nonlinear terms with an inhomogeneous forcing term [18], and this places the linear stability framework on a more solid footing. With this inclusion of the nonlinear term, the problem is better viewed in terms of a temporally stable input–output system, and stability-based modelling of wavepackets in turbulent jets is now almost exclusively performed in this manner. A notable exception is the study of Natarajan et al. [19], who use temporal eigenmode decomposition to devise feedback control for noise reduction.

In both homogeneous and inhomogeneous formulations of the stability problem, the non-parallelism of the flow makes the solution computationally expensive. This motivates the use of approximations that can be obtained by parabolising the governing equations. The most popular choice remains PSE, as employed by Rodriguez et al. [20] for a three-dimensional flow problem. The limitations of PSE, which are well known, are, to a large extent, overcome by the alternative "one-way" Navier–Stokes integration technique [21]; yet the simplicity and overall success of PSE continues to make it an attractive choice for weakly non-parallel flows. Resolvent SVD, on the other hand, fully incorporates non-parallelism, and it offers a complete and orthogonal basis for the projection of flow perturbations. But this framework at present requires knowledge of the turbulent mean flow, from reference data or from RANS simulations, and involves the hypothesis (simply put) that Reynolds stresses are uncorrelated in time and space. Nonlinearity, under these assumptions, only provides white-noise Reynolds stresses with non-zero mean.

Several recent resolvent-based jet studies [22–24] were presented at the colloquium. All of these demonstrate that the conceptual approach is theoretically well founded, and that good agreement with LES or experimental data may be obtained under favourable conditions. It is evident, however, that the role of turbulence in wavepacket modelling goes beyond that which it plays in producing the mean flow. While there is clear evidence that linear processes alone capture the dynamics well near the nozzle, where perturbation amplitudes are small and linear shear-instability mechanisms are strong, downstream of the point at which such waves become neutrally (locally) stable, linear predictions based on the homogeneous linear model or the leading resolvent mode tend to deteriorate [25–28]. There is now evidence to suggest that the nonlinear terms play an important role in sustaining the growth of perturbation energy beyond the neutral point, and that they also activate many acoustically important wavepacket traits, both of these processes occurring via the non-normality of the linear operator [29,30]. Understanding the structure of the nonlinear forcing term is clearly an important new goal. Preliminary work in this direction has been performed by Towne [31,32]. The dynamical-systems analysis by Semeraro et al. [33], presented at the colloquium, provides an original data-driven perspective in this regard.

During the discussion sessions, opinions diverged on the usefulness of extending the concept of turbulent viscosity to Reynolds stress fluctuations [23,34]. Such an approach, which amounts to absorbing parts of the nonlinear Reynolds stresses into the linear operator [35,36], was defended by some, whereas others propose to push the investigation of the "colour" of the nominal source terms in the quasi-laminar model [37]. The two approaches do not exclude each other, and further progress on this front is anticipated in the years ahead.

Appendix A. Supplementary material

The programme of the "Jet Noise Modelling and Control" colloquium can be found online at https://doi.org/10.1016/j.crme.2018.07.001.

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