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PII: S1270-9638(17)31374-3
DOI: https://doi.org/10.1016/j.ast.2018.06.027
Reference: AESCTE 4641

To appear in: *Aerospace Science and Technology*

Received date: 28 July 2017
Revised date: 11 March 2018
Accepted date: 26 June 2018

Please cite this article in press as: S. Bhaumik et al., Verification and application of a mean flow perturbation method for jet noise, *Aerosp. Sci. Technol.* (2018), https://doi.org/10.1016/j.ast.2018.06.027

Verification and Application of a Mean Flow Perturbation Method for Jet Noise

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Abstract

The stability properties of basic states are often elucidated by examining the evolution of small disturbances. Such studies have recently been successfully applied to mean turbulent states, obtained through averaging of experimental measurements or Large-Eddy Simulations (LES), for both wall-bounded as well as free shear flows. Typically, the equations are employed using the disturbance form of the equations. To circumvent the necessity to linearize the governing equations, an especially tedious task for viscous and turbulent closure terms, Touber & Sandham (Theor. Comput. Fluid. Dyn., **23**, 79-107, 2009) proposed an approach that achieves the same purpose by solving the full Navier-Stokes (NS) equations, with a forcing term to maintain mean flow invariance. The method places no restrictions, such as slow streamwise variations, on the underlying basic state. The goals of the current work are to first verify this mean flow perturbation (NS-MFP) technique and then apply it to the problem of jet noise. For the first thrust, we show that when the basic state is appropriately constrained, the technique reverts to Linear, Parabolized and Global stability methods. The method is then verified by reproducing the growth of unstable modes in an inviscid Mach 6 entropy layer. The application to jet noise considers subsonic Mach 0.9 and perfectly expanded supersonic Mach 1.3 round jets. The results are compared with those from Parabolized Stability Equations (PSE) and LES solutions, respectively, considering monochromatic and multi-frequency perturbations. The NS-MFP method successfully reproduces key features of the modal response, including Strouhal number dependent directivity of noise radiation. Aspects related to the manner in which the mean basic state is obtained, whether from LES or Reynolds-averaged Navier-Stokes (RANS) equation are also explored. In particular, the sensitivity of the perturbation to whether the eddy viscosity is included or not, is examined in reference to maximum intensity of pressure fluctuation, directivity of noise radiation and the rate of fall-off of the spectra at higher Strouhal numbers. The results indicate that a closer match on the noise-radiation characteristics is obtained when effects of eddy-viscosity on the disturbances are neglected.

Keywords: Navier-Stokes equation, Stability analysis, Parabolized stability equation (PSE), Linear stability theory (LST), Global stability analysis, Large-eddy Simulations, Mean flow perturbations

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