STABILITY ANALYSIS OF A COMPRESSIBLE TURBULENT FLOW OVER A BACKWARD-FACING STEP

Samir Beneddine[1] , Emerick Bodere [1] & Denis Sipp [1]
[1] *ONERA, Meudon, France.*

Abstract In this study we focus on the stability analysis of a compressible turbulent flow over a closed backward-facing step. To perform the stability analysis, we have computed a mean-flow from an unsteady 3D simulation. This analysis reveals a completely stable spectrum, with some global modes exhibiting a frequency close to the peaks of the frequency spectrum of the unstead 3D simulation. Since none of the modes are unstable, we have then performed a singular value decomposition that allows to see the optimal gain response of the flow at each frequency. This final study reveals several particular frequencies that match what is observed in the unsteady simulation.

INTRODUCTION

Flows over a backward-facing step have been intensively studied in the literature because of the wide number of engineering application that require better understanding of separation and reattachment phenomena, such as, for exemple, flows around airfoils, buildings, or internal flows in combustors. Consequently, there exists an abundant number of studies, both numerical and experimental, that focus on the dynamics of such flows (see for exemple [1, 2]). The present work aims at studying the frequency spectrum of a 3D compressible turbulent flow over a backward-facing step by performing a stability analysis.

UNSTEADY SIMULATION AND COMPUTATION OF THE MEAN FLOW

We consider a 3D compressible flow of air over a closed backward-facing step at a Reynolds number equal to 37000. We have first run an unsteady 3D simulation, from which we have computed a bidimensional mean-flow by averaging in time and in the spanwise direction. This mean-flow has been used to perform a linear global stability analysis. A discussion about the use of a mean-flow instead of a baseflow to run a global stability analysis can be found in [3].

The unsteady computation has also been used to compute power spectral densities of some of the variables of the flow. The spectrum associated to a sensor placed inside the shear layer is shown in Figure 1. One can see several noticeable peaks corresponding to typical unsteadiness of such flow [4].

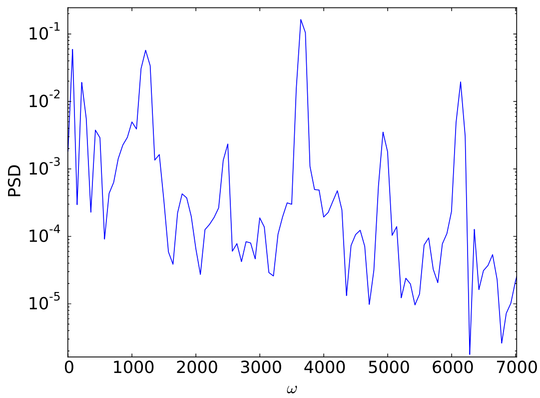

Figure 1. Power spectral density computed from the recording of the streamise velocity during the unsteady simulation, inside the shear layer.

GLOBAL STABILITY ANALYSIS

A global stability analysis consists in the study of the eigenspectrum of the jacobian matrix of the system, computed from the linearization of the governing equations of the flow. For each eigenmode, the real part of the associated eigenvalue corresponds to the growth rate of the mode σ, while the imaginary part corresponds to its frequency ω. More details about the general theory of global stability analysis can be found in [3].

Figure 2 shows the computed spectrum of the studied flow. One can see that all the eigenvalues are stable ($\sigma < 0$). This indicates that the flow does not display any oscillator-type behavior. Though several modes appear to have frequencies close to the peaks observed in Figure 1, the appropriate way to study such kind of noise amplifier flows is to focus on pseudo-resonances, by performing a singular value decomposition (svd) of the resolvent of the system [3].

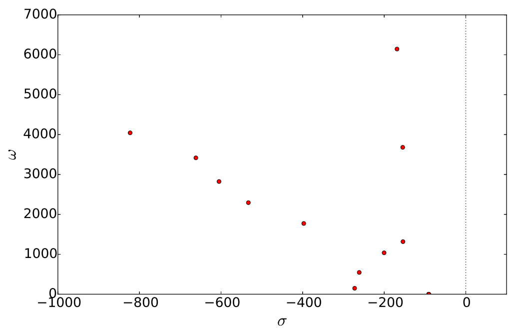

Figure 2. Spectrum associated to the studied flow. The horizontal axis correspond to the growth rate, and the vertical axis, to the frequency of the mode. One can see that the whole spectrum is stable ($\sigma < 0$).

SINGULAR VALUE DECOMPOSITION

We know that for noise amplifier flows, whose spectra are entirely stable, the physical relevence of the global modes is subject to discussion. A more appropriate study consists in performing a singular value decomposition of the resolvent of the system. This gives access to the optimal forcing and corresponding response of the flow for a given frequency. Such an approach allows to study the pseudo-resonances responsible for unsteadiness of the flow, originating from the superposition of stable global modes (see [3] for more details).
Figure 3 shows the resulting gain function. As expected we can observe some noticeable frequencies that match several peaks of Figure 1 (around ω = 1000Hz, 2400Hz and 4900Hz). In the talk, we will further discuss the relevancy of mean-flow stability to explain frequency spectra in turbulent flows.

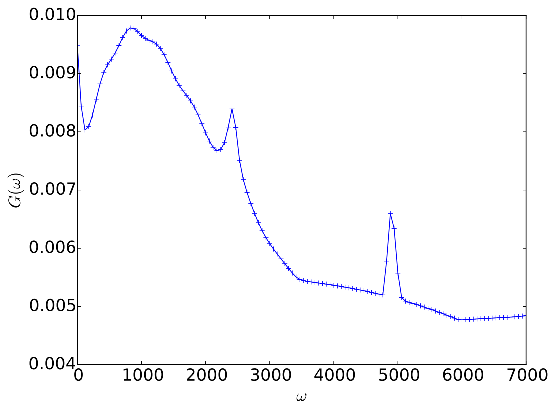

Figure 3. Optimal gain $G(\omega)$ vs frequency ω, computed by performing the svd of the resolvent of the system. One can see several noticeable frequencies that correspond to peaks observed in Figure 1.

References

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