STABILITY ANALYSIS OF SHOCKWAVE / TRANSITIONAL BOUNDARY-LAYER - LINK WITH SHEAR-LAYER DYNAMICS

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Summary Shockwave/boundary layer interactions (SWBLI) are found in many aeronautical applications such as air intakes or over expanded nozzle flows. Fully separated interactions have been widely studied in the past. Whatever the flow configuration (compressions ramps, shock reflection, blunt fin or over-expanded nozzles), low frequency shock motions are observed when the flow is separated, although their origin is not always clearly established. In the case of a SWBLI at moderate Reynolds number, it has been recently proposed to relate the low frequency motion of the leading shock to the dynamics of the separated region developed downstream. The objective of this work is to study the global stability of a SWBLI and especially the link between low frequency and dynamics of the separated zone. We will show that under certain conditions a SWBLI can be globally unstable and that the response to white noise of a SWBLI may be selective in frequency.

FLOW CONFIGURATION AND BASE FLOW

The objective of this work is to demonstrate that the low frequency behaviour experimentally observed in SWBLI can be linked to the intrinsic dynamics of the detached zone induced by the interaction. To this end, the evolution of an incident shock wave impinging a laminar boundary layer developing over a flat plate when the incident shock angle is gradually increased has been studied, see Fig. 1. The freestream inflow Mach number and the global Reynolds number remain unchanged. The test case considered has been experimentally and numerically studied by Degrez *et al.* [1]. The freestream inflow Mach number is 2.15 for the numerical simulation. The Reynolds number based on the distance X_{sh} between the plate leading edge and the inviscid shock impingement point is 10^5. The shock angle with respect to the horizontal is initially equal to $\theta = 30.8^o$.
The base state $\mathbf{Q} = (\rho, \rho\mathbf{U}, \rho E)^T$ is a solution to the time-independant compressible Navier-Stokes equations. A numerical solution of the SWBLI is obtained by solving the 2-D compressible Navier-Stokes equations written in conservative form and discretized by a high order finite-difference method (see [2] for the details). The base flow for $\theta = 30.8^o$ and this validation from the Degrez *et al.* result's are presented in Figures 2.

STABILITY ANALYSIS

The compressible Navier-Stokes equations are linearized around the base flow. This set of equations can be written into a classical dynamical system form

$$\mathbf{B}\frac{\partial \mathbf{q}}{\partial t} = \mathbf{L}\mathbf{q},$$

where $\mathbf{L}$ is the jacobian matrix of the compressible Navier-Stokes equations. This matrix being far too large to be explicitely calculated, a time-stepper approach combined with an Arnoldi algorithm is used to compute its eigenspectrum and associated eigenmodes.

SOME RESULTS

The study of the global stability of a SWBLI has been poorly studied so far. Early studies [3, 4] focused on the possibility to obtain a three-dimensional SWBLI. The objective of this paper is to study by a global approach instabilities developing in the shear layer located in the separated zone. Different interactions are studied by varying the incident shock angle $\theta = 30^o, \cdots, 35^o$ for 2-D and 3-D disturbances. These results will be compared to direct numerical simulations. Figure 3 shows an example of eigenspectrum for $\theta = 30.8^o$, $Re_{X_{sh}} = 10^5$ and a 2-D perturbation. The flow is globally stable but locally spatially convectively unstable. Modes (a) to (o) correspond to modes mainly located in the downstream boundary-layer of the interaction and spatially amplified. Modes (1) to (8) correspond to more localized modes associated with the shear layer and the separated zone. Fig. 4 shows an example of eigenfunction associated with the mode (i).

References

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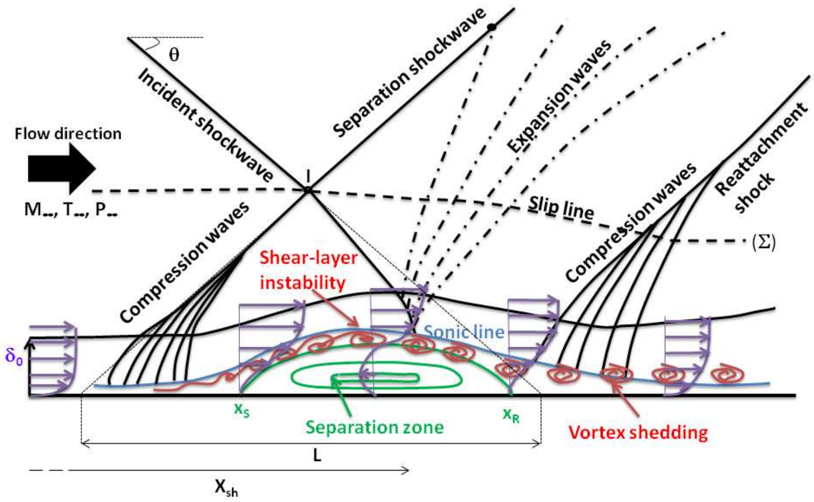
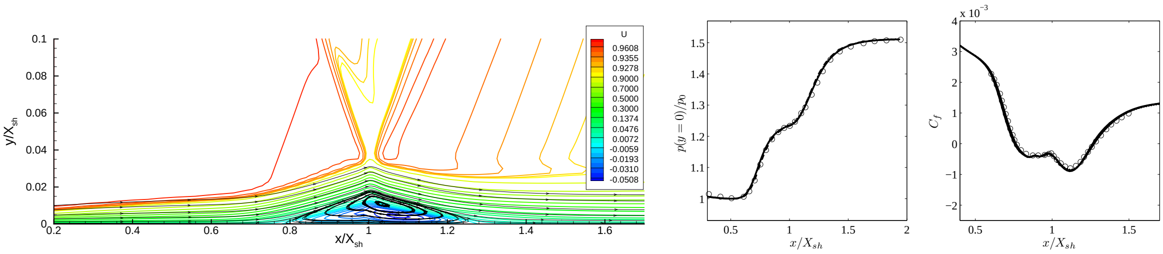


Figure 1. Schematic representation of the shock wave/boundary layer interaction.



(a) Iso-lines of longitudinal velocity $U(x, y)$ and streamlines. (b) $P(x)/P_0$ (c) $C_f(x)$

Figure 2. Base flow characteristics for $\theta = 30.8^o$, $Re = 10^5$.

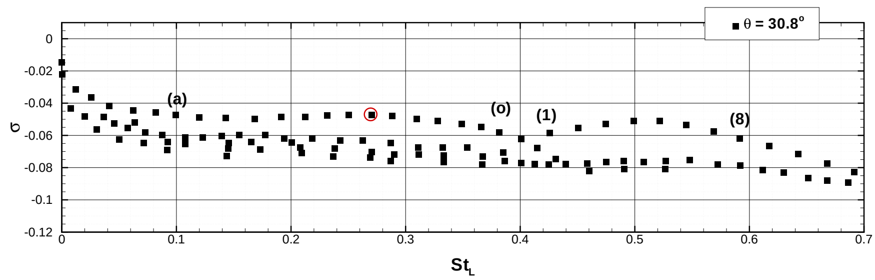


Figure 3. Eigenspectum for incident angle $\theta = 30.8^o$.

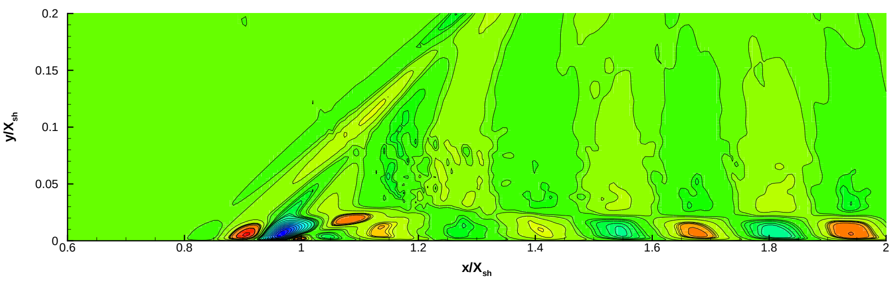


Figure 4. Eigenfunction for the real part of the streamwise velocity component for the incident angle $\theta = 30.8^o$ associated to the eigenvalue indicated by the red circle in Fig. 3.