NUMERICAL STUDY OF STABILITY OF FLOWS FROM LOW TO HIGH MACH NUMBER

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In the design process of new aerospace vehicles heat flux prediction is an important task that has to be carefully accomplished. The Thermal Protection System (TPS) has a great impact on the vehicle overall weight and therefore on its performance and payload. Boundary layer transition could increase the thermal load by a factor three or more and for this reason a better modeling and understanding is needed in order to reduce the TPS weight. A possible way to address this problem is to study the stability feature of the flow. While Direct Numerical Simulation (DNS) can provide insight in stability and transition phenomena, the high costs associated with it make such a tool not practical for design purposes. Other approaches, with several degrees of approximation are available; for our work a good compromise between physical understanding and cheap predictions is represented by the Linear Stability Theory (LST).

Target of this work is to present a consistent set of tools developed around the LST to compute flow stability at different regimes. The VKI Expandable Stability and Transition Analysis (VESTA) toolkit has been designed and tailored to provide a set of core utilities for the discretization, equations manipulation and solution of an eigenvalue problem. The upper layer is represented by the stability solver itself: subsonic, supersonic and hypersonic flows could be properly analyzed according to the LST, by means of specific functions. A set of standard scripts is available to perform more complex actions as computing a neutral stability curve or growth rates varying with frequencies or wave numbers.

Chebyshev collocation is used at all flow regimes while a modified version of the tau-method has been tested on subsonic flows. Both techniques provide similar accuracy but collocation method proved to be easier to implement and more flexible in boundary condition management. The compressible solver has been tested against several cases available in literature, showing the important effect of temperature in the stability computation. It has been tested also in the incompressible limit retrieving known results and showing a better conditioning than the incompressible solvers. At hypersonic speeds the vehicle is heated up by the strong shock in front of it. Eventually the temperature becomes high enough to promote the chemical dissociation of species and air should be considered as a mixture of different species. Simulations of flows with chemical reactions have been performed under the Local Thermodynamic Equilibrium (LTE) assumptions. Analysis of temperature and pressure influence showed that temperature is the driving parameter and that an increasing temperature is enhancing the instability of the flow. Also the critical Reynolds number decreases with increasing temperature. The effect of the shock is taken into account for supersonic and hypersonic flows. Its influence is more evident at higher Mach number where the shock is shallower. Effects are relegated to low wave numbers and it has been found out that the LTE assumption enhances its stabilizing feature, at least within the LST limit.

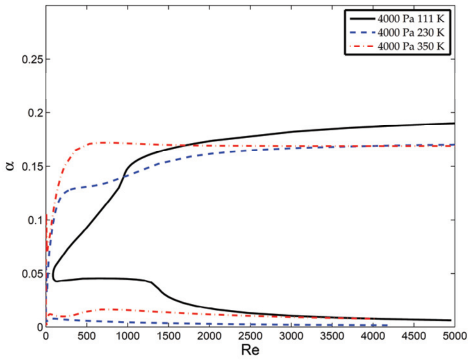

Figure 1 : Neutral stability curves for LTE flows at Mach10 and adiabatic wall

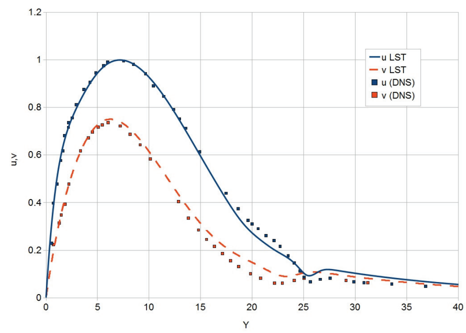

Figure 2 : Most unstable eigenmode velocity perturbations for a Mach 10 flow with adiabatic wall