Experiments on Shock Induced Laminar-Turbulent Transition on a Flat Plate at Mach 6

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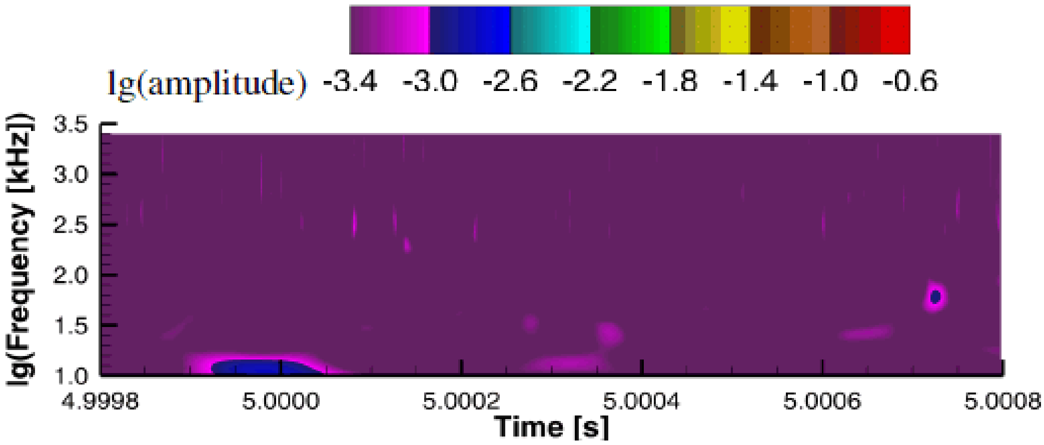
The transition from a laminar to a turbulent boundary layer is attended by an increase of the heat flux and drag. Therefore the correct prediction of this process is essential for the design of future hypersonic vehicles and their thermal protection systems. A great influence onto the transition process has the shock wave boundary layer interaction. In order to study these phenomena in the framework of the ESA-TRP "Laminar to turbulent transition in hypersonic flows" experiments the hypersonic wind tunnel H2K using several measuring techniques have been carried out. The investigations include the free boundary layer transition on a flat plate as well as the influence of a shock wave boundary layer interaction on the transition. The experiments were performed at Mach 6 at three different unit Reynolds numbers and with a translational displacement of the shock generator.

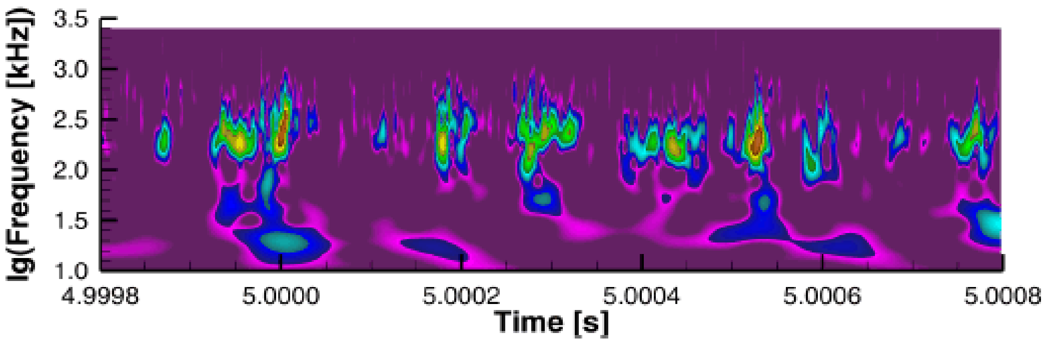
The transition region could be visualized by means of the infrared thermography and using a PEEK insert with low thermal conductivity. Additional flow visualization was carried out by Schlieren pictures that show the positions of all relevant shock waves. Kulite and PCB sensors measured static and dynamic pressure distribution along the base plate. For the first time thin film gauges, coaxial thermocouples and ALTP sensors were used for heat flux measurements in H2K. It has been noticed that the poor signal to noise ratio of the thin film gauges and the coaxial thermocouples does not allow measuring the dynamics of the heat flux. In contrary ALTP sensors provided useful static and dynamic data.

The known influence of the Reynolds number on the boundary layer transition as well as the effect of the shock wave boundary layer interaction (SWBLI) onto the transition process could be verified. Depending on the position of the SWBLI compared to the free transition location, it is either an impingement into a fully developed turbulent boundary layer or the SWBLI triggers the transition process. If the shock impingement is close to the start of the free transition, the boundary layer becomes fully turbulent afterwards. In case of a more downstream shock impingement the boundary becomes transitional, but relaminarizes afterwards.

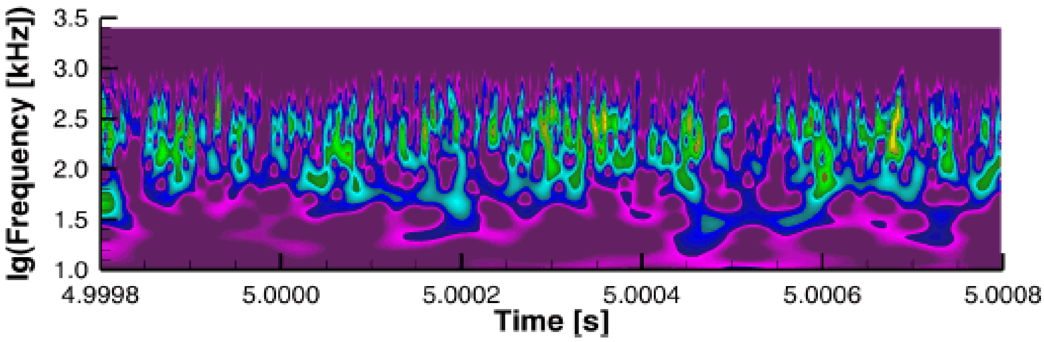
The Kulite sensors measured the pressure fluctuations at low frequencies arising from the SWBLI up to 1 kHz. The formation, growth and destruction of second (Mack) modes were measured with ALTP and PCB sensors. There is a clear influence of the Reynolds number onto the location, frequency and amplitude of the second (Mack) mode. The SWBLI induces modes similar to the second (Mack) modes at lower frequencies or causes a frequency shift of the existing second (Mack) modes. A wavelet analysis of the PCB and ALTP signals show differences of the wave packages of the natural second (Mack) modes of a free transition and the shock induced transition. It also allows studying the breakup process of the packages to turbulent structures.



(a) PCB 1: $x = 132.0\,\mathrm{mm}$; $y = -25.9\,\mathrm{mm}$



(b) PCB 2: $x = 212.0\,\mathrm{mm}$; $y = -35.7\,\mathrm{mm}$



(c) PCB 3: $x = 292.0\,\mathrm{mm}$; $y = -45.4\,\mathrm{mm}$

Figure 1: Wavelet analysis of the signal of a PCB sensor at locations with a laminar, transitional and turbulent boundary layer, $Re_u = 12 \cdot 10^6\ m^{-1}$, w/o shock