PHYSICAL ANALYSIS OF COMPRESSIBILITY EFFECTS IN THE TRANSONIC FLOW AROUND A SUPERCRITICAL AIRFOIL AT HIGH REYNOLDS NUMBER BY NUMERICAL SIMULATION

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Summary In transonic flow, specific combinations of the Mach number and of the angle of attack may engender a large-amplitude periodic motion of the shock-wave around a wing. This is triggered by the wake's large scale instability and leads to a complex shock-wave/boundary layer interaction. This phenomenon can create high fluctuations of the aerodynamic loads in conditions that can be near the cruising regime of aircraft. In the present paper, adapted statistical and hybrid turbulence modelling is used to capture correctly the buffet oscillations in agreement with physical experiments carried out by Jacquin *et al,* (2005). Among the methods used, the Organised Eddy Simulation, (OES), Braza et al (2006), as well as Delayed Detached-Eddy Simulation (DDES) (Spalart *et al* (2006)), are employed. The results are physically analysed by POD reconstruction, wavelet analysis, bi-spectra and autoregressive modelling, to capture the interaction between the shock motion and the wake instability (von Kármán mode).

FLOW CONFIGURATION

Jacquin et al studied the transonic buffet over the OAT15A profile, a 12.3%- thick supercritical airfoil. The freestream Mach and Reynolds numbers were 0.73 and 3 x 10^6 respectively and the angle of attack 3.5° . The latter was therefore chosen for a detailed flow field study using Laser Doppler Velocimetry, static pressure orifices and unsteady pressure transducers distributed over the model. The OAT15A flow is one of the selected test cases in the context of the European research program ATAAC-Advanced Turbulence Simulation for Aerodynamic Application Challenges. The numerical method used the NSMB code in MPI architecture of 512 processors (CINES-JADE Supercomputer).

RESULTS

Figure 1 shows the iso-*div (V)* velocity field that is varying practically as the derivative of density and illustrates the compressibility effects. These effects are related with the shock wave formation and buffet instability, that is triggered by feed back effects of trailing edge pressure, acting on the upstream supersonic 'pockets' formation. This mechanism was analysed by Bouhadji *et al* (2003) as a function of Mach and Reynolds numbers.

The present study shows the boundary layer detachment when the shock wave is at the most upstream position, the shear layer formation, accompanied by shedding of small scale shear-layer vortices and the von Kármán vortices formed downstream of the trailing edge. By performing a tracking of the waves formed at the trailing edge and travelling upstream and downstream, we can detect the feedback effect of the von Kármán mode on the buffet region. Therefore, these two modes, although originally independent, are found to strongly interact non-linearly. The interaction displays complex frequency combinations in the energy spectrum, essentially involving harmonics of the buffet frequency and the subharmonic of the von Kármán frequency (of order 2800/2 Hz). This interaction is studied by Autorgressive modelling (AR) and bi-spectra analysis. By filtering the signal and by applying Morlet's wavelet analysis, the frequency modulation versus time is produced within the frequency bump region.

Figure 3 shows the complex turbulence structure downstream of the shock and in the near wake, simulated by the DDES-SALSA model. When the separation region is at its maximum formation, it is found that the most 3D turbulence structure is produced, with development of the secondary instability along the span as a preferential spanwise wavelength, as first studied by Bourdet *et al, J. Flow, Turb. & Combust.* (2003). Figure 5 shows the POD reconstruction of the flow field, by using the first 18 POD modes. A detailed quantification of the 2D and 3D vortex structure will be provided.

CONCLUSIONS

The present paper addresses heading lines of the physics governing the transonic buffet at high Reynolds number and especially the influence of the near wake instability on the shock-boundary interaction.

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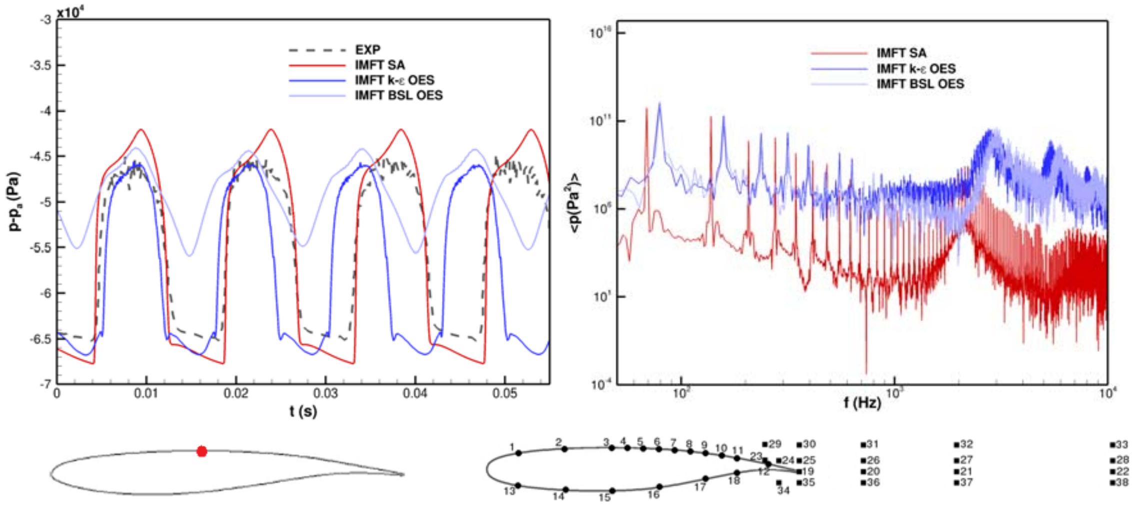

Figure 1. Wall pressure coefficient at the point indicated on the sketch, versus time (left) and at point 26 in the near wake (right)

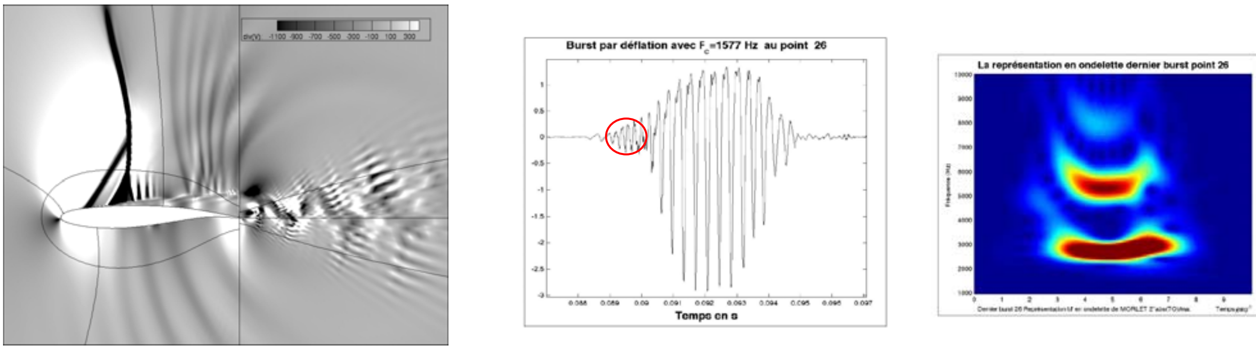

Figure 2 : Left: *Iso-div (V)* field, illustrating the compressibility effects: shock waves, separated boundary layer, shear-layer small vortices, trailing edge waves, von Kármán vortices and feedback mechanism; turbulence modelling *k*-*ω*-OES. Middle: pressure signal filtered in respect of the buffet frequency. Red-circled region shows higher frequency acceleration and frequency bump formation in respect of von Kármán mode; right: Morlet's wavelet analysis showing von Kármán mode modulation versus time.

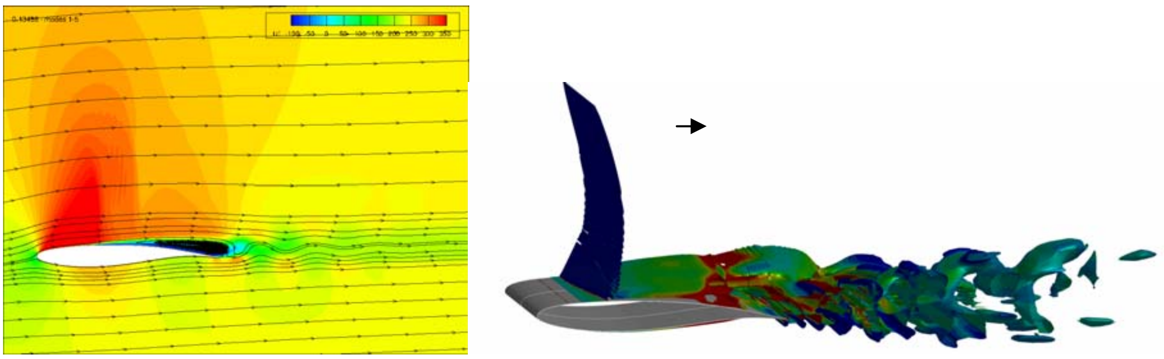

Figure 3. Left: POD reconstruction using 18 first modes. Right: 3D flow structure by means of the *Q* criterion for *Q*= 10, DDES apprach

References

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