Use of laminar flow technologies for supersonic drag reduction results of FP project SUPERTRAC

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The present paper deals with the control of the laminar-turbulent transition on a swept wing in supersonic conditions. This study has been carried out as part of the European Project SUPERTRAC (SUPERsonic TRAnsition Control; January 2005, June 2008). Two issues have been addressed with the same model: the first one is the control of the transition due to crossflow (CF) instabilities present on a swept wing, by using Micron-Sized Roughness elements (MSR); the second one is the prevention of the turbulent contamination along the leading edge by means of appropriate Anti-Contamination Devices (ACD).

The paper describes the work concerning the numerical approach, the model design, the tests in the ONERA S2MA wind tunnel in Modane and the analysis of the results.

Model definition

The selected profile for the test is symmetrical, with a relative thickness of 20% and a chord equal to 0.4m. Tests are realized at 0° angle of attack. The estimation of the contamination Reynolds number $\overline{R}*$ has demonstrated that this profile was appropriate to MSR tests at moderate sweep angle (laminar flow on leading edge for $\varphi \leq 30°$) and to ACD tests at high sweep angle (turbulent flow on leading edge for $\varphi \geq 60°$).

For MSR investigation [1], this preliminary phase determined efficient roughness element arrangements (wavelength and initial amplitude, corresponding respectively to the spanwise spacing and the height of the elements placed in the leading edge region); these configurations must be appropriate to reduce significantly the amplification of the instability which is responsible of the transition. This study is made by solving the nonlinear Parabolized Stability Equations, taking into account the target mode (most amplified stationary wave at transition), the killer mode (MSR configuration) and other ones. For example, figure 1 shows the damping effect of a killer mode (wavelength = 1.4 mm, dashed lines) on the amplitude of the target mode (full lines) when the initial amplitude of the killer mode (A_K) increases.

For ACD investigation, RANS computations (figure 2, [1]) have allowed the definition of the main characteristics of shapes potentially efficient to stop the turbulence along the leading edge. Seven different shapes have been chosen (five different bumps, two hollow shapes, figure 4).

Model manufacturing

The wing (chord 0.4 m, span 1.5 m), manufactured at ONERA Lille [2,3], is composed of a removable leading edge part and a main body. MSR and ACD are placed on the removable part. Two sections are equipped with pressure taps (at mid-span and near the wing tip).

Each MSR row is composed of about 35 small cylinders made of paint (height 10 micron, diameter 0.2 and 0.15 mm), distributed with a spanwise spacing equal to the “killer” disturbance wavelength ($1 \leq \lambda \leq 2$mm). The rows are placed at the critical abscissa parallel to the attachment line. Two groups of two rows each (same spacing, diameter 0.2 and 0.15 mm) are located on each model side. Unfortunately, only one row with MSR diameter of 0.15 mm was acceptable, due to manufacturing difficulty. The wake flow of each group was observed by one infrared camera.

Each ACD is sculpted on a small removable portion of leading edge (figure 4) which is located at about three times the wall boundary layer thickness from the wind tunnel wall. Three hot films placed respectively just upstream and downstream of the ACD and near the tip of the wing measure the shear stress fluctuations, informing about the nature of the boundary layer (laminar, transition, turbulent).

Tests in the S2MA wind tunnel

The test campaign has been performed in the S2MA wind tunnel, in October 2006. The presentation will show some typical results (see [4] for more information).

MSR have been tested at wing sweep angle of 20°, 25° and 30°, at Mach number 1.5 and 2.0, for total pressure values between 0.5 and 1.25 bar. As we can observe on the infrared image (figure 3), the control action of the MSR is not efficient. Globally, all the MSR rows move more or less the transition upstream, depending on their own characteristics and the test conditions. This rather disappointing result could be explained by a too big height of the MSR (10 micron), as pointed out by two applied criterions, but smaller MSR manufacturing was not realistic at the time of the tests.

ACD have been tested at wing sweep angle of 65°, at Mach number 1.7 (flow without shock) and 2.7 (with shock), for a total pressure range between 0.3 and 1.4 bar. The action of the different ACD was varying, depending on the shape. Results allowed to rather well understand the mechanism of such devices, qualities and drawbacks of each of them. A certain shape has been particularly efficient, pushing away the critical value of $\overline{R}*$ from 250 to about 400 at Mach number 2.7, which is an interesting success in supersonic conditions (figure 4).

Conclusion

A lot of knowledge has been acquired at each stage of this study in supersonic condition: numerical prediction, manufacturing, testing. Concerning the MSR investigation, the initial disturbance amplitude has to be more precisely reproduced by a better adaptation of the element size to the conditions. For the ACD investigation, the potential gain has been clearly demonstrated for a suitable bracelet shape. On the basis of these results, a category of ACD should be improved from a shape and size point of view.

Acknowledgement

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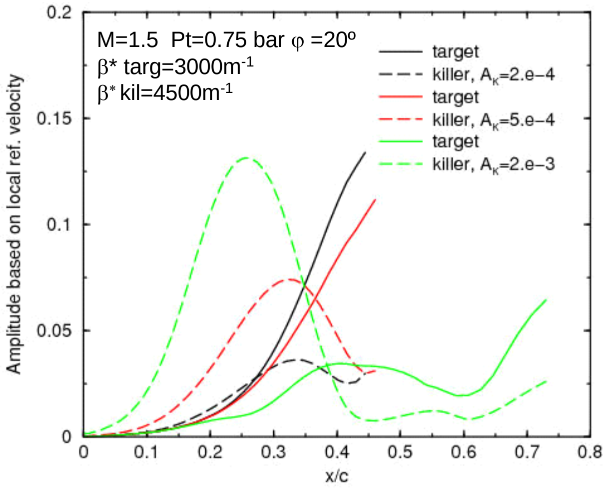

Figure 1: Example of nonlinear PSE computation (MSR investigation)

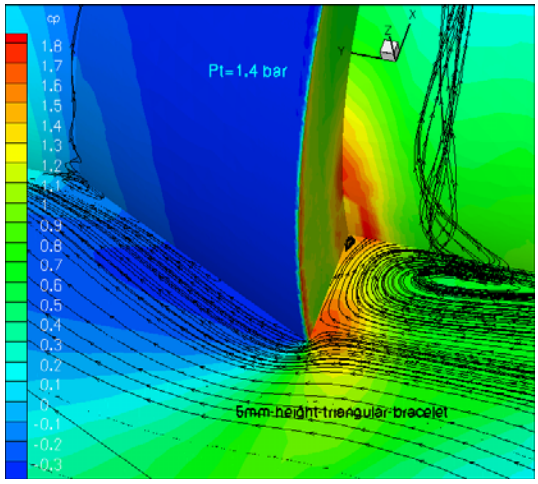

Figure 2: Example of RANS computation (ACD investigation)

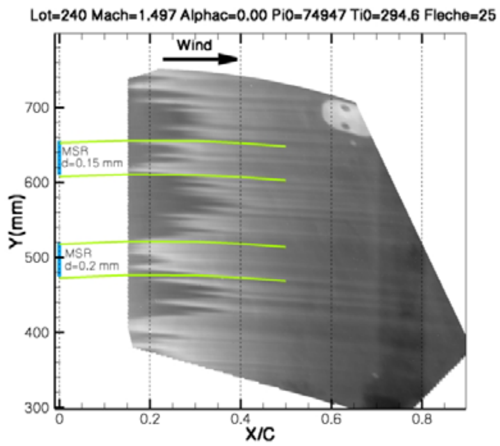

Figure 3: Example of infrared image (MSR tests)

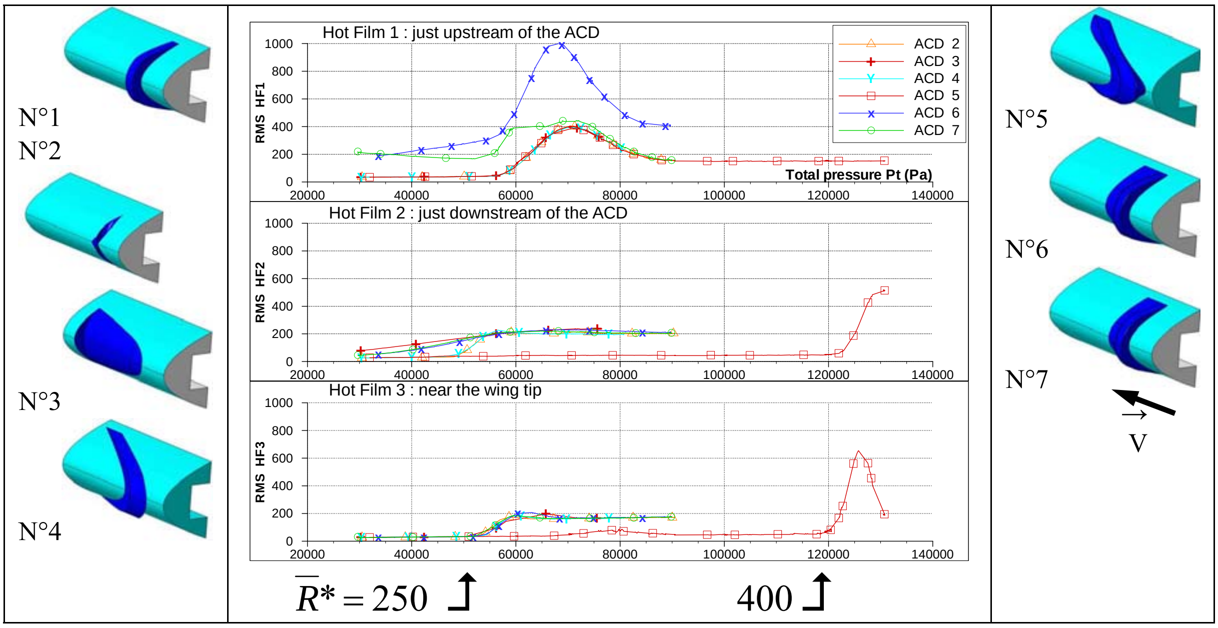

Figure 4: ACD effect detected by the hot films