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# Effect of vortex generator on the boundary layer detachment on NACA0015 2D foil.

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Control of detachment of the boundary layer around a foil found many applications in various configurations for aircraft the ability to suppress or delay the separation phenomenon leads to enhanced levels of lift, reduce noise and drag. Many studies have been experimentally conducted to test the effectiveness of different actuators. For example, regarding the methods called "active" which introduce external energy into the fluid, it distinguishes the use of movable walls *Modi et al.* [1], methods based on suction or blowing *Wygnanski* [2], *McCormick* [3], acoustic methods *Collins* [4], thermal *Chang* [5] or electromagnetic *Gad-el-Hak* [6]. In recent years, synthetic jets have been used to control flow separation and to stabilize the boundary layer by adding/removing momentum with the formation of vortical structures *Wygnanski* [7]. More recently, *Gilarranz et al.* [8] performed a study of flow separation over NACA0015 airfoil with synthetic jets control, but the modification by the control of the boundary layer has not been clearly identify.

Furthermore, concerning the boundary layer manipulators, vortex generators have been used for many years in applied aerodynamics on airplane wing *Velte et al.* [9] or *Angele and Grewe* [10]. In spite of these industrial applications very few data is available concerning the impact of a single longitudinal vortex (outside the foil) on the local or global characteristics of the flow.

The present study investigates experimentally the effects of a single vortex generated on a 2D NACA0015 foil. A particular attention is paid on near wake dynamics (Kàrmàn street, shear layer and Strouhal number) with and without vortex. In order to understand the underlying mechanisms both global (efforts) and local (velocity) measurements have been performed. Two dimensional LDV measurements using a refined grid in the boundary layer have been performed at incidences not so far from the detachment occurrence and Stereoscopic PIV measurements have been carried out in order to analyse the topology of the flow at stall and before stall occurrence.

Experiments have been conducted in the test section of the water tunnel of the French naval academy. The flow characteristics correspond to the upstream Reynolds number based on NACA0015 chord length of  $5 \cdot 10^5$ . The vortex is generated by a NACA0020 foil with elliptical plan form located 2 chords upstream of the 2D foil *Pichon* [11]. The experimental configuration is shown on Figure 1. On the plan form of the 2D foil the vortex determines 2 zones namely an outflow area where the vortex induces a velocity field directed from the wall to undisturbed flow and an inflow area where the vortex induces a velocity field directed toward the foil.

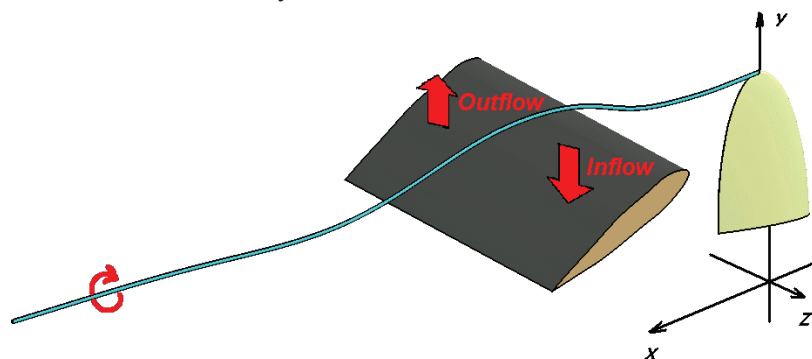


Figure 1: Experimental setup.

Lift and drag measurements have been performed with a strain gauge balance with and without vortex and are reported on Figure 2. Obviously the values of both lift and drag coefficients are not affected by the upstream vortex for incidences lower than 7°. Between 7° and 15° the lift coefficient remains unchanged but the drag coefficient increases rapidly. For larger values of the angle of attack the hysteric loop, characteristic of the static stall disappears and its crisis of lift value transforms in a plateau like behaviour. The presence of the vortex induces a modification of the movement of the detachment point, and their oscillations are inhibited.

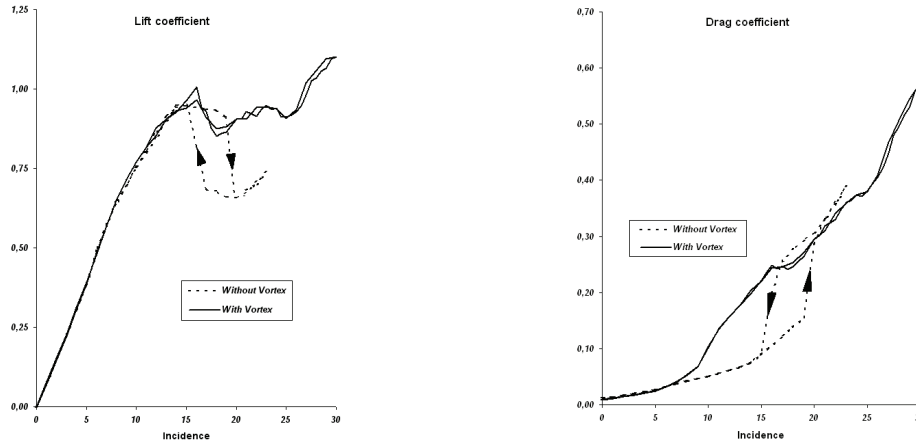


Figure 2: Lift and drag coefficient of the NACA0015 foil with and without vortex.

Concerning the structure of the boundary layer, measurements of vertical and longitudinal velocities are performed on the wall normal from the outer region of the boundary layer at different stations  $x/c$  in order to evaluate the displacement and momentum thicknesses at 15°. Figure 3,

these measurements are reported as the shape factor  $H_{12}$  (replaced by  $h = \frac{H_{12} - 1}{H_{12}}$  in order to

conserve the same order of magnitude even in the detachment area *Kline et al.* [12]). The  $h$  values corresponding to classical incipient detachment and complete separation are also reported. It can be seen that, in the inflow region the boundary layer is attached until  $x/c=0.7$  and the shape value is near than the one obtained in turbulent boundary layer case. In the outflow region the complete separation is reached for  $x/c= 0.65$  instead of  $x/c=0.45$  without vortex. As it is expected in the inflow region the vortex decreases the separation near the trailing edge by the transfer of momentum in the boundary layer leading a reduction of separation (*Velte et al.* [9]).

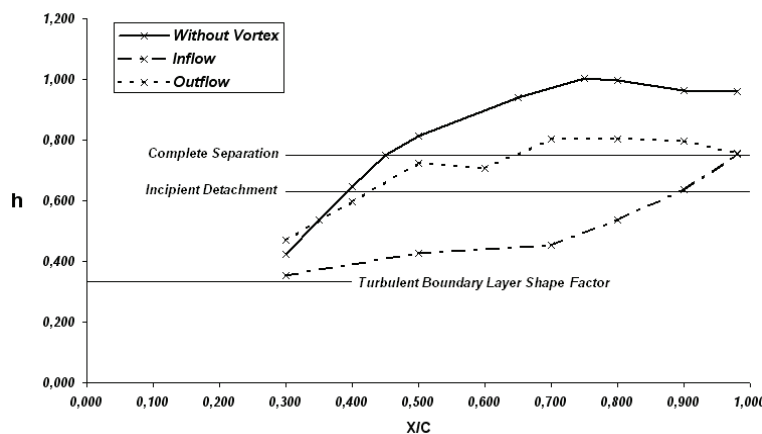


Figure 3: Shape factor in the boundary layer for different span positions.

High speed stereoscopic PIV measurements have been realized for higher incidences (15°, 20°, 25°) in the vertical plane  $(x,y)$ . Figure 4, shows the iso-contours of normalized longitudinal  $U$  and vertical  $V$  velocity components without vortex in the spanwise plane  $z=0$  and with vortex at inflow and outflow regions. In the outflow region the detachment is thicker and the wake is deviated towards positive  $y$ . As expected through the  $h$  value evolution, in the inflow region the flow is maintained attached and thus large incidences can be achieved without stall occurrence.

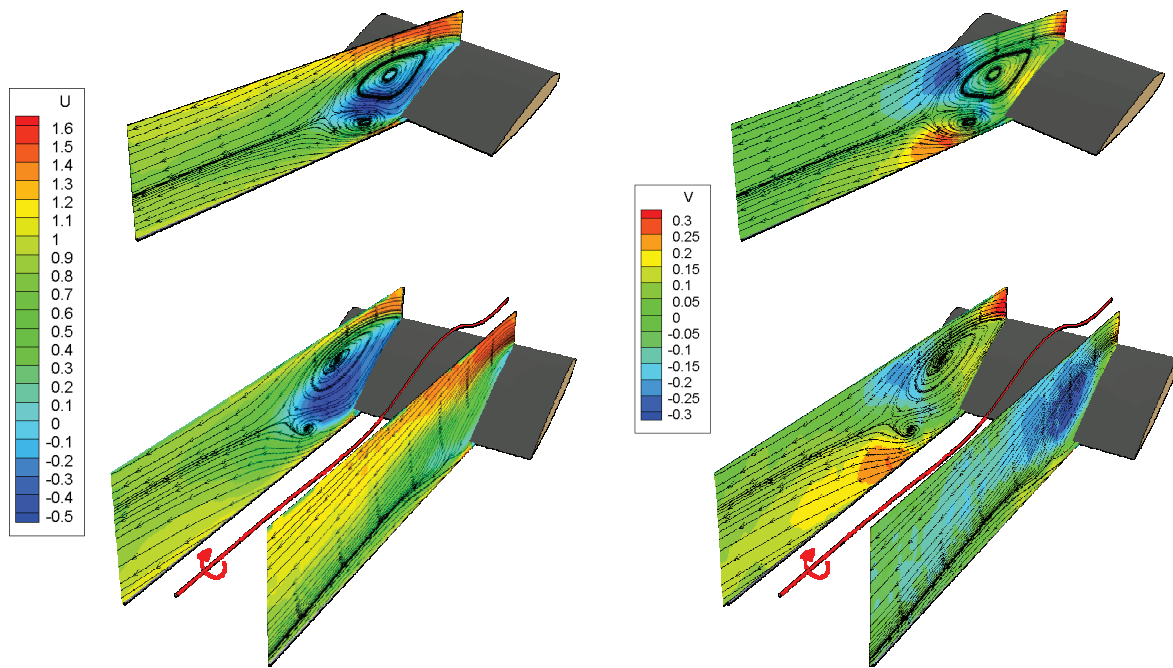


Figure 4 : Iso-velocity contours of U (left) and V (right) components at 25° superimposed with 2D (streamline).

Spectral analysis has been performed to determine the effect of the vortex on the shedding frequency. On Figure 5 spectra measured in the far wake (2 chords downstream of trailing edge) of the foil and associated Strouhal numbers are reported.

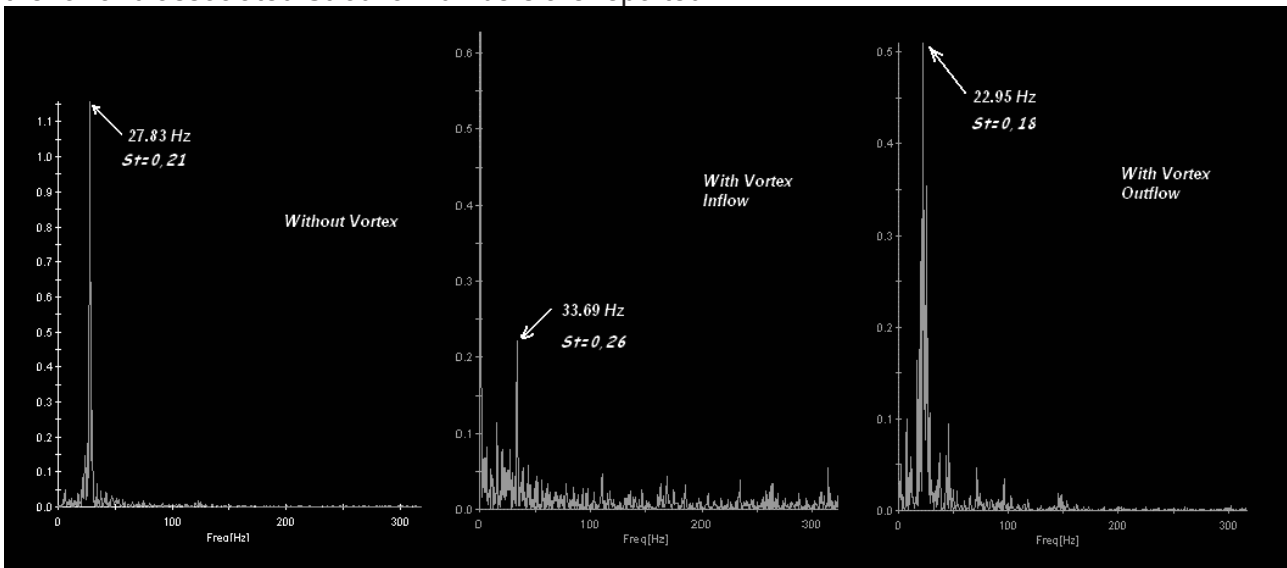


Figure 5: Spectra in the wake

As it is observed by *Djeridi et al.* [13] and *Sarraf et al.* [14] without vortex the establishment of von Kàrmàn instability ( $St = 0.21$ ) is associated with an increase of the maximum spectral amplitude and a decrease of the frequency. In the inflow area the Strouhal number increases and in the outflow region it slightly decreases. This behaviour is consistent with an inhibition of the establishment of the Kàrmàn instability in the inflow area as shown by the iso-contour of vertical component where the two lobes structure disappears.

To better understand the physical mechanisms of inhibition of Kàrmàn Street and boundary layer reattachment in the inflow area, near wake turbulent quantities, shear layer topology and modal energy distribution are studied by use of the full data base acquired at different incidences.

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