TANDEM AIRFOIL VORTEX INTERACTION IN DEEP-STALL

Hétru Laurent, Kolb Sébastien, Montagnier Olivier & Faure Thierry M.
Air Force Research Center (CReA), French Air Force Academy, Salon de Provence, France

Abstract Deep-stall is a flow regime which may occur in tandem airfoil configurations at high angle of attack. It results from a detached flow on the downstream airfoil and a drop of the lift, rendering the elevators ineffective for a potential recovery. The present numerical simulation describes vortices interaction with the downstream airfoil and its effect on change in lift for a given tandem airfoil configuration.

I INTRODUCTION

The phenomenon of stall is well-known for a single airfoil and leads to a collapse of the lift and a dramatic increase of the drag. On T-tail airplane configuration, where the upstream airfoil is the wing and the downstream one the tail, deep-stall occurs for high angles of attack when the tail is inside the turbulent wake of the stalled main wing. It is a stable equilibrium, where the elevators are ineffective for a potential recovery. This behavior has been described [1], [2] after the crash of the BAC 1-11 in 1963. As deep-stall is essentially two-dimensional, the present study focuses on time development of the flow resulting on the interaction between two airfoils. The aim of this numerical simulation is to correlate the motion of flow vortices and their interaction with lift drop.

II TANDEM AIRFOIL CONFIGURATION

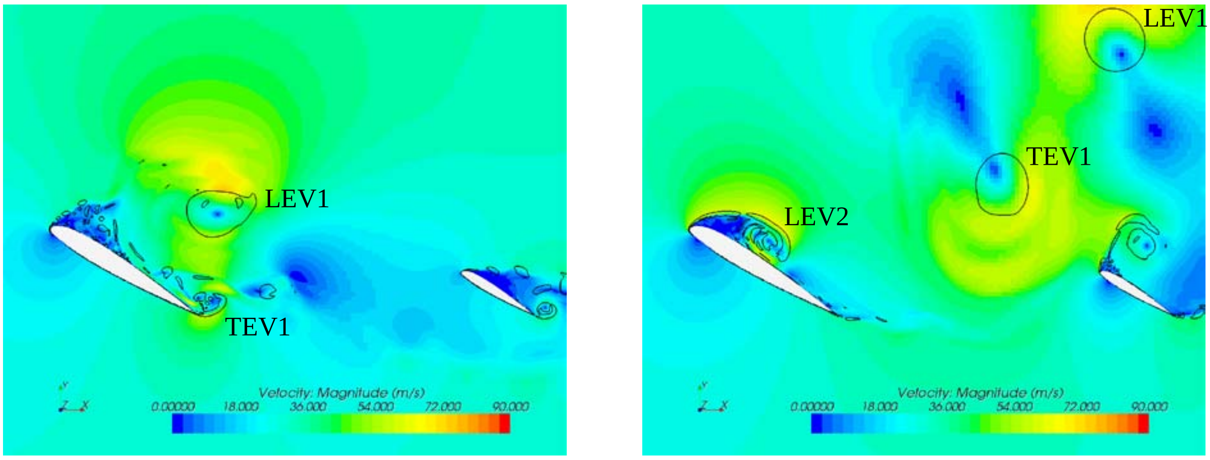
As the flow dynamic frequencies are far larger than the change in the tail airfoil angle of attack, corresponding to a corrective action on the elevators, a benchmark configuration is studied disregarding any change in the incident flow. The tandem airfoil configuration consists in two NACA 23 012 airfoils, whose chords are respectively c for the wing (upstream airfoil) and c / 2 for the tail (downstream airfoil). The distance between the airfoils is $2c$ along the upstream airfoil chord and c in a direction orthogonal to that chord. The flow is incompressible and the Reynolds number built on the upstream wing chord is 300 000. Numerical simulations are carried out with a Detached Eddy Simulation (DES) model [3] implemented in the Star-CCM+ software and using a near-wall k-ω RANS model, coupled with a classical LES method in selected flow windows [4]. Concerning time solver, a second order finite differences implicit scheme is used. The calculation domain is a box of $20c\times20c$, the two airfoils are placed in the center of the box, consisting in 2 109 371 cells rectangular structured mesh. Each time step is get after 10 spatial iterations of the advection term. For present results, the wing and tail angle of attack, relative to the upstream infinite flow direction, is set at α =30 deg, corresponding to a position near deep-stall equilibrium.

III VORTEX STRUCTURE INTERACTION

The spatial Q-criterion is used to detect flow vortical structures [5]:

$$Q = -\frac{1}{2}\left[\left(\frac{\partial U_x}{\partial x}\right)^2 + \left(\frac{\partial U_y}{\partial y}\right)^2 + \frac{\partial U_x}{\partial y}\frac{\partial U_y}{\partial x}\right]$$

It is the second invariant of the velocity gradient tensor, $Q > 0$ defining the inner part of a vortex. **Figure 1** presents the velocity magnitude for two different phases of the wing airfoil vortex shedding, corresponding to the maximum and minimum lift of the tail airfoil. The leading edge (LE) wing airfoil vortex shedding frequency is 88 Hz. The black contours identify a threshold level of the Q-criterion in order to locate the vortices. **Figure 2** shows the time development of the wing and tail airfoil lift coefficients and tail drag coefficient. The periodic repetition of the following events is observed from time development of velocity fields. A LE vortex is generated on the wing and advected on the airfoil upper side before its ejection: this time corresponds to the maximum lift of the wing (positions 1, 2, 3 in **Figure 1**). A trailing edge (TE) wing vortex is then generated and rapidly ejected from the wall. If no wing vortex is located in the vicinity of the tail, the incident flow on the tail presents low velocity magnitude, involving a decrease in dynamic pressure and flow deflection, and leading to a lift fall (**Figure 1**-a and **Figure 2** position a). Both LE and TE wing vortices are advected toward the tail airfoil. The LE wing vortex passes far away the tail and has little influence on its lift. However, the TE wing vortex passing near the tail induces larger velocity magnitude on the tail and an increase of its upstream dynamic pressure and local angle of attack, resulting in a lift rise (**Figure 1**-b and **Figure 2** position b). Note that this lift maximum is neither associated with the separation of a LE nor TE vortex from the tail airfoil. Furthermore, the maxima and minima of tail lift and drag arise at the same time. The identification of the aerodynamic coefficients for additional flow angles of attack in a flight dynamics model would lead to build the phase portrait (α, $d\alpha/dt$).



a) b)

Figure 1. Velocity magnitude and identification of vortices with the *Q*-criterion (black line) for: a) minimum value of tail lift, b) maximum value of tail lift. LEV1: leading edge vortex 1, TEV1: trailing edge vortex 1, LEV2: leading edge vortex 2.

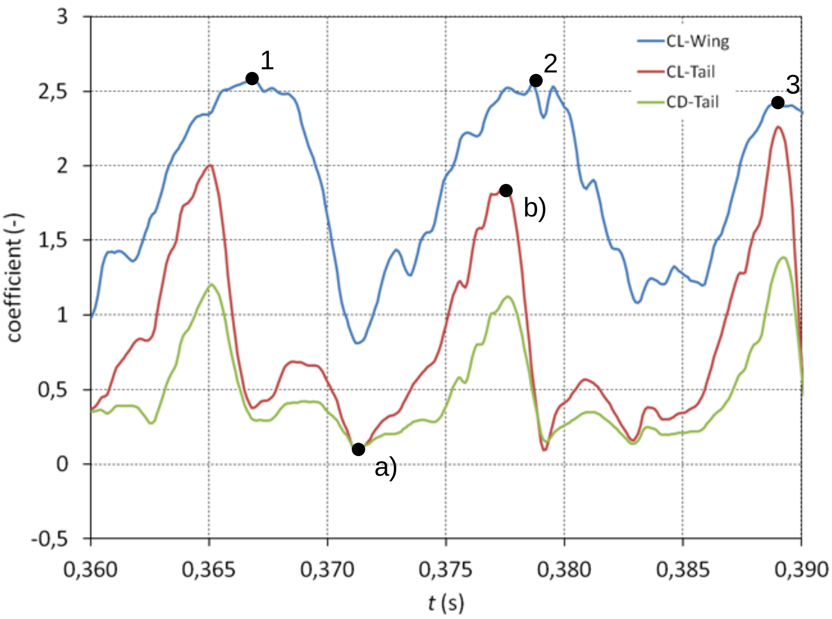


Figure 2. Time development of wing (blue) and tail (red) lift coefficients and tail (green) drag coefficent: a) maximum value of tail lift, b) minimum value of tail lift.

References

[1] E.R.R.T. Taylor. A systematic study of the factor contributing to post-stall longitudinal stability of T-tail transport configurations. *AIAA Aircraft Design and Technology Meeting* November 1965.

[2] E.R.R.T. Taylor. Deep stall aerodynamic characteristics of T-tail aircraft. *NASA conference on aircraft operating problems* NASA SP-83, 1965.

[3] P.R. Spalart, W.H. Jou, M. Strelets, S.R. Allmaras. Comments on the feasibility of LES for wing and on a hybrid RANS/LES approach. *1st AFOSR International Conference on DNS/LES* Louisiana Tech University, Ruston, August 1997.

[4] M. Strelets. Detached eddy simulation of massively separated flows. *AIAA 2001-0879* 2001.

[5] J.C.R. Hunt, A.A. Wray, P. Moin. *Eddies, stream and convergence zones in turbulent flows*. Center for Turbulence Research Report CTR-S88: 193, 1988.