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Buffet and buffeting control in transonic flow

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Abstract

In transonic flow conditions, the shock wave/turbulent boundary layer interaction and the flow separations on the upper wing surfaces of a civil aircraft induce flow instabilities, "buffet" and then structural vibrations, "buffeting". Buffeting can greatly affect aerodynamic behavior. The buffeting phenomenon appears when the aircraft's Mach number or angle of attack increases. This phenomenon limits the aircraft's flight envelope. The objectives of this study are to cancel out or decrease the aerodynamic instabilities (unsteady separation, movement of the shock position) due to this type of flow by using control systems. The following actuators can be used, "Vortex Generators" situated upstream of the shock location and a new moving part designed by ONERA, situated at the trailing edge of the wing, the "Trailing Edge Deflector" or TED. It looks like an adjustable "Divergent Trailing Edge". It is an active actuator and can take different deflections or be driven by dynamic movements up to 250 Hz. Tests were performed in transonic 2D and 3D flow with models well equipped with unsteady pressure transducers. For high lift coefficients, selected deflections of the "Trailing Edge Deflector" increase the wing's aerodynamic performances and delays the onset of "buffet". Furthermore, in 2D flow "buffet" condition, the "Trailing Edge Deflector", driven by a closed-loop active control using the measurements of the unsteady wall static pressures, can greatly reduce "buffet". In 3D flow "buffeting" conditions, the 2D flow control principle is available but some differences must be considered. Vortex generators have a great impact on the separated flows. The separated flow instabilities are greatly reduced and the buffet is totally controlled even for strong instabilities. The aerodynamic performances of the airfoil are also greatly improved.

Keywords: Transonic flow; Control; Closed loop; Separated flow; Buffet; Buffeting; Actuators; Trailing edge

1. Introduction

In general term, buffeting is the structural response to an aerodynamic excitation created by a viscous phenomenon that may exist on different parts of a body in a flow. This aerodynamic excitation, buffet, is due to pressure fluctuations. The following phenomena can produce enough energy to excite the structure:

– the pressure fluctuation levels in a flow separation bulb,
– the pressure fluctuation levels in a vortex,
– transonic buffet, fluctuations of pressure levels in the shock wave and in separation area (movement of the location of the shock and of the flow separations levels away from the shock wave to the leading edge).

The flow instabilities, buffet, that induce buffeting are natural and self-sufficient. No upstream flow fluctuations produce buffet. These phenomena can be observed on aircraft, rocket, turbomachine stages, etc.

Buffeting limits the flight envelope of civil aircraft. Even if buffeting is not dangerous and destructive, it can increase structural fatigue, affect aircraft maneuverability and decrease passenger comfort.

The aims of this study are to cancel out or decrease aerodynamic instabilities, buffet, by using control systems. Only

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Nomenclature

A	gain of the control law
alpha, α	airfoil angle of attack
c	airfoil chord length
C_l	lift coefficient
C_d	drag coefficient
$d, \delta, \delta(t)$	deflector angle
δ_m	mean deflector angle (control law)
$\delta'(t)$	dynamic deflector angle (control law)
M0	free stream Mach number
ν	cinematic viscosity
P	pressure or shock location (control law)
Q0	free stream kinetic pressure
Re, Re0	Reynolds number Re $=$ V0 c/ν
RMS	root mean square
t	time
τ	time delay of the control law
x/c	chord wise position from LE$/c$
V0	free stream velocity

transonic buffet, with shock location and separated flows instabilities, is studied in this paper.

"Vortex Generators" actuator situated upstream of the shock wave was used to decrease separated flows. A new moving part located at the trailing edge of the wing, "Trailing Edge Deflector" or TED, designed and patented by ONERA, was used to delay buffet and buffeting onset and to reduce buffet instabilities. It looks like an adjustable "Divergent Trailing Edge". It is an active actuator and can take different deflections or be driven by dynamic movements up to 250 Hz.

These control systems were tested in transonic flow cases, two-dimensional flow, 2D, and three-dimensional flow, 3D. Aerodynamic studies on stiff 2D airfoils in ONERA T2 wind tunnel were performed to analyze the effect of the actuators on the instabilities. In a second phase, the new control system, TED, was studied in transonic 3D flow. A model similar to transport aircraft was designed and manufactured with three independent TED and more than 100 unsteady pressure transducers. Tests were performed in ONERA S2 wind tunnel.

2. General description of the transonic buffet phenomenon

Buffet can appear in many flight flow conditions. It is accentuated in transonic flow by the movement of the shock wave location caused by the flow separations, when they spread from the shock to the trailing edge. Only buffet in transonic flow with "shock wave/turbulent boundary layer interaction and flow separations", is described in this section.

In 3D transonic flow conditions, the shock wave/turbulent boundary layer interaction and flow separations induce flow instabilities, "buffet", and then structure vibrations on their eigen modes, "buffeting" (these modes can be different from aerodynamic instability modes). It can have a significant effect on the aerodynamic behavior of the aircraft. The "buffet" phenomenon appears at high lift coefficients when the aircraft's Mach number or the angle of attack increases. This phenomenon limits the aircraft's flight envelope (Fig. 1).

Data taken from the bibliography and 2D and 3D transonic flow tests have made it possible to describe the buffet phenomenon. Transonic flows are often crossed by shock waves induced by a sudden recompression of the flow (Fig. 2). These waves interfere with the boundary layer. A complex, localised interaction takes place with deterioration of the local speed distribution until flow separation occurs [2,5]. When the intensity of the shock wave is great enough, through an increase in the angle of attack or in the flow Mach number for example, the flow separation spreads to the trailing edge and it increases in size. Instabilities then develop on a large scale. The size of separation flow fluctuates as the position of the shock wave moves from downstream to upstream and *vice versa* (Fig. 2). The frequencies and amplitudes of the fluctuations depend on the shape of the airfoil and on the aerodynamic conditions of the flow. The pressure levels, and therefore the lift, vary very greatly. The term buffet can be used to describe these aerodynamics instabilities and can produce "buffeting".

But generalities on the 3D instabilities at the origin of the 3D buffet on the upper side of a wing are difficult to present because each case is particular. In fact, the geometrical parameters used to the wing characterisation which can influence the 3D flow are various, sweep angle, aspect ratio, twist law, span-wise evolution of the airfoil, ... The aerodynamic instabilities between a 2D and 3D transonic buffet seem to be very similar [6,12] as described upside. These two phenom-

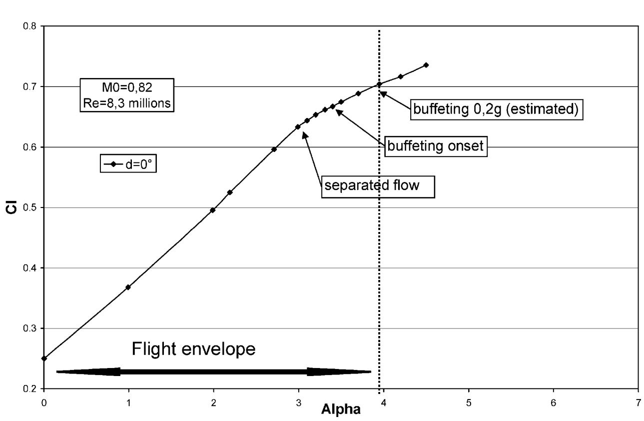

Fig. 1. Example of flight envelope limitation [2].