Shock-buffet Instability of 3D Wings

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Shock-buffet Instability

Shock buffet is a transonic flow instability phenomenon in which a shock wave generated on a lifting surface interacts with a separated boundary layer, resulting in self-sustained oscillating flow over the surface. The instability exists for a range of mean-flow Mach numbers and incidence angles. The instability onset boundary is presented in figure 1 for the case of NACA0012 airfoil (via wind tunnel tests and CFD simulations).

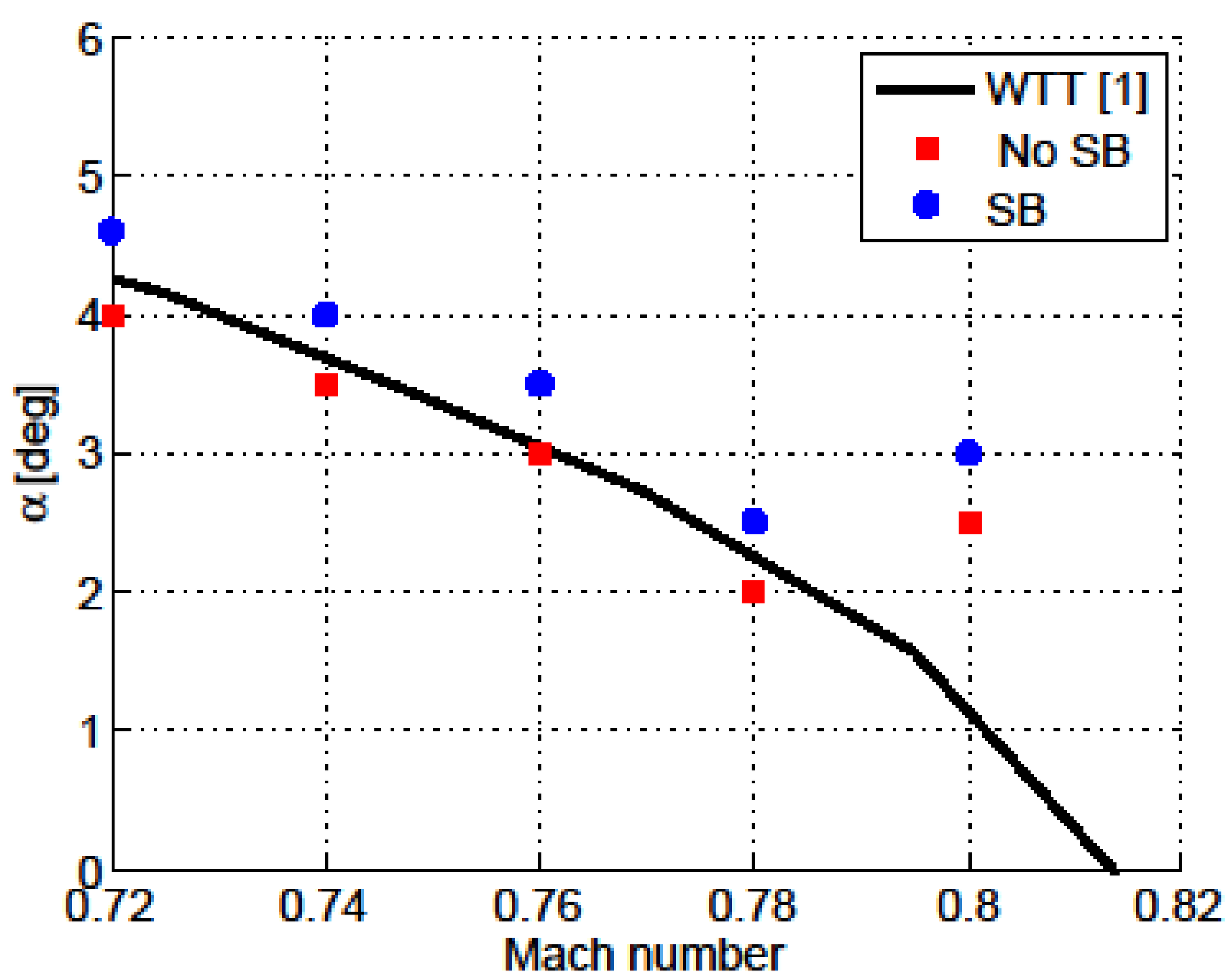

Figure 1. Instability onset boundary, NACA0012 airfoil

2D Physical Mechanism

The physical mechanism of shock-buffet was studied by means of Unsteady Reynolds-averaged Navier-Stokes (URANS) simulations of three different airfoils, suggesting the essential link between the source of instability and the geometrical shape of the airfoil.

The buffet is initiated by shock/separation-bubble unstable interaction. The instability depends on strengthening of the shock as it (initially) travels upstream. Figure 2 presents upper surface pressure variations as the shock travels from its most downstream to its most upstream chord position.

The shock strengthening is explained by the combined effect of three factors: the ***wedge*** (shock inclination due to separation) and ***dynamic*** (shock motion against the upstream flow direction) effects that tend to increase the shock strength as it moves upstream, and the airfoil surface ***curvature*** effect that tends to decrease its strength as it moves upstream. Figure 3 presents Mach maps and flow streamlines around the NACA0012 airfoil at extreme aft and forth shock positions.

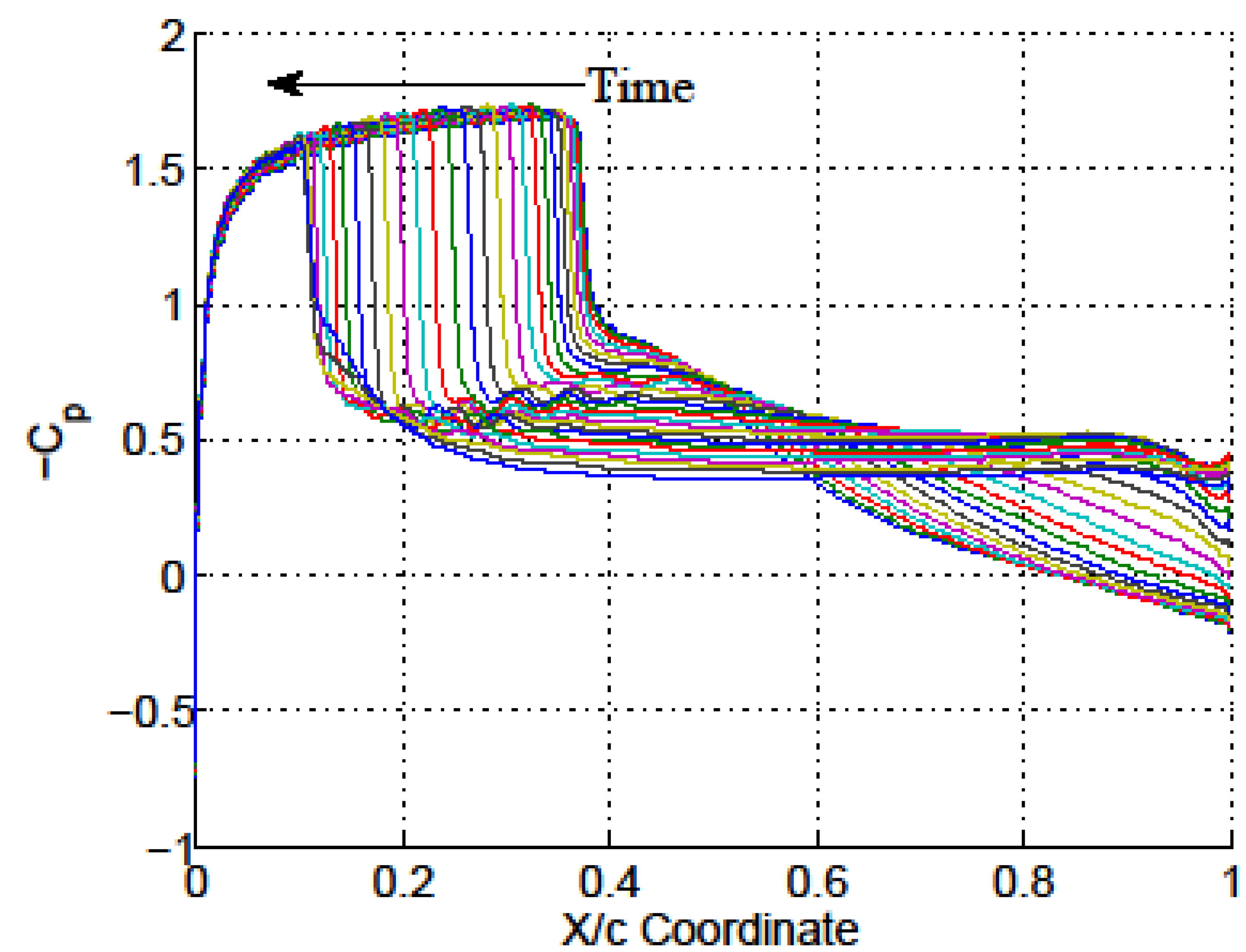

Figure 2. Surface pressure variation during a single buffet cycle

Necessary Conditions for Buffet Onset

Based on these results, two necessary criteria for shock-buffet onset conditions were suggested:

a) The shock position is aft of and sufficiently close to the maximum upper-surface curvature location
b) Significant flow separation occurs aft of the shock

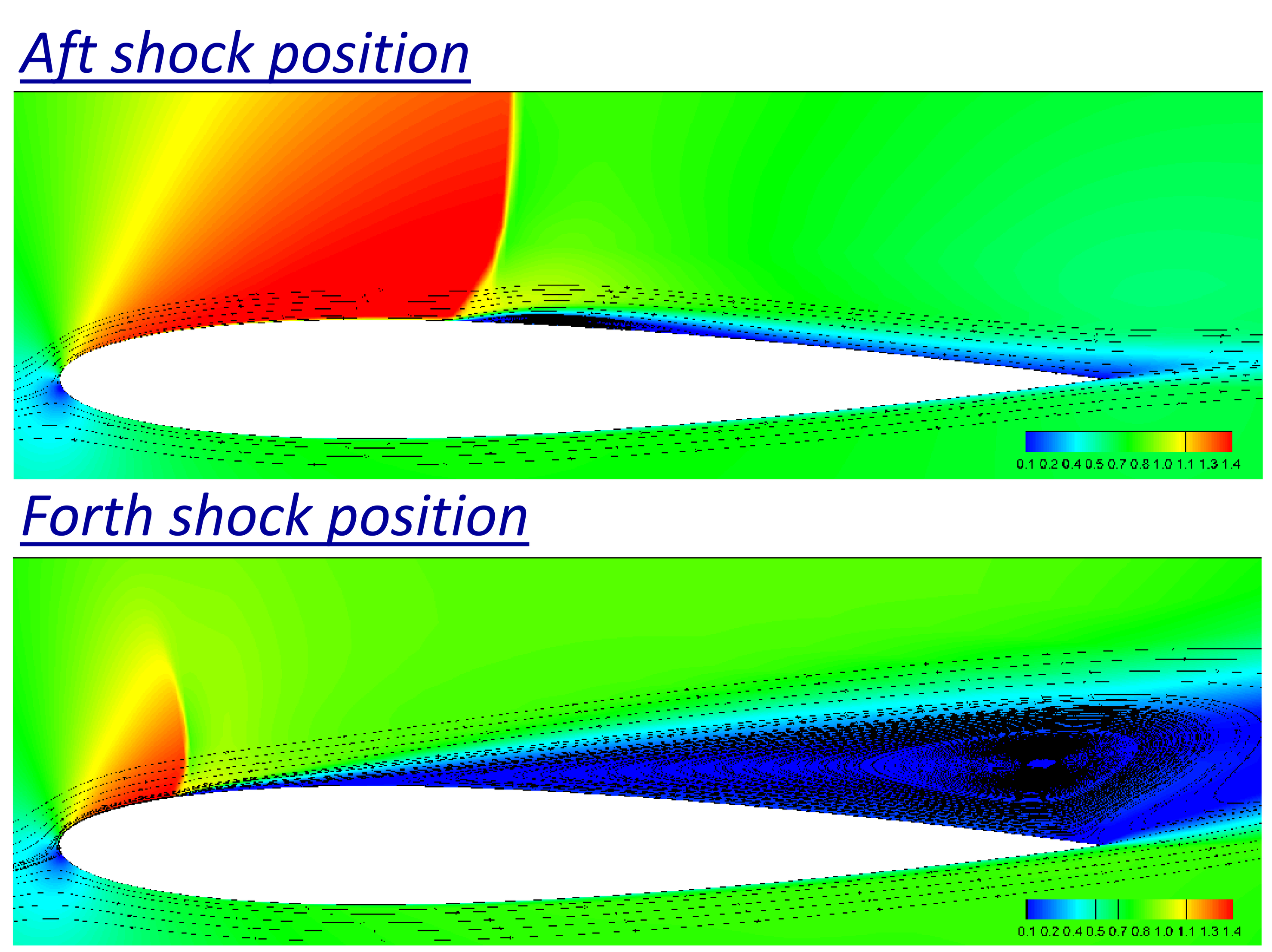

Figure 3. Mach maps and flow streamlines extreme shock locations

3D Effects on the Physical Mechanism

Shock-buffet characteristics were studied on finite, swept, transonic wings. The following phenomena are identified:

a) Both chordwise and spanwise periodic shock oscillations are observed

3D Effects – cont'd

b) Shock oscillations are non-harmonic and typical reduced frequencies are considerably higher than for 2D cases
c) Buffet characteristics are governed by the sweep angle, λ-type shock pattern and corresponding regions of separated flow

Figure 4 presents upper surface pressure and boundary-layer streamlines at pre-buffet and buffet flow conditions for the 30[deg] swept, 6.5 aspect ratio transonic OAT15A wing.

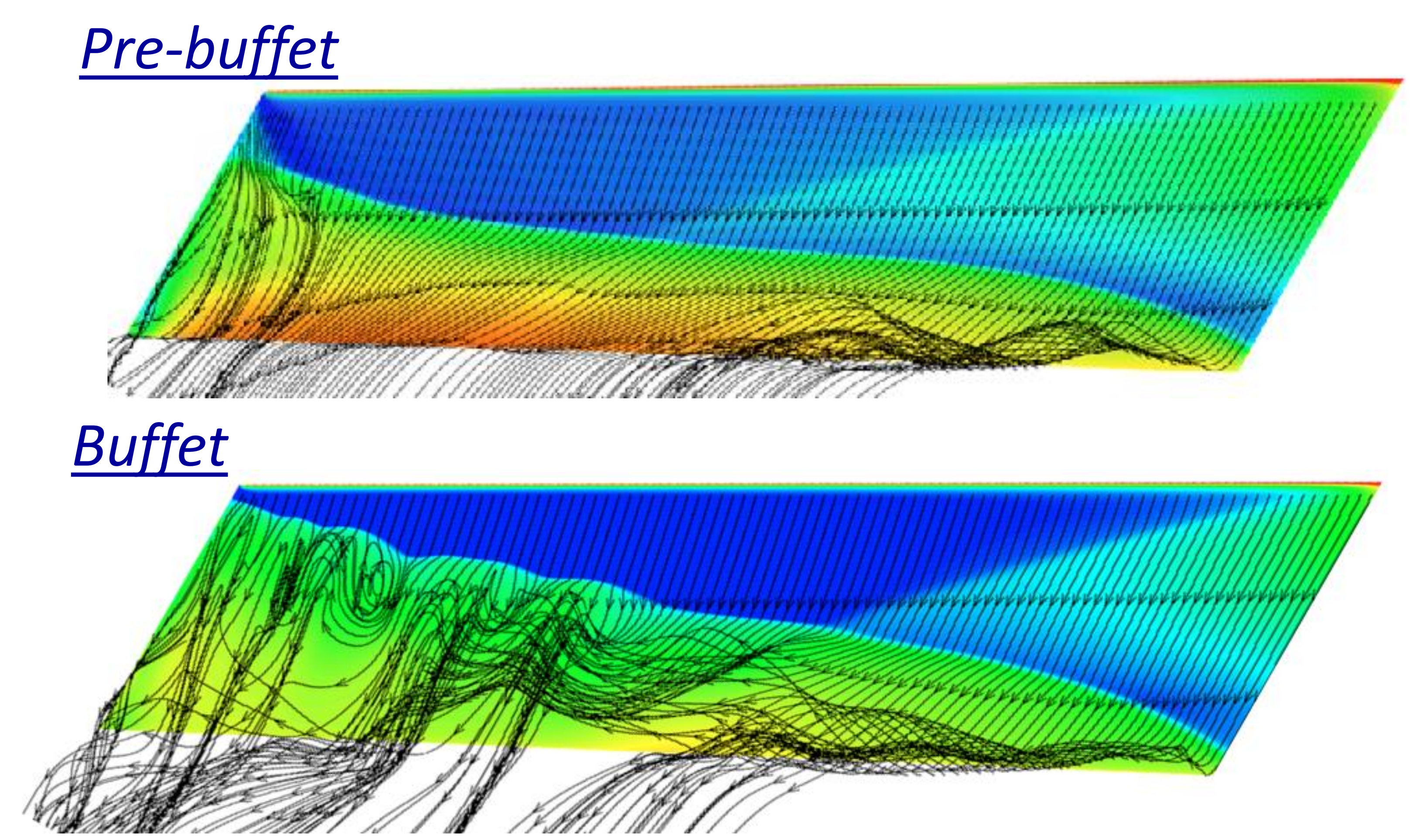

Figure 4. Surface pressure and boundary-layer streamlines at pre-buffet and buffet flow conditions, OAT15A transonic wing

Unsteady Aerodynamics Response

The unsteady aerodynamic response in the vicinity of shock buffet conditions was studied by simulating pitch and flap oscillated airfoils. Pitching moment frequency response is presented in figure 5. A resonance was observed at the buffet natural frequency. Positive phase of the pitching moment response suggests unstable aeroelastic phenomena may occur about buffet conditions.

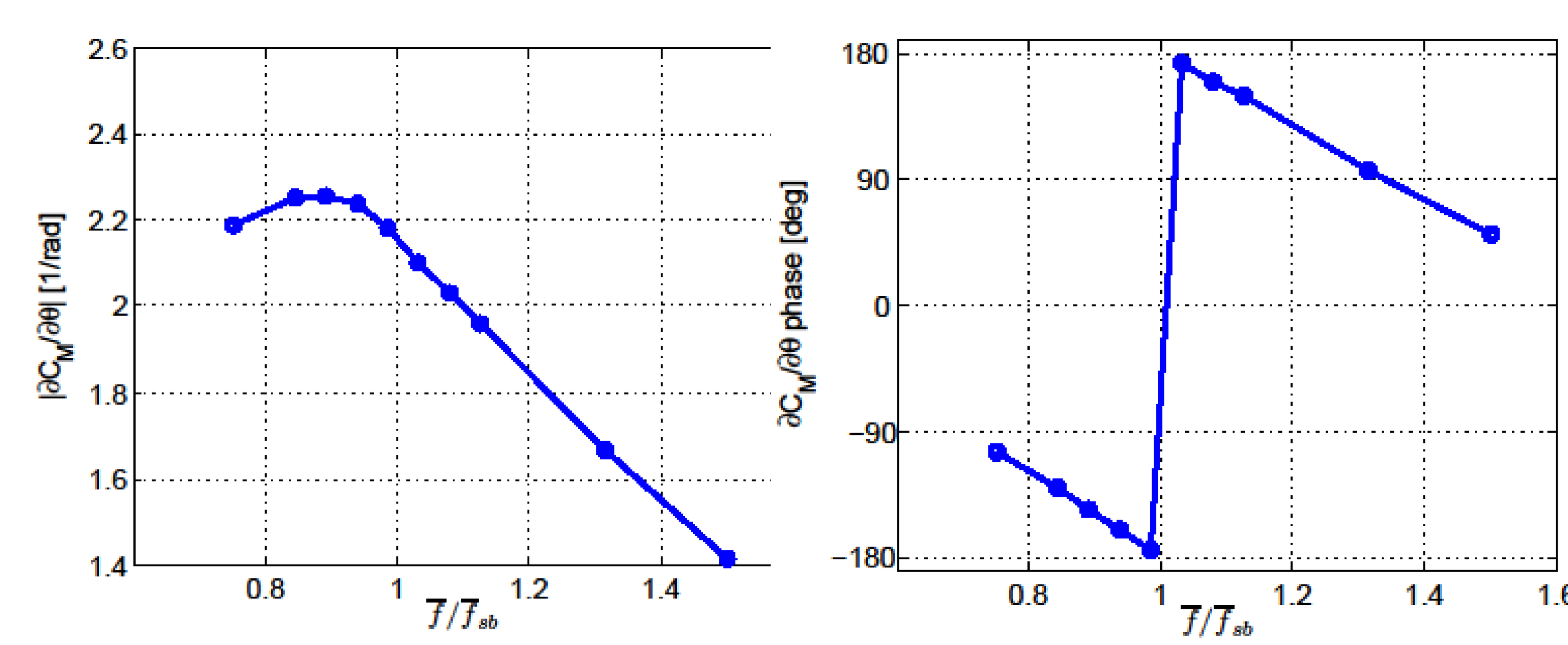

Figure 5. Frequency response of the pitching moment to pitch excitation at buffet flow conditions, NACA0012 airfoil