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Influence of Mach number and angle of attack on the two-dimensional transonic buffet phenomenon

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Abstract

Within a narrow band of flight conditions in the transonic regime, self-sustained shock oscillations that involve the interaction between shock-waves and intermittently separated shear layers may develop. This phenomenon, known as transonic shock buffet, limits the flight envelope and is detrimental to both aircraft handling quality and structural integrity. In this investigation, numerical simulation of transonic shock buffet over the OAT15A aerofoil is performed to explore the buffet envelope. Unsteady Reynolds-Averaged Navier-Stokes simulations are validated against available experimental data to ascertain the most effective combination of simulation parameters to reproduce autonomous shock oscillations. From the baseline test case, the influence of Mach number and angle of attack on the nature of the buffet response is investigated. Radial Basis Function surrogate models are developed to represent the variation of buffet amplitude and frequency with flight condition. While the frequency is found to increase monotonically with both parameters, variation in buffet amplitude through the region of shock unsteadiness is more complex, particularly at high angles of attack. This is related to a bifurcation in the behaviour of the shock. As incidence increases from onset, the shock dynamics transition from periodic oscillations over the suction surface to quasi-periodic motions, whereby the shock is propelled forward into the oncoming flow during its upstream excursion.

Keywords: Transonic shock buffet; unsteady aerodynamics; shock-wave/boundary layer interaction

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Nomenclature

τ	=	Nondimensional time $\frac{ta}{c}$
a	=	Speed of sound (m/s)
α	=	Freestream angle of attack (°)
M	=	Freestream Mach number
t	=	Time (s)
c	=	Chord (m)
f	=	Frequency (Hz)
U	=	Freestream velocity (m/s)
Re	=	Freestream Reynolds number
C_L	=	Lift coefficient
$C_p^{'}$	=	Root mean square pressure coefficient
$\bar{C_p}$	=	Mean pressure coefficient
Δx	=	Mean streamwise grid spacing on suction surface (% c)
$\bar{x_s}$	=	Mean shock location (c)
$\bar{C_L}$	=	Mean lift coefficient
k	=	Reduced frequency $\frac{2\pi fc}{U}$

1. Introduction

For certain flight conditions in the transonic regime, large amplitude autonomous shock oscillations involving the interactions between shock-waves and thin, separated shear layers may arise. This transonic buffet phenomenon is a limiting factor in aircraft performance. The reduced frequency of shock oscillation is typically on the order of the low-frequency structural modes, resulting in an aircraft that is susceptible to limit cycle oscillations (LCOs), and as a consequence, diminished handling quality and fatigue life.

Hilton & Fowler [1] first observed transonic shock-induced oscillations over six decades ago, yet the physics governing this complex phenomenon remains elusive. In the early work by Pearcey [2], shock buffet onset was linked to the bursting of a shock-induced separation bubble, a condition that has since been determined insufficient for the emergence of shock-induced oscillations [3, 4]. In the seminal work of Tijdeman & Seebass [5], three distinct forms of shock oscillation at transonic flow conditions were identified. Type A consists of sinusoidal shock motion on the aerofoil suction surface, with a shock of varying strength present throughout the cycle. Type B oscillations are similar to Type A; however, as the shock moves downstream

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