EXPERIMENTAL INVESTIGATION OF VERTICAL TAIL BUFFETING ON A TRIPLE-DELTA-WING CONFIGURATION IN TRANSONIC FLOWS

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ABSTRACT

The performance of modern high-agility aircraft is particularly affected by the consequences of vertical tail buffeting at high subsonic and transonic Mach numbers and medium to high angles of attack (AoA). High-performance aircraft are characterized by low aspect-ratio wings and medium to high sweep angles. In particular, multi-delta-wing configurations exhibit high-angle-of-attack maneuvering capability due to nonlinear vortex-induced lift. At low AoA, the boundary layer around the leading edge interacts with the entrained flow and generates a large-scale leading-edge vortex. At higher angles of attack, the vortex core flow becomes unstable, indicated by strong fluctuations in axial velocity profiles and an adverse axial pressure gradient over the wing [1]. Above a certain AoA, the vortices exhibit a structural change in the onset of vortex breakdown, characterized by a high turbulent flow field downstream of the vortex breakdown position. The vortex breakdown induces significant pressure fluctuations, leading to severe structural vibrations on the vertical tail. This complex aeroelastic phenomenon is defined as tail buffeting [2] and contributes to a significant reduction in the flight performance of high-agility configurations. While experimental studies have investigated vertical tail buffeting in low-speed wind tunnels [3, 4], there is a lack of experimental results for multi-delta-wing configurations under flight-relevant Mach numbers.

The DLR-F23-T configuration investigated in this study is a generic triple-delta-wing half-span wind tunnel model with an ogival cosine-chined forebody, a vertical tail, and a peniche (see Fig. 1). The wing consists of three main sections, the so-called leading-edge vortex controller (LEVCON), the strake, and the main wing, with leading-edge sweep angles of $\varphi_{W,1} = 45°$, $\varphi_{W,2} = 75°$, and $\varphi_{W,3} = 45°$, respectively [5]. The wind tunnel model is further defined by three characteristic lengths, the wing root chord ($c_{r,W} = 0.575$ m), the total length ($l_M = 0.862$ m), and its half span ($s_M = 0.420$ m), cf. Fig. 1. The vertical tail (VT) is designed as a V-tail and has a height of $b_{VT} = 0.157$ m. The baseline configuration features a VT with a dihedral angle of $\nu_{VT} = 28°$ relative to the xz-plane, while a second configuration uses a VT with a dihedral angle of $\nu_{VT} = 45°$. For each configuration, both a quasi-rigid and a flexible VT are designed and implemented. The rigid components are made of steel (Ramax HH), while the flexible components are 3D-printed from polyamide (PA12).

The experimental study is conducted at the Transonic Wind Tunnel Göttingen (DNW-TWG). The DNW-TWG is a closed circuit, continuous wind tunnel of Göttingen type whose test section has dimensions of 1.0 m (W) x 1.0 m (H) x 4.5 m (L). The wind tunnel test section features perforated walls specifically designed to enable high transonic flow. The DLR-F23-T model is mounted on the rotatable disk of the hydraulic-actuated test-rig in the test section of the DNW-TWG, see Fig. 2. The upper wing surface of the wind tunnel model is equipped with 71 unsteady surface pressure transducers, arranged in three spanwise-aligned pressure sections (S_1 to S_3).

On the vertical tail, 26 transducers of the same type are installed. To assess structural excitation due to buffeting, the model is fitted with several uniaxial accelerometers. The root of the vertical tail is instrumented with three T-rosette strain gauges to capture strain and root bending moments.

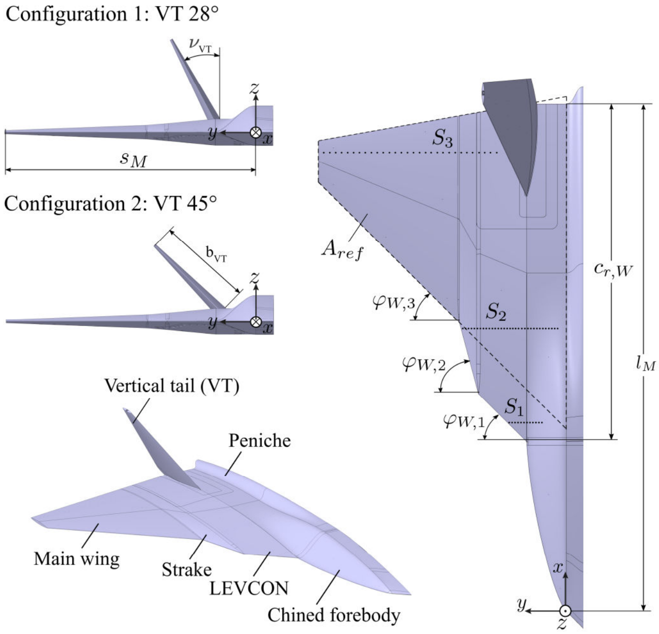

Figure 1: Geometry of the DLR-F23-T configuration.

Figure 2: DLR-F23-T model mounted on the hydraulic-actuated pitching test rig in the perforated test section of the DNW-TWG wind tunnel.

Figure 3 depicts the lift coefficient C_L and the pitching moment coefficient C_{my} for the configuration with the rigid vertical tail ($\nu_{VT} = 28°$) for a Mach number of 0.55. The bars indicate the corresponding standard deviations. The lift coefficient increases linearly with a constant gradient up to $\alpha = 17°$. The maximum lift coefficient $C_{L,max}$ is reached at $\alpha = 21°$. At this angle of attack, it is hypothesized that the midboard vortex (MBV) starts to break down over the wing, leading to a reduction in vortex-induced lift and a decrease in total lift. The pitching moment coefficient shows a significant increase between $\alpha = 21°$ and $\alpha = 22°$, indicating the buffet onset. From $\alpha = 22°$, strong fluctuations in the pitching moment coefficient are observed, as indicated by the increased standard deviation. Figure 4 shows the power spectral density (PSD) of the pressure fluctuations c_p' at the inboard side of the rigid vertical tail ($\nu_{VT} = 28°$) for three different angles of attack. The frequency spectrum at an angle of attack of $\alpha = 20°$ exhibits a broadband character without a dominant peak. The first buffet peak is detected at $\alpha = 22°$, which is consistent with the buffet onset in both the lift and pitching moment coefficient. At $\alpha = 24°$, a dominant buffet peak is observed at a frequency of 416 Hz, corresponding to a reduced frequency of $k = 0.84$ ($k = f \cdot c_{MAC}/U_\infty$).

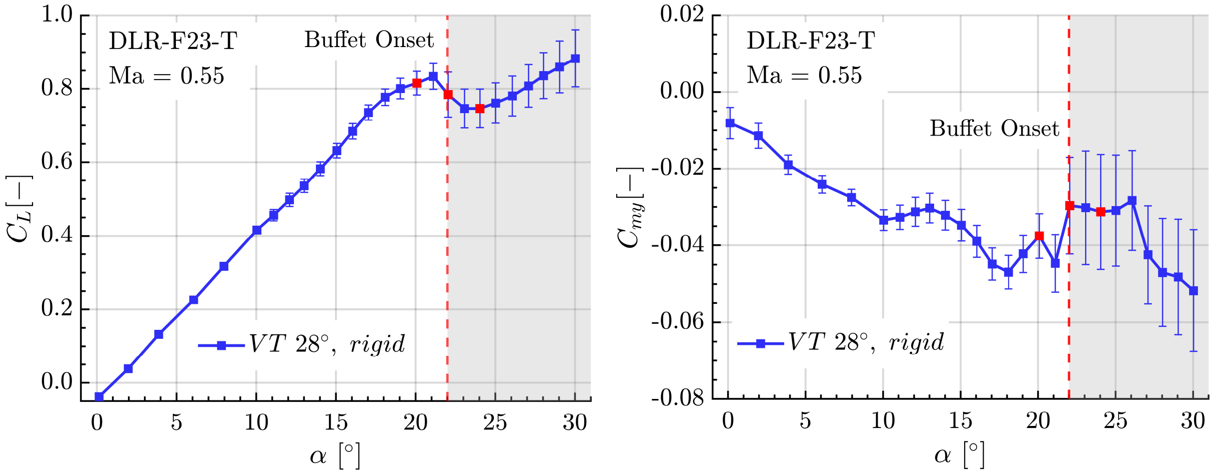

Figure 3: Lift coefficient C_L (left) and pitching moment coefficient C_{my} (right) of the DLR-F23-T configuration with rigid vertical tail ($\nu_{VT} = 28°$) for Ma = 0.55 and $Re_{l\mu} = 2.31 \cdot 10^6$.

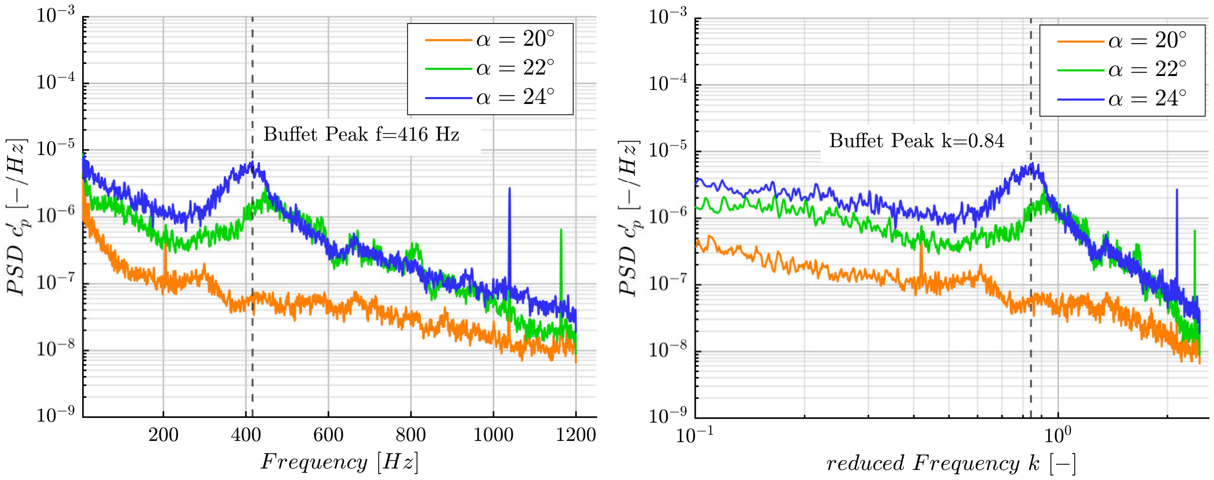

Figure 4: Power Spectral Density (PSD) of the pressure fluctuations c_p' at the inboard side of the vertical tail ($\nu_{VT} = 28°$, rigid) for Ma = 0.55 and $Re_{l\mu} = 2.31 \cdot 10^6$.

In this study, vertical tail buffeting on the DLR-F23-T wind tunnel model is analyzed in more detail, considering variations in the vertical tail dihedral angle ($\nu_{VT} = 28°$ and 45°) and material properties (quasi-rigid and flexible). A comprehensive evaluation of the experimental measurements, including aerodynamic forces and moments, unsteady pressure data, acceleration data, root bending moments, and modal analysis of the wind tunnel model, will provide findings on the coupled aerodynamic-structural behavior of the vertical tail.

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