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Corresponding author: Sedlacek Dominik
e-mail of corresponding author: dominik.sedlacek@tum.de
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Title

Influence of the Leading-edge Radius on Vortex Development at Hybrid-Delta-Wing Configurations

Authors

Dominik Sedlack[1], Ankit Kasi[1], Christian Breitsamter[1]*

** Corresponding author*
[1] Technical University of Munich, 85748 Garching bei München, Germany, dominik.sedlacek@tum.de

Abstract

Vortices and vortex systems are of high importance for high-agility aircraft. For configurations with low aspect ratio and medium to high leading-edge sweep, the flow separates at the leading edge and forms a vortex system. At configurations with multiple swept leading edges two or more vortices develop and interact with each other. The flow characteristics of slender and non-slender delta wings have been investigated extensively [1]. Luckring et al. [2] has shown the influence of the leading-edge radius on a 65° delta wing. A blunt leading edge leads to a part span leading-edge vortex separation and is more dependent on the Reynolds number. Extensive investigations regarding multiple swept wing configurations with sharp leading edges and the interaction of the resulting vortices were carried out at the Chair of Aerodynamics and Fluid Mechanics (AER) of the Technical University of Munich (TUM) [3]. To expand the knowledge of the leading-edge radius influence on delta wings with multiple swept leading edges, several experiments are conducted.

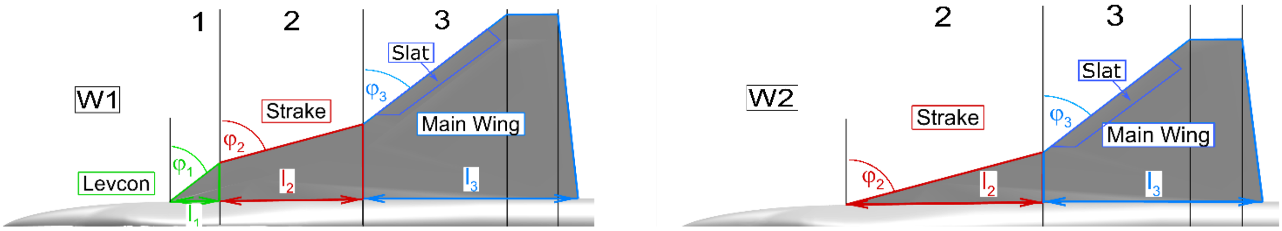
In this study, experimental investigations of the flow field at two hybrid-delta-wing configurations are perfomed. The investigated configurations are shown in Fig. 1. The first is a triple-delta-wing configuration, the so-called NA1 W1, cf. Fig. 1a. The NA1 W1 consists of three wing segments of different leading-edge sweep: The front part with a medium leading-edge sweep of $\varphi_1 = 52.5°$, followed by a wing mid-section with a high leading-edge sweep of $\varphi_2 = 75°$ and the rear wing section with similar wing sweep as the front section $\varphi_1 = \varphi_3$. The second configuration is a double-delta-wing configuration called NA1 W2, see Fig. 1b, and is characterized by a high leading-edge sweep φ_2 in the front part (strake), and a rear wing section with a medium leading-edge sweep φ_3. Both configurations are tested with a sharp leading edge and a blunt leading edge with a radius of 0.25% as well as 0.5% with respect to the root chord length. Experiments using particle image velocimetry (PIV) as well as force and moment measurements were conducted in the Göttingen type low speed wind tunnel facility at TUM-AER.

In Figure 2 a, the lift (C_L) and pitching moment (C_{my}) characteristics as function of the angle of attack α are shown for the considered configurations. For the W1 configuration, illustrated with filled squares, the lift polar shows the expected non-linear lift increase for angles of attack $\alpha > 8°$. A decrease in $C_{L,\alpha}$ for $\alpha > 12°$ indicates

the appearance of vortex breakdown above the wing. This is also in agreement with the strong increase in the pitching moment coefficient implying a decrease in lift generation in the rear portion of the wing. This also occurs for the double-delta-wing configurations but the decrease in lift and increase in pitching moment is more abrupt and occurs at higher angles of attack α > 22°.

Fig. 2b shows the distribution of nondimensional axial velocity at angle of attack of α = 24° for a cross flow plane located at x/c_r = 0.65 obtained by the PIV measurements. Both configurations show a burst inboard vortex (IBV) and a stable midboard vortex (MBV). The breakdown of the triple-delta-wing configuration (upper image) occurred more upstream and the area of stagnating or reversed flow is larger compared to the double-delta-wing configuration. Latter, shows only slightly reduced flow velocities compared to the inflow velocity.

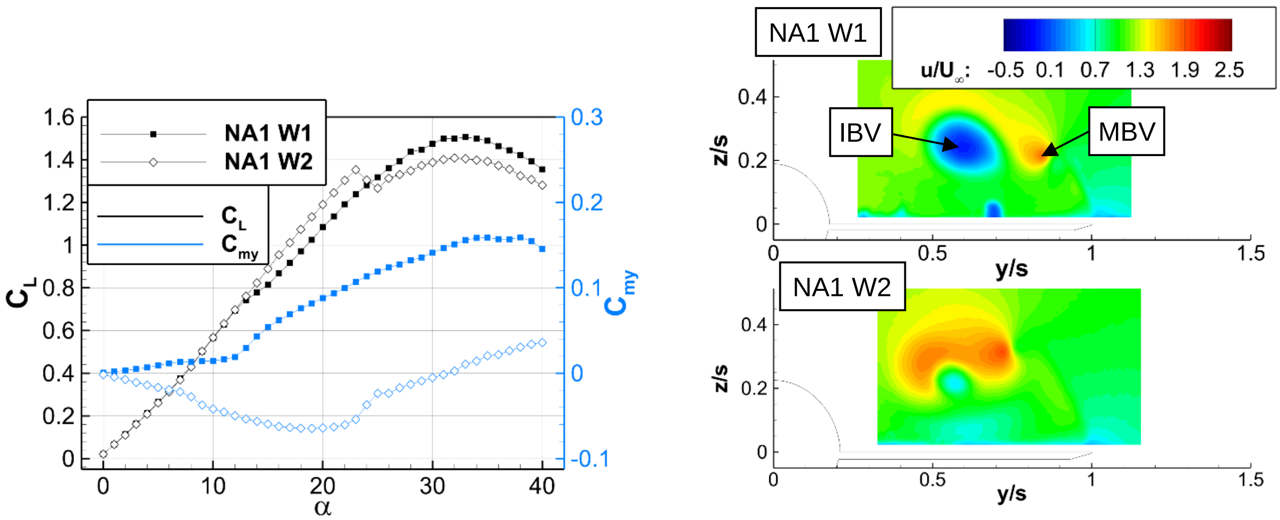
The differences between these configurations will be further discussed in regards to the influence of the leading-edge radius. Especially, the influence on the vortex-vortex interaction between the inboard and midboard vortices and on the vortex breakdown is relevant to the flight characteristics of these configurations.



a) NA1 W1 Planform

b) NA1 W2 Planform

Fig. 1: Hybrid-delta-wing planforms



a) Lift coefficient and pitching moment coefficient for both configurations with sharp leading edges as function of the angle of attack

b) Distribution of nondimensional axial velocity u/U_∞ based on PIV data at x/c_r = 0.65 and α = 24°

Fig. 2: Experimental results at hybrid-delta-wing configurations with sharp leading edges by means of force and moment coefficients as well as PIV measured velocity fields at Ma = 0.15 and Re = 3.0 · 10^6.

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