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Dihedral influence on lateral–directional dynamic stability on large aspect ratio tailless flying wing aircraft

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Abstract The influence of dihedral layout on lateral–directional dynamic stability of the tailless flying wing aircraft is discussed in this paper. A tailless flying wing aircraft with a large aspect ratio is selected as the object of study, and the dihedral angle along the spanwise sections is divided into three segments. The influence of dihedral layouts is studied. Based on the stability derivatives calculated by the vortex lattice method code, the linearized small-disturbance equations of the lateral modes are used to determine the mode dynamic characteristics. By comparing 7056 configurations with different dihedral angle layouts, two groups of stability optimized dihedral layout concepts are created. Flight quality close to Level 2 requirements is achieved in these optimized concepts without any electric stability augmentation system.

1. Introduction

Tailless flying wing configuration aircraft have advantages in aerodynamic and structural efficiency because of their simple shape and they have attracted wide interest in both military and civilian fields. Civilian flying wing aircraft include the Boeing X-48,[1,2] the low noise transporter developed by Cranfield University,[3,4] the flying wing aircraft in the studied by the Russian Central Aerohydrodynamic Institute (TsAGI),[5] and the 250-seat flying wing concept in Beihang University.[6] In the field of military aviation, several countries have developed UCAV with tailless configurations, such as the X-45,[7,8] X-47B,[9] nEURO, etc.[10]

An ideal flying wing aircraft blends wings and fuselage into a lifting body without horizontal or vertical stabilizers. Compared to conventional configurations, it is of low yaw stiffness and yaw damp because of the absence of vertical stabilizers. Therefore, tailless aircraft often exhibit poor lateral dynamic stability. Historically, there have been two methods to solve this problem.

The first method originated from the Northrop cooperation, which started its research on tailless aircraft during the

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1940s. Experimental studies on the flight characteristics of tailless aircraft led to the development of the stability augmentation system.[11,12] This technology laid the foundation for the future success of modern tailless aircraft, such as the famous B-2 bomber.[13] Another approach came from the Germany-based Horten brothers, who conducted their research on pure tailless aircraft using the glider testbed during the 1930s.[14] On their successful tailless fighter, the Ho. 229 (Go. 229), an acceptable lateral–directional flight quality was achieved by using an appropriate sweepback angle and tap ratio without any electronic augmentation.

In most pure tailless aircraft developed in recent years, an electric stability augmentation system is used.[15] In contrast, this paper examines a method to increase the lateral dynamic stability on pure tailless aircraft through use of dihedral layout optimization. Considering a global and multidisciplinary audience, the planform and airfoil of each spanwise section of the tailless aircraft are designed to meet applicable aerodynamic and low observability requirements. Assuming a fixed sweepback angle, tap ratio and aspect ratio, only the dihedral angles may be altered to meet the flying quality requirements. Aerodynamic principles indicate that changes in the dihedral angle can alter the angle of attack along the spanwise section while the aircraft is in sideslip, leading to changes in the lift distribution along the spanwise section and changes in the lateral–directional aerodynamic derivatives. However, these changes in lift distribution caused by the dihedral will only work when the aircraft is in sideslip. Thus, the adjustment of the lateral–directional aerodynamic derivatives can be achieved by setting the dihedral angle along the spanwise section, without affecting the lift-drag ratio performance.

Nickel and Wohlfahrt[14] qualitatively described the effect of the simple shaped dihedral on "Skid Roll" stability, which is a term for lateral static stability, but lateral dynamic stability is decided by further elements of the aircraft. The effect on lateral dynamic stability when using a complex dihedral on a large aspect ratio tailless aircraft was studied in this paper. The vortex lattice method was used to calculate the stability derivatives, and lateral–directional linearization small disturbance equations were used to calculate the characteristics of lateral dynamic stability. Through the calculation and analysis of results from 7056 configurations of dihedral distribution, two groups of lateral stability optimized concepts were created. Flight quality close to Level 2 requirements according to the MIL-8785C[16] was finally achieved using these concepts.

2. Description of study object

A conceptual small tailless unmanned aerial vehicle was selected as the object of study. The initial aircraft parameters were obtained through traditional design methods. The main parameters of the aircraft are as follows: wingspan of 7 m, length of 2.8 m, wing area of 7.2 m^2, and mass of 104 kg for a typical level flight. The planform view of the aircraft is shown in Fig. 1. The moments of inertia are calculated by modeling every component of the aircraft in CATIA. These moments of inertia as related to lateral–directional stability are shown in Table 1.

The distribution of dihedral angles of the aircraft was divided into three sections, as illustrated in Fig 1. To study the influence of different layouts of dihedral angles on lateral–directional stability, the range of dihedral angles considered for the inner section γ_1 and outer section γ_3 span from $-10°$ to $10°$. To avoid affecting the design of landing gears due to low height of wingtips, the range of dihedral angles considered for the middle section γ_2 was restricted between $-5°$ and $10°$. The dihedral angles in the three sections can be changed in intervals of 1° individually. Thus, with 21 potential degrees for the inner section, 21 for the outer section, and 16 for the middle section, there were a total of 7056 unique candidate layouts for dihedral angle distribution in the design space.

To study lateral–directional stability of the aircraft at different airspeeds, four airspeeds were selected (20, 30, 40, 50 m/s), and the level flight angle of attack for each airspeed was calculated. Next, the derivatives of lateral motion according to the angle of attack and airspeed were calculated. These aerodynamic coefficients and stability derivatives were calculated using the vortex lattice method.[17–19] This method was chosen for its high computation rate, and its computation accuracy in the range of airspeed in this work was widely validated.[19] In the aerodynamic calculation program, the mean camber surface of the aircraft was divided into n vortex

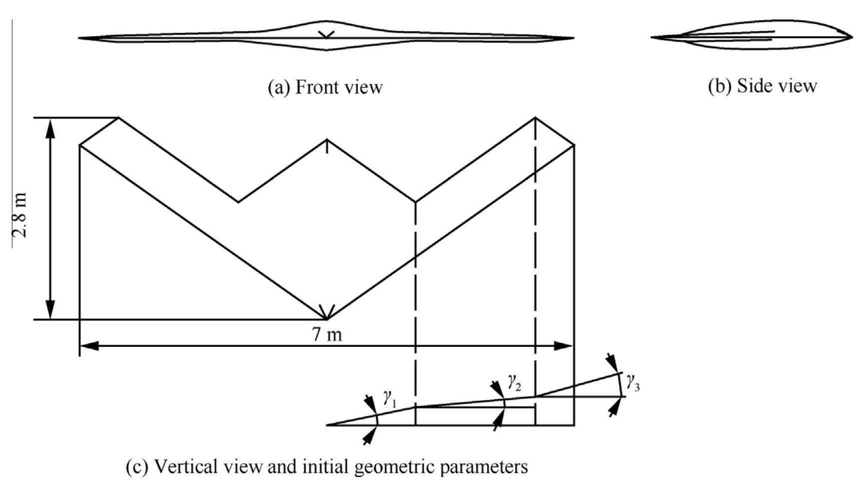

Fig. 1 Conceptual planform and the definition of initial geometric parameters.