Research on low-speed aerodynamic characterictics of flying wing standard model with low-aspect ratio

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Abstract. In order to study the aerodynamic characteristics of low-aspect ratio flying wing configuration, low speed wind tunnel tests and numerical simulation were carried out base on CHN-F1 standard model. The research results show that the repeatability accuracy of the test data is good for being benchmark to CFD verification and validation. In the range of medium angle of attack (less than 14 °), the aerodynamic coefficient changes linearly, and the root mean square of the test data is small. With the increase of the angle of attack, the aerodynamic coefficient changes nonlinearly. It is found that the simulation results were in good agreement with test data in the lift linear section.

Keywords: Low aspect ratio flying wing, low speed aerodynamics, computational fluid dynamics.

1. Introduction

The tailless and low-aspect ratio flying wing is a potential one of the best aerodynamic layout for the next generation fighter aircraft [1]. The features of large swept and wing-body fusion that make the flying wing has the higher aerodynamic efficiency and better structural performance. However, due to lack of the main vertical and horizontal stabilizer, the stability and control performance of the flying wing layout are insufficient. For example, the aircraft may pitch up rapidly as large longitudinal disturbance. When maneuvering at low speed and high angle of attack (such as takeoff and landing), the breakdown of the asymmetric separated vortex on the Leeward side may lead to lateral instability [2]. These special aerodynamic characteristics are different from the conventional aircraft, and traditional design experience is not applicable. Therefore, it is particularly necessary to develop standard model for wind tunnel test and CFD validation to research on the aerodynamic characteristics for low-aspect ratio flying wing layout.

Since the 1980s, a series of wind tunnel standard model tests for the mid-aspect ratio flying wing are performed by many countries. The AVT-161 working group of the NATO Research and Technology Organization developed a general unmanned aerial vehicle model named SACCON [3], which is used to obtain routine and dynamic aerodynamic data in the DNW-NWB wind tunnel and a 14×22 *ft* low-speed wind tunnel of NASA Langley Research Center [4]. The US Air Force Research Laboratory and Boeing released the 1303 UCAV model and carried out wind tunnel test in a wide range of mach number [5]. Later, the US Naval Graduate School used this model to capture the images of wing induced vortex motion in water tunnel [6]. Additional, the QinetiQ Company at the United Kingdom performed flow PIV expermients in 5m low-speed wind tunnel [7]. For low-aspect ratio configurations of flying wing, Lockheed Martin developed the ICE (Innovative Control Effects) model including 101 and 102 configurations, which were supported by the US Air Force Laboratory and the Navy, based on the 101 configuration, a series of static and dynamic aerodynamic measurements were completed [8].

Aiming at the key aerodynamic problems of the low-aspect ratio flying wing layout, China Aerodynamics Research and Development Center (CARDC) designed a standard model named CHN-F1 and carried out contrast tests including conventional force measurement, support interference correction and data correlation in several wind tunnels [9]. In the present investigation, a new phase of low-speed aerodynamic tests and preliminary numerical simulation were completed. This work improved the standard model database of flying wing, provide refined benchmark data for the verification and validation of relevant software, and also provide data support for the engineering design of low-aspect ratio flying wing layout.

2. Wind test and discussion

2.1 Wind tunnel and test model

The tests were completed in a low-speed wind tunnel with 4m wide and 3m high at CARDC. The effective area of the central section of the test section is 10.72m^2. the CHN-F1 flying wing standard model is a tailless and single-leading wing-body fusion layout, which has leading edge sweep back angle of 65 ° and rear sweep back angle of 47 °. The scale of the test model is 1:11. As shown in Figure 1, the total length of the fuselage is 1.393m, the full span length of the wing is 1.039m, the average aerodynamic chord length is 0.869m, and the reference area is 0.699m^2. The pitch moment reference point is located in the symmetry plane and 0.6267m away from the top of the nose.

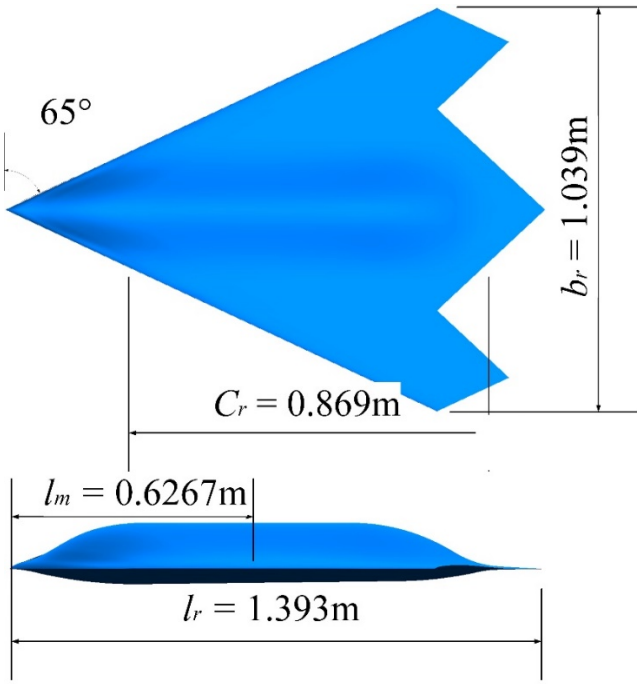


Figure 1. Basic geometry parameters of the model

The model equipped a tail support system shown in Figure 2. The test wind speed is 70m/s (Mach number 0.2), and the Reynolds number is 4.0×10^6. In the test, the model angle of attack changes from - 2 ° to 60 °. The final aerodynamic data is corrected with tunnel wall interference and support interference.

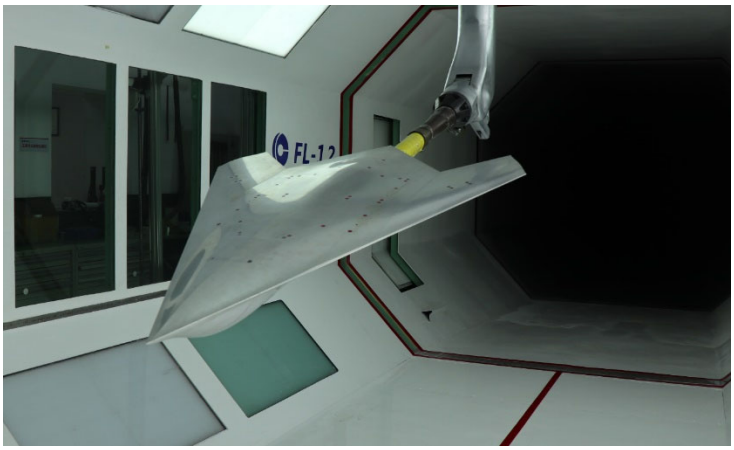
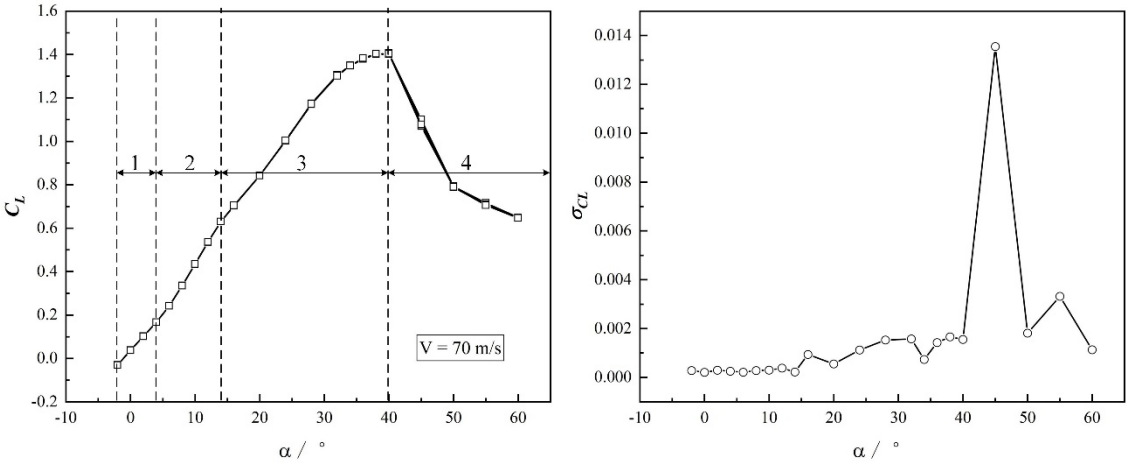


Figure 2. Picture of the model in the wind tunnel

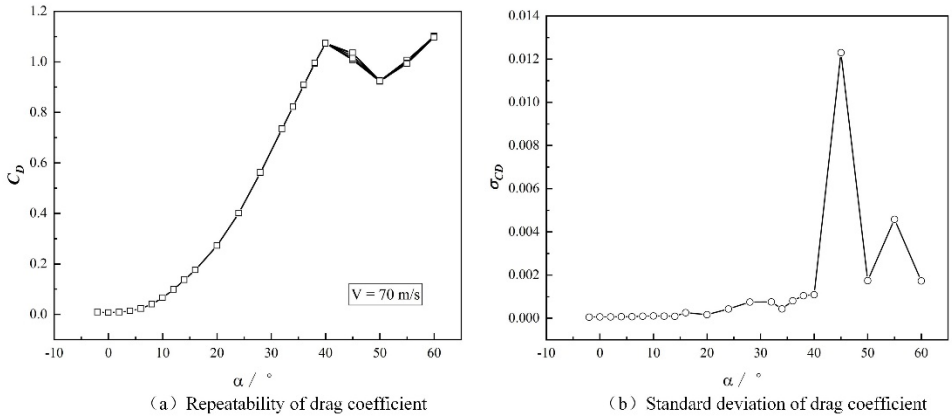
2.2 Test results and discussion

Figures 3(a) to 5 (a) show the repeatability curves of aerodynamic coefficients with measurement of six times. It can be seen that the test data have good repeatability. According to the change trend of lift coefficient with angle of attack in Figure 3 (a), it can be divided into four different stages. When the angle of attack is in the rage of -2°~4°, the flow on upper wing surface of the flying wing is dominated by the attached flow, and the lift coefficient changes linearly. with the increase of attack angle (from 4° to 14°), a pair of stable longitudinal vortex occurs on the upper wing, which improves the lift characteristics of the model and slightly increases the lift line slope; From the angle of attack of 14° to the critical angle of attack of 40°, the longitudinal vortex on the upper wing surface may broken, which is resulting in reducing the lift line slope and a nonlinear change. When the angle of attack exceeds critical angle, the lift enters the stall state. Figure 4 (a) shows that the drag coefficient increases nonlinearly with the angle of attack. Figure 3(b)-5 (b) shows the root mean square error of aerodynamic coefficients at different angles of attack. The root mean square error of each aerodynamic force is small below the angle of attack of 14°. When the angle of attack exceeds 14 °, the aerodynamic force presents unsteady changes due to the separation flow on the upper wing surface, which caused large dispersion of aerodynamic forces measured many times. Especially when the angle of attack exceeded critical angel, the uncertainty of aerodynamic measurement is higher.



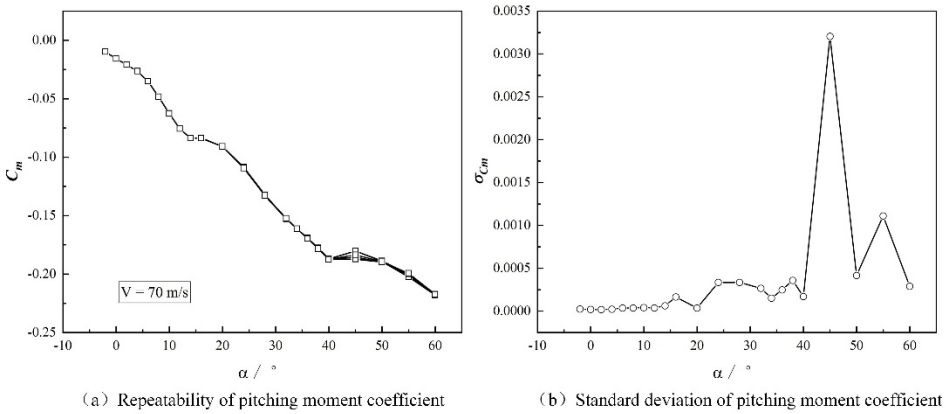
（a）Repeatability of Lift coefficient （b）Standard deviation of lift coefficient

Figure 3. Lift coefficent and test presision versus angle of attack



（a）Repeatability of drag coefficient （b）Standard deviation of drag coefficient

Figure 4. drag coefficent and test presision versus angle of attack



（a）Repeatability of pitching moment coefficient （b）Standard deviation of pitching moment coefficient

Figure 5. Pitching moment coefficent and test presision versus angle of attack

3. Numerical simulation and discussion

3.1 Numerical methods and grids

the computational fluid dynamics software (NNW-FlowStar) was used for more details of aerodynamic characteristics of the CHN-F1 model. NNW-FlowStar is a large-scale parallel CFD software developed by CARDC discretized by finite volume method base on grid center, which is applicable to simulate subsonic and transonic aerodynamic characteristics and aerodynamic loads for aircraft. The calculation model adopts symmetrical semi-model with mixed grid shown in Figure 6. The number of grid elements is 9.4 million, and the height of the first layer of grid is 0.00002m.

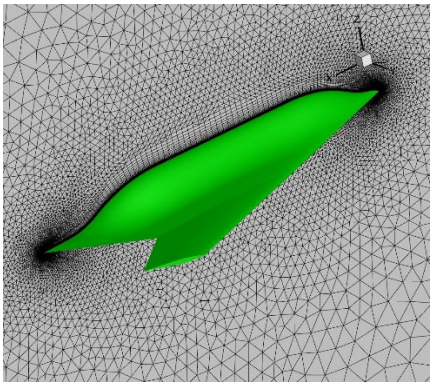


Figure 6. Grid of symmetrical surface

The flow was modelled by Reynolds-averaged Navier-Stokes (RANS) equation with the Spalart-Allmaras (S-A) turbulence model. The Roe flux difference and the central scheme were used to discretize convection and viscous item respectively. And the time item discretization adpot the implicit LU-SGS method. For low Mach number simulation, Weiss and smith method [10] is employed for preconditioning matrix.

3.2 Simulation results and discussion

Figure 7-9 shows the comparison of aerodynamic prediction curve and wind tunnel test under the same conditions. the calculated and experimental values of lift coefficient and drag coefficient are good of agreement under angle of attack of 30 °. When the angle of attack is more than 30 °, the prediction of aerodynamic force has an error and the maximum value of lift coefficient is 7%. As shown at Figure 10, the leading edge of the wing induces two longitudinal vortex pairs. Due to the existence of large separated flow on the leeward side of the model, the longitudinal vortex pairs has strong unsteady motion characteristics. When angle of attack is increasing, There may be alternating

fragmentation, which makes the flying wing heading unstable. Through the above discussion, the one equation SA model can not accurately capture the separated flow. It can be seen from Figure 9, the prediction of pitching moment coefficient is more difficult. Under 10 ° angle of attack, the simulation and test data are relatively similar, the difference is growing with the increase of angle of attack. This is because the moment coefficient is a small quantity compared with other aerodynamic coefficients, and the smaller uncertainty will make the prediction error greater. Therefore, for the aerodynamic prediction of the flying wing configuration at high angle of attack, it may be more appropriate to use the unsteady RANS / LES method which is better prediction of separation flow.

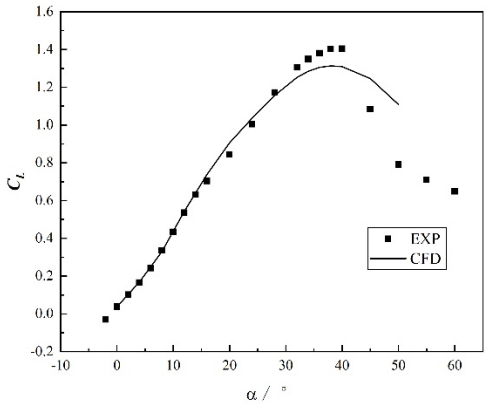


Figure 7. Lift coefficient prediction versus angle of attack

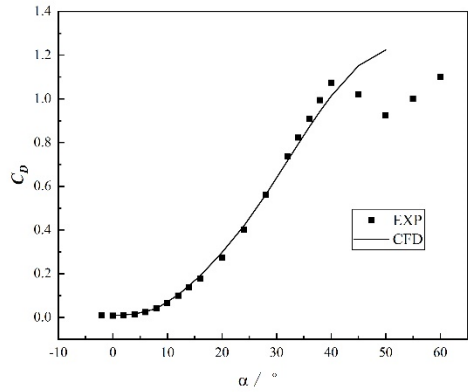


Figure 8. Drag coefficient prediction versus angle of attack

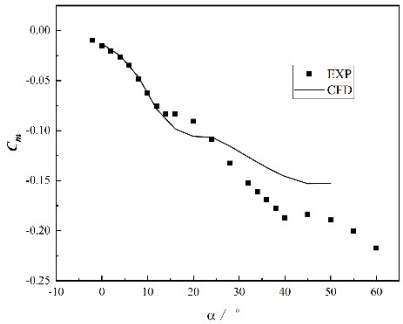


Figure 9. Pitching moment coefficient prediction versus angle of attack

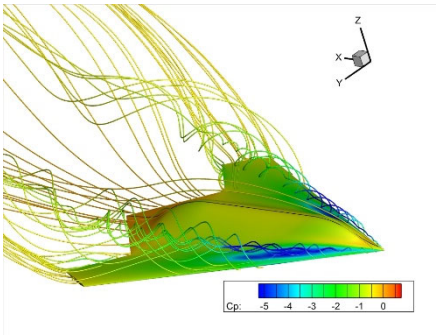


Figure 10. Streamline at angle of attack 20°

4. Conclusion

In this work, the basic longitudinal aerodynamic characteristics of a low-aspect ratio flying wing configuration are obtained at low-speed wind tunnel and by CFD menthod. The low speed longitudinal aerodynamic data has high repeatability accuracy and can be used as the standard data for CFD verification and validation. In the lift linear segment, the SA model can better predict the aerodynamic force, but in the high angle of attack, the traditional RANS model can not accurately catch the aerodynamic characteristics of the flying wing layout because it can not accurately simulate the separated flow.

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References

[1] A.L. Bolsunovsky, N.P. Buzoverya, B.I. Gurevich, et. al. Flying Wing Problens and Decisions[J]. Aircraft Design, 2001, 4: 193-219.

[2] C.M. Liersch, K.C. Huber. Conceptual Design and Aerodynamic Analyses of a Generic UCAV Configuration[R]. AIAA Paper 2014-2001.

[3] R.M. Cummings. Introduction: SACCON Uninhabited Combat Aerial Vehicle Experimental and Numerical Simulations[J]. Journal of aircraft, 2012, 49(6): 1541.

[4] T.D. Loeser, D.D. Vicroy and A. Schuette. SACCON Static Wind Tunnel Tests at DNW-NWB and 14'x22' NASA LaRC[R]. AIAA Paper 2010-4393.

[5] S.J. Woolvin. A Conceptual Design Study of the 1303 UCAV Configuration[R]. AIAA Paper 2006-2991.

[6] B.K. Mclain. Steady and Unsteady Aerodynamic Flow Studies Over a UCAV 1303 Configuration[D]. Naval Postgraduate School, Monterey,California. 2009

[7] S. Mcparlin , R. Bruce, A. Hepworth, et al. Low Speed Wind Tunnel Tests on the 1303 UCAV Concept[R]. AIAA Paper 2006-2985.

[8] Gillard W J. Innovative control effectors (configuration 101) dynamic wind tunnel test report. Rotary balance and forced oscillation tests[R]. AFRL-VA-WP-TR-1998-3043

[9] Zhong S , Li W , Su J , et al. Three types of transonic wind tunnel wall interference correction method and their application on low aspect ratio flying wing calibration model[J]. Acta Aerodynamica Sinica, 2016, 33(3):296-301.

[10] J.M. Weiss , W.A. Smith. Preconditioning Applied to Variable and Constant Density Flow[J]. AIAA Journal, 1995, 33(11): 2050-2057.