High Credible Simulation and Validation of Turbulence models effects on a low-aspect-ratio flying-wing model

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Abstract

Flying-wing is an advanced low-aspect-ratio aircraft in transonic and supersonic flight conditions. Such low-aspect-ratio layout has high aerodynamic efficiency and good stealth performance. In order to meet the requirements of future flight vehicle aerodynamic experiment and research, especially the requirement of supersonic flight, domestic research institutions designed a low-aspect-ratio flying-wing model in house and carried out wind tunnel aerodynamic experiments. A research platform for low-aspect-ratio fusion body flight vehicle is set up. In this paper numerical simulations are conducted for flying-wing aerodynamic characteristics at different attack angles in supersonic flow condition by using high credible CFD software AVICFD-X. AVICFD-X is an unstructured grid solver aiming at solving full Mach range flow field, which is developed by Chinese Aeronautical Establishment. Then numerical simulation of aerodynamic characteristics by using different turbulent models are presented and discussed. It can be concluded that the numerical results of lift, drag, pitching moment coefficient are in good accordance with wind tunnel test data. Compared with RANS simulation, the SALSA-DDES and IDDES improve the computation accuracy of aerodynamic characteristics at high attack angle. The accordance of simulation and experiment validates the computational accuracy of AVICFD-X.

Keywords: *low-aspect-ratio flying-wing, supersonic, turbulence models, wind tunnel experiment, simulation and validation*

Nomenclature

RANS – Reynolds Averaged Navier-Stokes
LES – Large eddy simulation
Rung-SALSA DDES – hybrid DDES model
Rung-SALSA IDDES – hybrid IDDES model
SA DDES –Spalart-Allmaras DDES
SA IDDES –Spalart-Allmaras IDDES
SST-kw DDES –Menter SST-kw DDES
SST-kw IDDES –Menter SST-kw IDDES
SA-one equation –Spalart-Allmaras model
AVICFD-X – CFD software
AOA –Angle of Attack
2D – Two dimensional
3D – Three dimensional
y+ – grid generation criteria
MAC – Mean aerodynamic chord
° – attack angle degree
CL – Lift coefficient
CD – Drag coefficient
Cm – Pitch moment coefficient
L – A subscript for Lift
D – A subscript for Drag
m – A subscript for Pitch moment

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1. Introduction

1.1. Current research status

The wind tunnel testing techniques have progressed and improved all these years, in order to meet the technical requirements of future aircraft development. Many types of advanced and new flight vehicle will appear and work in future. Flying-wing is such an advanced low-aspect-ratio flight vehicle in transonic and supersonic flight condition, which has an advantage of high aerodynamic efficiency and good stealth performance. Domestic institution designed a flying-wing standard model in house and carried out wind tunnel aerodynamic experiments. Some numerical simulations using different turbulent models are conducted for aerodynamic characteristics in transonic and supersonic flow by various CFD software. An experiment and research platform for low-aspect-ratio fusion body flight vehicle is set up. Finally this complete experiment platform and the systematical research technique can provide technical support in the development of new type aircraft.

1.2. Research model and grid

Low-aspect-ratio is a feature of standard flying-wing model. Fig.1 is the two dimensional sectional view of the standard flying-wing model. The geometrical datas are listed below, which are designed by China Aerodynamics Research and Development Center and China Academy of Aerospace Aerodynamics.

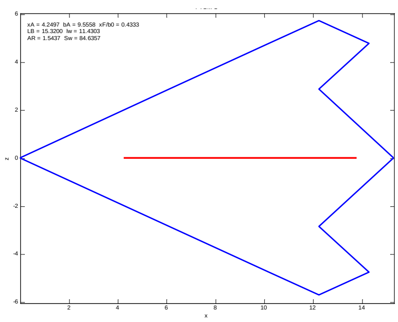

Fig 1. 2D shape of standard flying-wing model

Real model configurations:

- Leading edge sweep angle: 65°
- Trailing edge sweep angle: ±47°
- Ratio of span and chord: 1.54
- Fuselage length: 15.3m
- Span size:11.4m
- Averaged chord: 9.56m
- Reference point of weight: 25%MAC
- Full area: 84.6m^2

Fig.2 is the two dimensional wing airfoil profile of the standard model. The flying wing has four control surfaces in span direction. The relative thickness of wing airfoil is 10.4%, 5%, 5%, 4%.

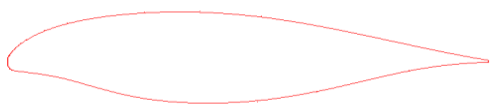

Fig 2. 2D wing airfoil profile of standard model

The sectional view in three dimension of flying-wing model is shown in Fig.3 in below chapter.

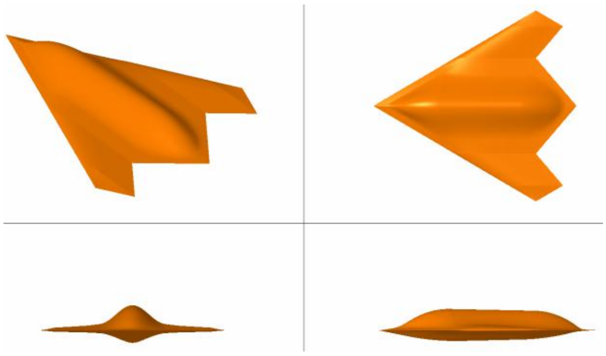

Fig 3. Three dimension sectional view of flying wing model

1.3. Experiment model

In wind tunnel testing, the experiment model has a scale ratio of 1:19 with the real flying-wing model. In high speed flight condition, the experiment model configuration statistics are listed in Table1 below.

Table 1. Configuration and geometry

parameters	geometry
Reference area	0.234 m^2
Bottom area	0.00262 m^2
Vertical length	0.5032 m
Transverse length	0.6020 m
Re reference length	0.5032 m
Reference point of moment	0.3627m

1.4. Simulation software

Numerical simulations are conducted for aerodynamic characteristics at different attack angles in supersonic flow by using high credible CFD software AVICFD-X. AVICFD-X is developed by Chinese Aeronautical Establishment. It is an unstructured grid solver aiming at solving full Mach range flow field and is widely applied for aerodynamic characteristics and load computation. Various turbulent models are integrated and applied in AVICFD-X. The RANS models include SA-one equation model, SST-kw model, Rung SALSA model and others.The RANS-DES hybrid model include Rung-SALSA DDES, Rung-SALSA IDDES, SST-kw DDES, SST-kw IDDES, SA-one equation DDES, SA-one equation IDDES and so on.

1.5. Grid generation

Grid generation is the basic of numerical simulation.The flying-wing grid type is structured and has a topology of "O" style. The total vertex number of half model is about 10 million. According to the geometry model the surface grid is generated firstly, then the volume grid is generated. A three levels grid generation method is applied in practice. The first grid layer attached to body surface is applied to simulate the viscous boundary layer flow. The second grid layer in the middle part is applied to simulate the spatial flow.The third grid layer in far field is for the far flow simulation.The whole computation domain size is about 100 times of wing chord length. Based on the grid criteria y+=1, the first gird spacing is set 10E-6m in normal direction, and the coarsening ratio is set 1.2. X-axis is the same as the flow direction. Y-axis points to the lift direction. Z-axis is the same as the wing span direction. Fig.4 is a capture of the half model grid in below.

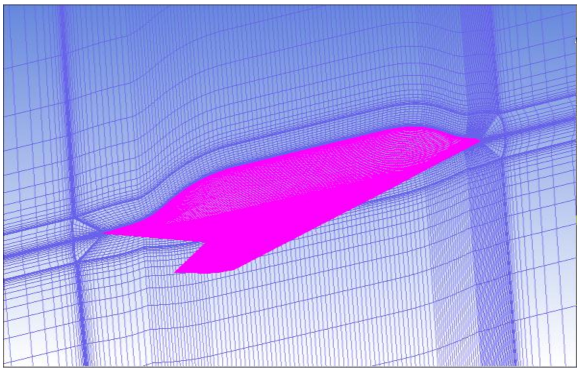

Fig 4. Flying-wing half model grid

2. Computation and analysis

2.1. simulation status

Numerical simulation mainly focus on the Flying-wing aerodynamic characteristics in supersonic flow. The computation parameters of steady flow RANS simulation should be defined in CFD software AVICFD-X firstly. The flow Mach number is defined 1.05 and 1.51 in numerical simulation. The flow static temperature is 300K. In case of Mach number is set 1.05, SA-one equation turbulent model is applied to compute aerodynamic coefficients such as CL, CD, Cm. In case of Mach number is set 1.51, SST-kw turbulent model is applied to compute aerodynamic coefficients such as CL, CD, Cm. The angle of side slip is defined 0° and the attack angle changes from 0° to 18° with an angle increment of 2°. So the computation status sums to 9 for all computation cases.
Unsteady simulation mainly focus on aerodynamic characteristics at high attack angle. In unsteady flow DES simulation, the Rung-SALSA DDES and Rung-SALSA IDDES models are used. In steady flow RANS simulation, only the Rung-SALSA model is used. In both unsteady and steady flow simulation cases the attack angle "AOA" is set 28°.

2.2. RANS simulation results

Table 2 is the AVICFD-X computation results of the aerodynamics coefficient about lift and drag as well as pitch moment. Simulation results include CL, CD, Cm while the incoming flow Mach number is defined as 1.05. The attack angle changes from 0° to 18° with an angle increment of 2.

Table 2. SA computation results (Mach 1.05)

AOA	CL	CD	Cm
0	0.02996	0.02443	-0.01746
2	0.11345	0.02743	-0.01746
4	0.19963	0.03450	-0.01746
6	0.29885	0.04969	-0.01746
8	0.40607	0.07388	-0.01746
10	0.51228	0.10653	-0.01746
12	0.61350	0.14676	-0.01746
14	0.70762	0.19303	-0.01746
16	0.78749	0.24167	-0.01746
18	0.87003	0.29949	-0.01746

In below Fig.5 shows that the simulation results of aerodynamics coefficients compare with the wind tunnel testing data. Fig.6 shows the aerodynamics coefficients converge history in computation. The simulation results of CL, CD, Cm are in good accordance with wind tunnel test data. The stable converge history proves the steady flow simulation feature.

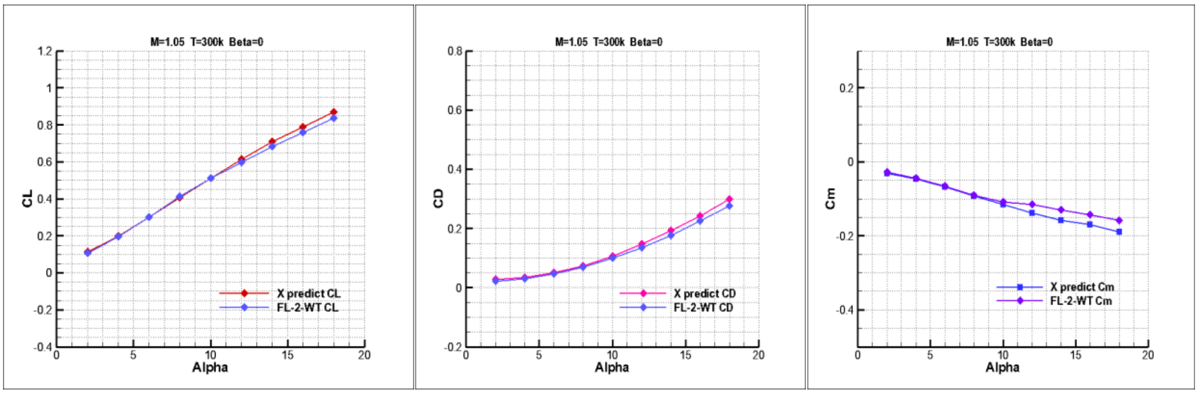

Fig 5. Aerodynamics coefficients comparison with experiment data (Mach=1.05)

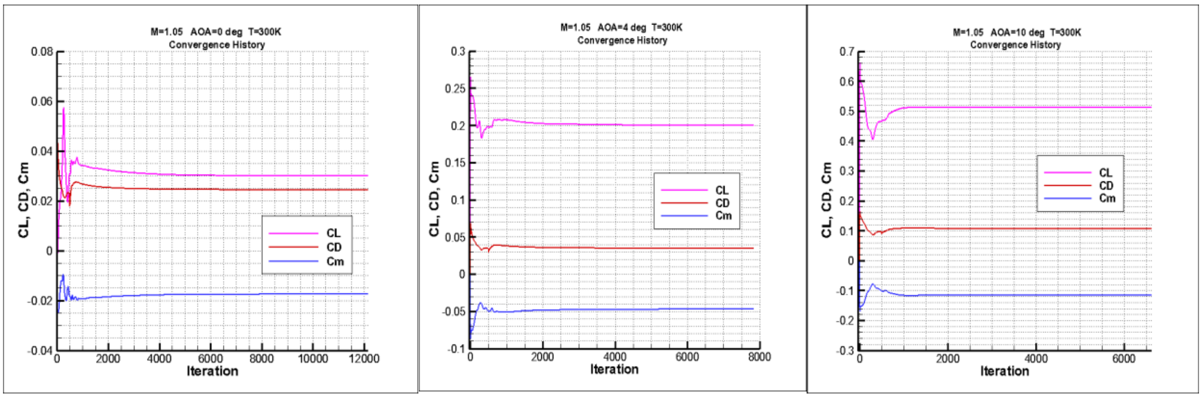

Fig 6. Aerodynamics coefficients computation converge history (Mach 1.05)

Table 3 is the AVICFD-X computation results of the aerodynamics coefficient about lift and drag as well as pitch moment. Simulation results include CL, CD, Cm while the incoming flow Mach number is defined as 1.51 in supersonic flow. The attack angle changes from 0° to 16° with angle increment of 2 degree. From Fig.7 we know that CL, CD, Cm coefficients are in very good accordance with wind tunnel test data. The stable aerodynamics coefficients converge history in Fig.8 proves the steady flow feature in a case that the attack angle is 16°, 14°, 12°. In Fig.9 the streamline shows that some flow separation appears on tail surface part. In simulation it is concluded that the flow separation becomes intense when the attack angle is greater.

Table 3. SST computation results (Mach 1.51)

AOA	CL	CD	Cm
2	0.09442	0.02577	-0.02819
4	0.17027	0.03318	-0.04516
6	0.24754	0.04615	-0.06332
8	0.32582	0.06473	-0.08266
10	0.40148	0.08865	-0.10102
12	0.47306	0.11744	-0.11773
14	0.54115	0.15130	-0.13346
16	0.60686	0.18973	-0.14861

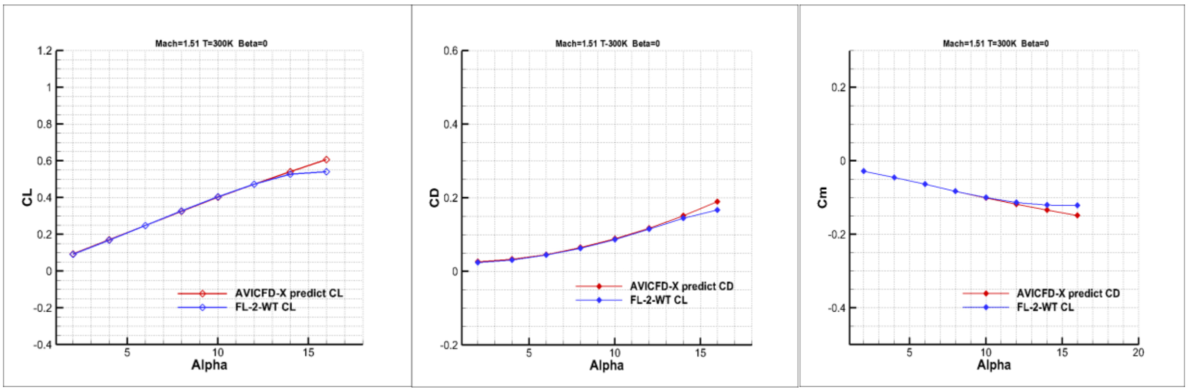

Fig 7. Aerodynamics coefficients comparison with experiment data (Mach=1.51)

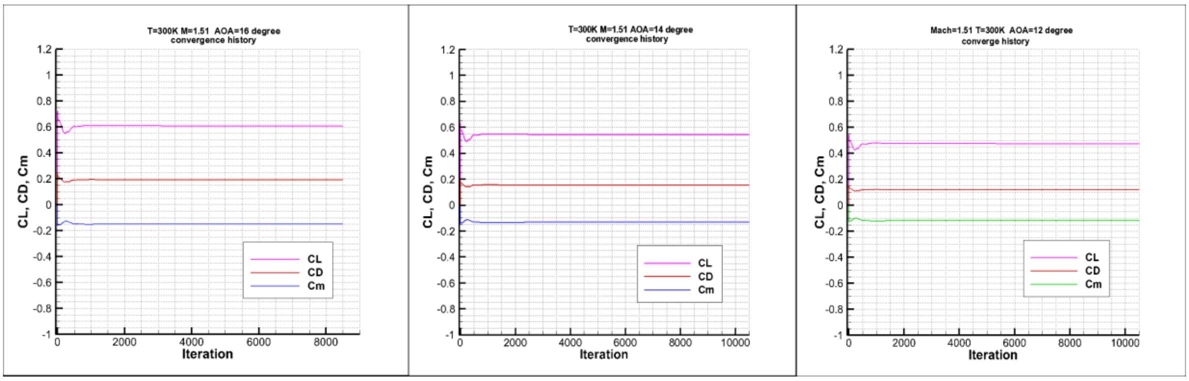

Fig 8. Aerodynamics coefficients computation converge history (Mach 1.51)

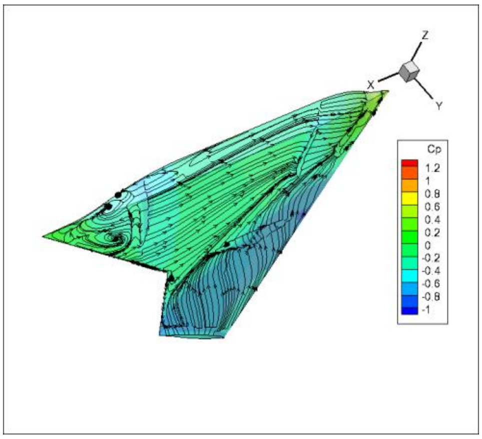

Fig 9. Streamline on flying wing surface (Mach 1.05)

2.3. Hybrid DES simulation results

The simulation method is the hybrid turbulent model of RANS and LES. The DES model such as Rung-SALSA DDES and Rung-SALSA IDDES models are well integrated in AVICFD-X. The incoming flow static temperature is set 300K. In case of the incoming flow velocity is 70m/s and the attack angle is set 28°, AVICFD-X software compute CL, CD, Cm coefficients of flying-wing model by using three kind of turbulent models. Rung-SALSA DDES and Rung-SALSA IDDES are applied in unsteady simulation, whereas RANS model Rung-SALSA is applied in steady simulation. Taking experiment data as a reference, the computational accuracy of different turbulent models are compared and investigated. The Rung-SALSA simulation result is compared with the time averaged simulation result by Rung-SALSA DDES and Rung-SALSA IDDES. The computation efficiency by different models is also discussed here. By comparison we know that the computation efficiency of SA-DDES model is better than others.

Table 4. Simulation results comparison (AOA28°)

model	CL	CD	Cm
RANS	1.1252	0.54859	-0.12083
SALSA-DDES	1.1296	0.55202	-0.13069
SALSA-IDDES	1.13098	0.54962	-0.12983
experiment	1.141	0.5789	-0.13300

Table 4 shows the simulation accuracy comparison by three models in steady RANS and unsteady DES computation while the attack angle is 28° . It can be concluded from Table 4 that the SALSA-DDES and SALSA-IDDES improve the computation accuracy of aerodynamic lift, drag, pitch moment coefficient at high attack angle.

Table 5. Computation efficiency comparison (AOA28°)

model	steps	iteration	time
SALSA-DDES	10000	20	49h
SALSA-IDDES	10000	20	52h
SA-DDES	10000	20	30h
SA-IDDES	10000	20	34h

Table 5 shows the computation efficiency comparison by several models in DES unsteady computation while the attack angle is 28° . In a precondition that the simulation results accuracy are approximately in the same level, it can be seen from Table 5 that the computation efficiency of SALSA-DDES model is better than others.

3. Conclusion

Taking an advanced low-aspect-ratio aircraft Flying-wing as the research model, in this paper many numerical simulations are conducted for flying-wing aerodynamic characteristics at different attack angles in supersonic flow condition by using high credible CFD software AVICFD-X. By simulation we draw a conclusion that the numerical results of lift, drag, pitching moment coefficients are in good accordance with wind tunnel test data. The accordance of simulation and experiment validates the computational accuracy of AVICFD-X. At high attack angle the unsteady and steady simulation are carried out. Compared with steady RANS simulation, the unsteady Rung-SALSA DDES and Rung-SALSA IDDES simulation improve the computation accuracy of aerodynamic characteristics at high attack angle. The computation efficiency of SA-DDES model is better than other models.

References

- Journal article

    1. Zhang Y B, Zhou N C, Chen J T: Numerical simulation research of Reynolds number influence to low-aspect-ratio flying wing model, Acta Aerodynamica Sinica, 2015, 33(3).