COMPUTATION AND WIND TUNNEL TESTING VALIDATION OF WHOLE COMPLEX CONFIGURATION AIRCRAFT IN HIGH-SPEED FLOW

Wang Junhong, Zhang Miao, Chen Yingchun, Feng Lijuan, Liu Tiejun, Zhou Tao

(The First Aircraft Institution of AVIC-1 Shanghai Branch, Shanghai, 200232, China)

Key words: Whole aircraft; Complex configuration; CFD; Wind tunnel test validation.

Abstract. Simulation of whole aircraft flow field in complicated Configuration. Analyze the aerodynamic characteristic results of the high-speed of whole aircraft with different parts, such as aileron, elevator, and rudder, then compare and validate the CFD results by the wind tunnel data. Explore the suitable simulation method and principal for the high-speed aerodynamic characteristic of whole aircraft in complex configuration. Finally get the reasonable simulation method and principal of the high-speed aerodynamic characteristic of whole complex configuration aircraft and provide the corresponding reference for the civil aircraft design.

NOMENCLATURE

M – free stream Mach number
Alf, AOA – angle of attack
β – sideslip angle
δ_e – elevator deflection angle
δ_r – rudder deflection angle
δ_a – aileron deflection angle

0. INTRODUCTION

Until the 1970s, wind-tunnel test techniques are the main design method of the aircraft aerodynamics design, while numerical calculation is simply used as the engineering evaluation method. With the development of computational fluid dynamics and the computer science, CFD method is highly valued and more widely used in the aircraft aerodynamic design.

The wide use of CFD method greatly changes the design pattern of modern aircraft:
In the conception design and the primary design stage, CFD is the main method, while the test is used as a validation for the selected design. In detailed design stage of the aircraft, CFD is an important way of accurate calculation and test data correction, and as instructions and supplements of the wind tunnel test. This paper calculates the whole aircraft flow field of some model airplane in complicated configuration, obtaining a set of CFD method by comparison and analysis, and validates the reasonability of the simulation method with the test data.

1. PURPOSE OF RESEARCH AND METHOD DESCRIPTION

Combined with some civil aircraft design, aiming at the whole aircraft flow field in complicated configuration, by changing domain size and grid density, the outer field of civil airplane is simulated, then the results are compared with the tests data, attempting to find appropriate domain size and total grid number which can meet the need in engineering. In all the simulations the hexahedron structural grids are used.

2. ANALYSIS OF THE INFLUENCE OF CALCULATION DOMAIN SIZE AND TOTAL GRID ELEMENTS ON THE SIMULATION RESULTS

Calculative state:
The half model of the whole aircraft, H=11000m
M=0.78, AOA= - 4 ~ 10 degree

2.1. Influence of different calculation domain size on the simulation results

Choosing appropriate domain size, relatively accurate field information can be attained. More importantly, accurate computed results can be attained using minimum grid number, improving the computing efficiency.
In this paper, three different field domains are selected. The reference domain shape is an approximate sphere (Fig.1). The free stream direction size of the domain is twenty times of fuselage size. The other two are: 1.5 times of the reference size, 0.5 times of the reference size. The calculated results of three different domain sizes are compared, as shown in Fig.2 and Fig.3.

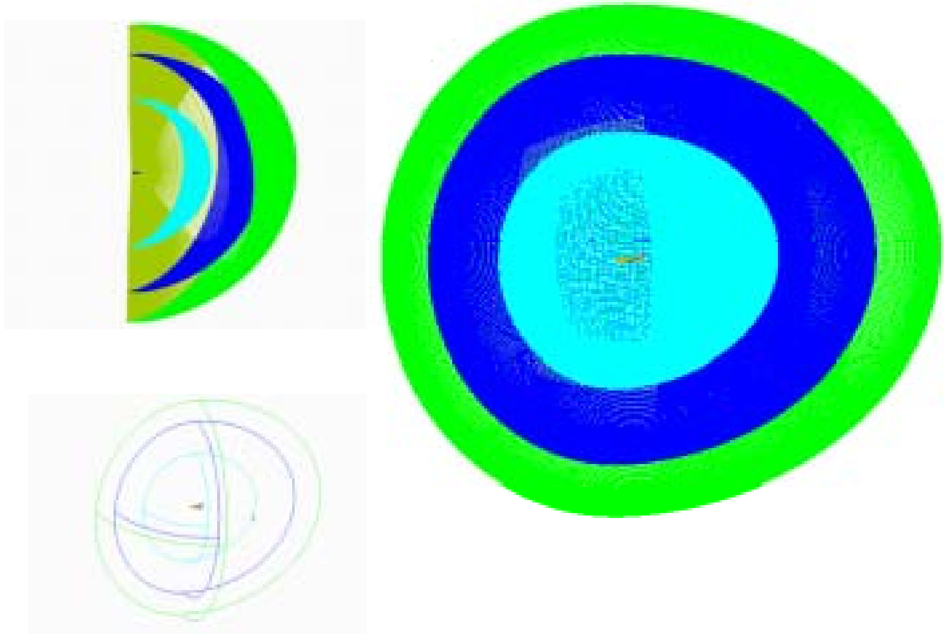
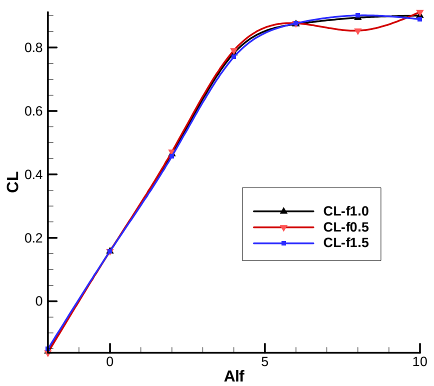


Fig.1 the sketch map of different domain size



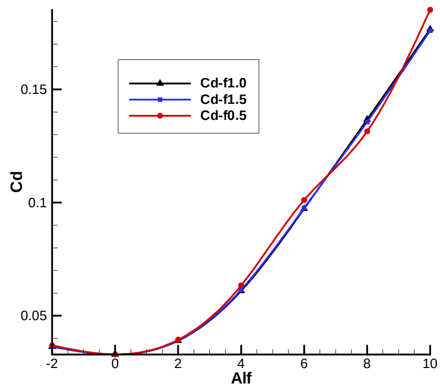


Fig.2 Lift comparison of different domain size   Fig.3 Drag comparison of different domain size

In Fig.2 and Fig.3, the results of 1.5 times of reference size are almost the same as the results of the reference size, the error of 0.5 times is obvious. This indicates the reference domain size is reliable.

2.2. Influence of different total grid elements on the simulation results

From the calculated results above, using the domain size of 10 times of the fuselage size, accurate and acceptable results in engineering can be obtained. Then we take this domain size as the standard size, strictly controlling the grid distribution law of the wall nearby, and reasonably modify the grid distribution of the far field, three sets of different density grid elements are obtained. One is 1.5 million, the other two are 3 million, and 6 million. The layout of them is shown in Fig.4

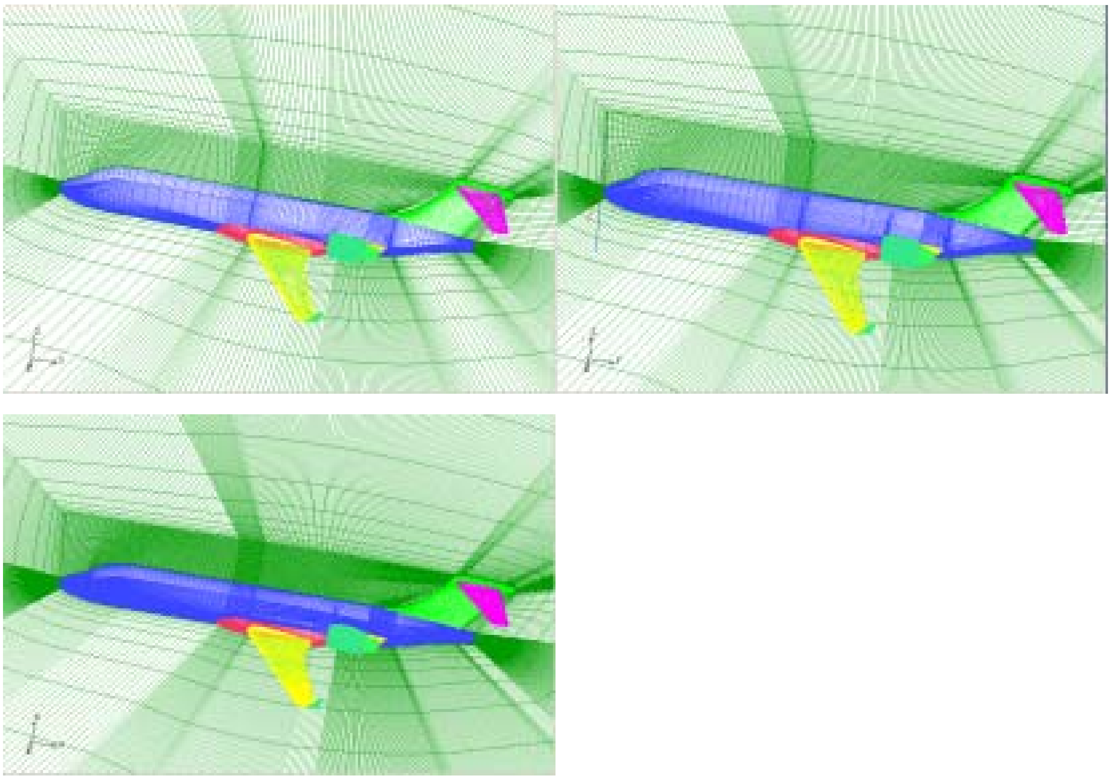


Fig.4 Grid distribution of the whole domain

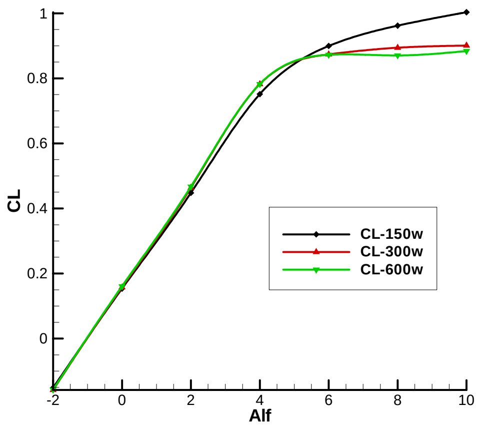


Fig.5 Lift curve of different grid density

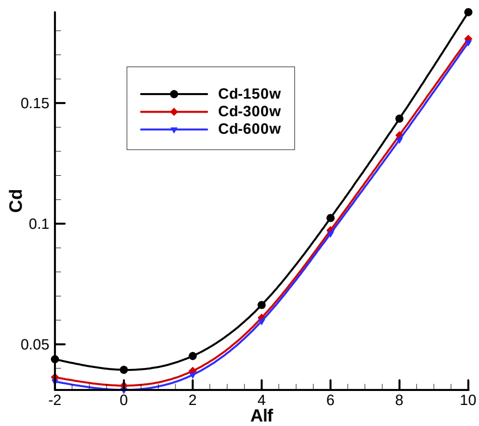


Fig.6 Drag curve of different grid density

From Fig.5 and Fig.6, it is visible, in the case of the whole aircraft, the calculated aerodynamic results of different grid density have obvious difference. As for the drag curves, the results of 3 million grid elements and the 6 million grid elements are nearly same, while the results of 1.5 million are on the high side. As for the lift curves, the shape of 1.5 million grid elements has obvious difference with the other two. Comparing the results of 6 million grid elements with the 3 million results, the aerodynamic characteristics of these two is almost same in precision. Considering the calculation efficiency, we think the 3 million grid elements can meet the engineering need.

From part 2.1 and 2.2, accurate results in engineering can be obtained using calculated model with domain size of 10 times of fuselage size and 3 million grid elements.

3. ANALYSIS OF CALCULATED RESULTS AND VALIDATION OF WIND TUNNEL DATA

3.1. Aerodynamic characteristics curves of the whole aircraft

The cruise configuration of the whole aircraft with 3 million grid elements is calculated, the results are compared with wind tunnel data.

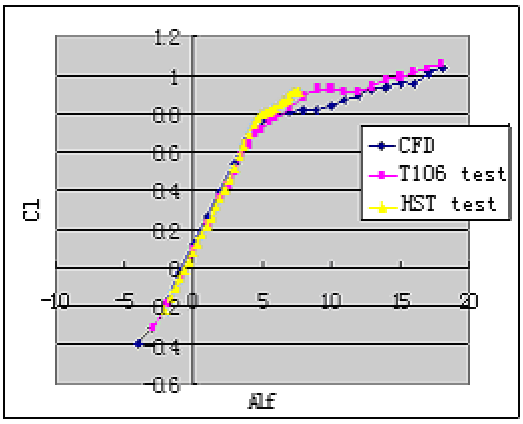


Fig.7 Comparison of lift

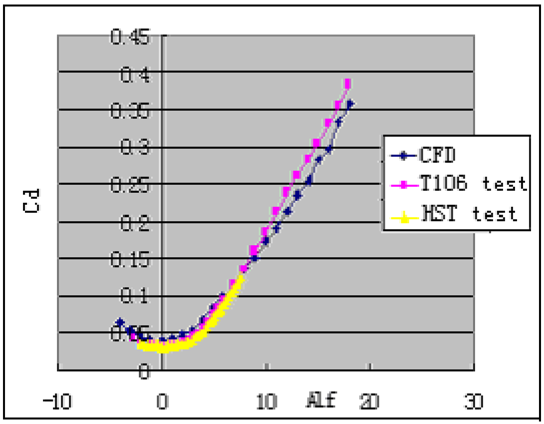


Fig.8 Comparison of drag

From Fig.7 and Fig.8, it is visible, in the linear part of the lift curve, the calculation fits well with the test data. With the angle of attack increasing, there is a obvious difference. The maximum deflection occurs at 9 degree. The calculated results of the drag is a little higher than the test data when the angle is small, and is a little lower than the test data at the range of big angle. The average error is nearly 6 percent.

3.2 Pressure distribution contrast of some parts

The simulations for the typical states of the complicated configuration of the whole aircraft are done and compared with the test data. The comparisons of pressure distribution on some main parts are shown in the figures below.

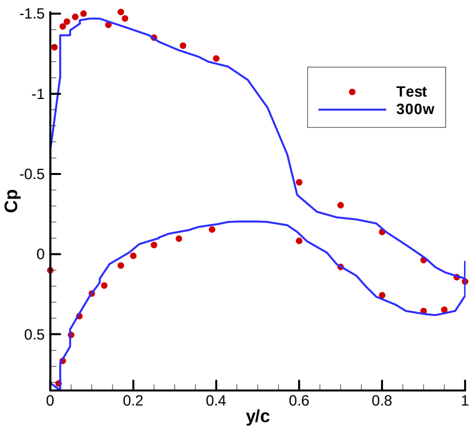


Fig.9 Pressure distribution at x=3.0m on the wing (M=0.78, AOA=6)

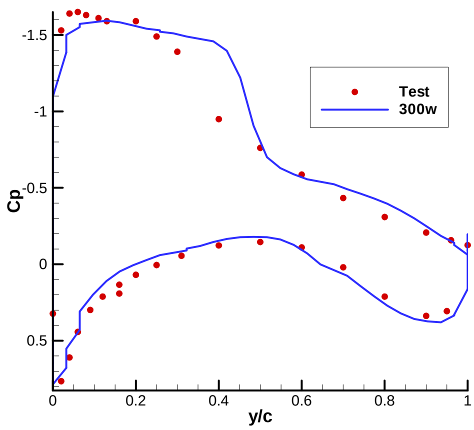


Fig.10 Pressure distribution at x=5.05m on the wing (M=0.78, AOA=6)

From Fig.9 and Fig.10, it is obvious that on the wing the calculated results are fit very well with the test data.

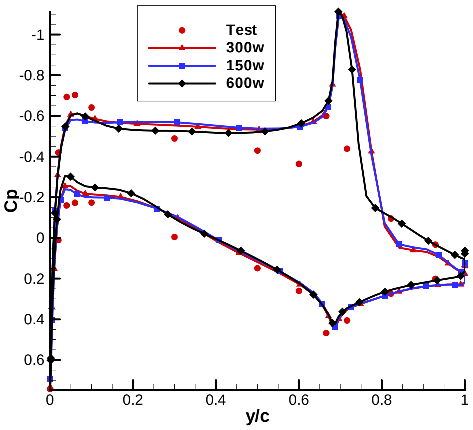


Fig.11 Pressure distribution at X=1.837m horizontal tail (M=0.82, AOA=3, $\delta_e = +10$)

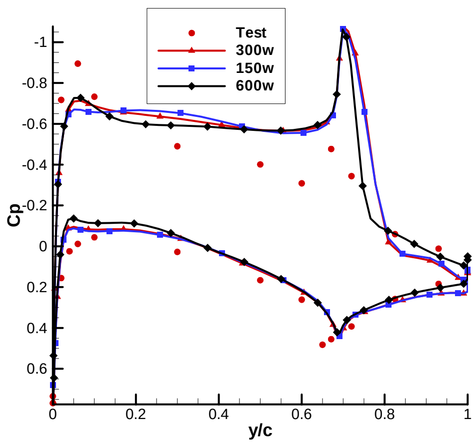


Fig.12 Pressure distribution at X=2.624m horizontal tail (M=0.82, AOA=3, $\delta_e = +10$)

From Fig.11 and Fig.12, it is visible that, the changes of total grid elements number have little influence on the pressure distribution. The results of 6 million grid elements are closer to the test data.

On the lower surface of the whole horizontal tail, the calculated results fit well with the test data. On the upper surface, the two have obvious difference. Because in the test there is a gap at the joint of the elevator and the horizontal stabilizer, in the calculation the real flight state is simulated and there is no gap.

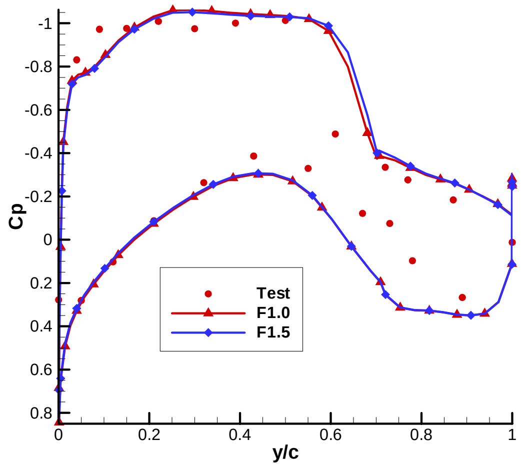


Fig.13 Pressure distribution at X=10.75m of wing (M=0.82, AOA=3, δ_a = +5)

From Fig.13, we can see that, the changes of domain size (F1.0&F1.5) have little influence on the pressure distribution on the wing. The calculated results fit well with the test data on the main wing. On the aileron the two have obvious difference, because in the test there is gap at the joint of the main wing and the aileron, in the calculation the real flight state is simulated and there is no gap.

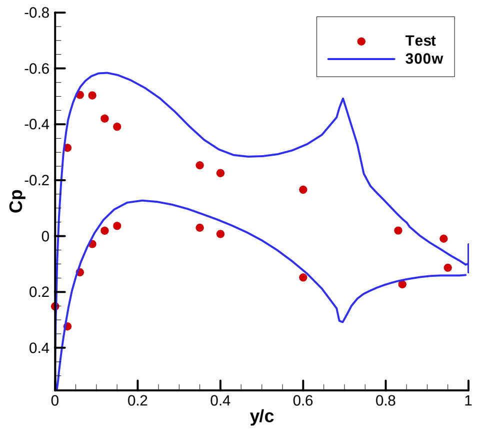


Fig.14 Pressure distribution at X=3.177m vertical tail (M=0.82, β= -3, δ_r = +10)

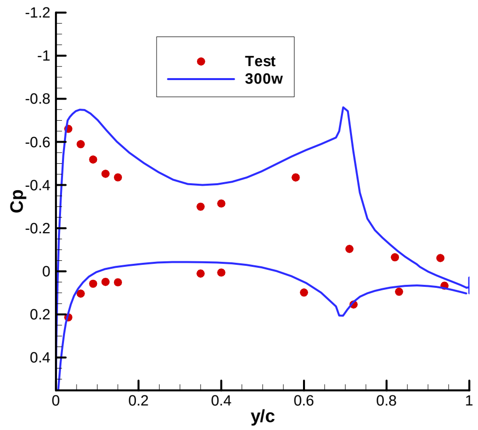


Fig.15 Pressure distribution at X=4.211m vertical tail (M=0.82, β= -3 °, δ_r = +10)

From Fig.14 and Fig.15, it is visible that, on the left side of the vertical tail, the calculated results fit well with the test data. On the right side, the two have obvious difference. Because on one side, there is a gap at the joint of the rudder and the vertical stabilizer in the test, in the calculation there is no gap; on the other side, due to rudder deflection angle and the sideslip angle, the right side can be seen as the lee side of the heavy camber airfoil.

From all the pressure distribution charts (from fig.9 to fig.15), it indicates that, using the domain size of 10 times of fuselage size with 3 million grid elements, the calculated results are reliable and acceptable in engineering.

4. CONCLUSIONS

According to the calculated results of different domain size and different grid number, combining with the validation by the wind tunnel test, and considering the factor of calculation efficiency, we can draw a conclusion: using the domain size of 10 times of fuselage size with 3 million grid elements, the calculation can high effectively obtain accurate results in engineering, which can be used in civil aircraft design engineering.