Numerical simulation of aerodynamic characteristics of multi-element wing with variable flap

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Abstract: Based on the Reynolds averaged Navier-Stokes equation, the mesh generation technique and the geometric modeling method, the influence of the Spalart-Allmaras turbulence model on the aerodynamic characteristics is investigated. In order to study the typical configuration of aircraft, a similar DLR-F11 wing is selected. Firstly, the 3D model of wing is established, and the 3D model of plane flight, take-off and landing is established. The mesh structure of the flow field is constructed and the mesh is generated by mesh generation software. Secondly, by comparing the numerical simulation with the experimental data, the prediction of the aerodynamic characteristics of the multi section airfoil in takeoff and landing stage is validated. Finally, the two flap deflection angles of take-off and landing are calculated, which provide useful guidance for the aerodynamic characteristics of the wing and the flap angle design of the wing.

Key words: multi-element wing; mesh generation; numerical simulation.

1. Introduction
In the course of flying in the air, the lift of a plane is mainly generated by the wing, and the resistance is also produced on the wing. The magnitude and direction of the lift and drag values of the wing depend to a great extent on the shape, characteristics and dimensions of the wing, i.e. airfoil geometry (wing profile), wing geometry, etc..

The modern aircraft aerodynamic design tools selection design and optimization design can not only accurately predict the aerodynamic characteristics of aircraft layout absolute quantity, relative quantity can also accurately predict caused by small changes in design parameters on the aerodynamic characteristics of change. Wang Yuntao, with "sub trans CFD software platform" (TRIP2.0) numerical simulation of complex flow of 30P-30N multi-element airfoil, the main purpose is to affect the assessment of turbulence models and transition position on the pressure distribution and airfoil multi segment speed type [1] typical stations. Liu Peiqing, on a plane wing airfoil mounted control different height Gurney simulation results show that the installation of Gurney flap can increase the lift coefficient and drag coefficient of multi-element airfoil, but will strengthen the wake flow instability [2]. Mao Jun and so on, using computational fluid dynamics method of civil aircraft two-dimensional lifting device, that is, the design of multi section airfoil [3]. The analysis and calculation of aerodynamic characteristics of multi section airfoils has become one of the focuses of computational fluid dynamics research.
2. The establishment of 3D wing model based on FLUENT

2.1. The three-dimensional structure of the wing
In this paper, the DLR F11 wing of the German Aerospace Center is taken as the object of study. The reference geometry parameters of the DLR F11 airfoil (wing shape as shown in Figure. 1.1.1) are calculated:
- Reference area of the semi-span model = Sref/2 = 419130 mm²
- Mean aerodynamic chord (MAC) = 347 mm
- Wing semi-span = 1400 mm
- Moment reference center (MRC): x=1430 mm, y=0.0 mm, z=-42 mm

The 3D model of DLR F11 wing is established by using CATIA 3D modeling software. Three dimensional models of flat flight, take-off and landing are established, such as 1.1.2, flat flight model / take-off model / landing model.

![Figure 1. Wing profile](image1)

![Figure 2. DLR F11 wing plane takeoff / takeoff / landing 3D model diagram](image2)

2.2. Mesh of wings
The flow around an airfoil is an external flow problem, and the boundary of the basin is far from the wing. But this is not possible for the simulation. Generally, the tail boundary of the basin should be more than 10 times the length of the wing rotation. In the simulation, the structured grid without the wings, and structured grids in the aspect of the inheritance of the calculation accuracy and efficiency of grid and grid generation standards than other types have obvious advantages, need to use ANSYS software in the ICEM series CFD software to build the flow field structure and geometry of mesh generation, and
to facilitate further calculation. Structured mesh is adopted, and the mesh number is about 10 million. The grid is divided into plane flight, take-off and landing respectively, such as DLR, F11, wing mesh. Figure 1.2.1 shows a schematic diagram of the whole grid and the grid section; figure 1.2.2 shows a schematic diagram of the front and back grid grid, fly level before and after the flap is closed, take off and landing different before and after the open angle of flap.

![Figure 3. DLR F11 wing overall frame mesh diagram](image)

![Figure 4. DLR F11 wing flat takeoff / landing / landing grid diagram](image)

3. Simulation test calculation
In order to study the typical configuration of aircraft, a similar DLR-F11 wing is adopted to validate the prediction capability of the method. The flap angle is 32 degrees, and the angle of the flap is 26.5 degrees. The experimental data are compared with the structural mesh and unstructured mesh simulation. Using the S-A turbulence model, the Maher number is 0.175, and the corresponding Reynolds number is 15.1 * 106. Angle of attack ranged from -3 degrees to -24 degrees. The contrast test data is ETW (European, Transonic, WindTunnel) RUN238 data. As shown in Figure 2.1, the DLR-F11 simulation pressure nephogram, shown in figures 2.2.1 and 2.2.2, shows the comparison of lift and drag coefficients between the structural mesh, unstructured mesh and the experimental simulation.

![Figure 5. DLR-F11 simulation pressure nephogram](image)
Figure 6. Lift coefficients between structured mesh, unstructured mesh and experimental simulation

Figure 7. Lift to drag ratio between structured mesh, unstructured mesh and experimental simulation

The results show that the slope of the lift coefficient curve between the numerical simulation results and the experimental results is slightly different, which may be due to the differences between the two models of numerical simulation and experiment. The calculated results are in good agreement with the experimental results at low and mid attack angles, but in the nonlinear region, the lift coefficient is small and the stall delay is compared with the experiment. When the stall coefficient is 20 degrees, the maximum lift coefficient is 2.873. The maximum lift coefficients of the structured and unstructured grids are 2.827 and 2.893, respectively, and the stall angles are 24 and 22 degrees respectively. The structure network is closer to the experimental value, which shows that the structure network is more effective. (Green: experiment; Red: structured mesh; blue: unstructured grid)

The computed lift and torque curves are compared with the results of the literature [4] and the wind tunnel test results, as shown in Figure 2.3.1 and figure 2.3.2. From figure 2.3.1 and figure 2.3.2 shows that the calculated results are in good agreement with the literature [4] in the stall angle before the lift coefficient of two forecast is slightly less than the test value, which results in [5-6] and consistent, which may be due to not considering the influence of transition, for the turbulence, and the model in the wind tunnel test there will be deformation, but not considering the factors of stall angle, between the results between experimental values and the results in the literature; the same stall attack angle of lift coefficient calculation values and test values of maximum deviation is 2%; the torque curve calculation compared with literature results and experimental data show that the prediction is more consistent. The model is consistent with the wind tunnel test load distribution.
In summary, the numerical calculation method and grid strategy on the aerodynamic performance prediction precision has reached advanced level at the present stage and in good agreement with the experimental results, the prediction for the wing aerodynamic characteristics is feasible.

4. Calculation results and discussion
Calculation of configuration is installed in the body of the simplified large chord, medium aspect ratio, slat / wing / trailing edge flap three configuration. The calculation model shows that the leading edge wing angle is 30. Angle of takeoff and landing, trailing edge flaps were selected two groups of angle comparison, leading edge slats and trailing edge flaps from the wing tip extends to the root and into the body. Using the S-A turbulence model, the Maher number is 0.175, and the corresponding Reynolds number is $3 \times 10^6$. Angle of attack range from 0 degrees to 28 degrees. Using ANSYS FLUENT software import mesh model, numerical simulation.

4.1. Aerodynamic characteristics change with attack angle
The angle of attack for fixed wing aircraft is the angle in which the wing moves in advance (the direction of the airflow) and the chord (different from the axis of the fuselage), which is the basis for determining the attitude of the wing in the airflow. Under the condition of keeping the Maher number unchanged, the numerical simulation method is used to change the angle of attack to observe the changes of aerodynamic characteristics, and compare with the wind tunnel experimental data. The wind tunnel test data are from two two stage high lift prediction workshops (hiliftpw) sponsored by the American aerodynamic Committee ([7-8]). As shown in figures 3.1.1, 3.1.2 and 3.1.3, the lift coefficient, drag coefficient and lift drag ratio change with the angle of attack.

The following changes of stall angle, lift coefficient and drag coefficient was basically constant variation down torque coefficient with increasing angle of attack and gradually reduce, calculated the aerodynamic characteristics of the variation of the test result and the value and the same trend.
4.2. The influence of deflection angle

Gaps in multi section airfoils can produce many effects such as ring volume, suction, pressure recovery, and boundary layer. Therefore, it is necessary to make a simulation calculation of the flap deflection angle of the multi wing. In this section, the effects of different deflection angles on aerodynamic forces during take-off and landing are investigated. The takeoff angle is chosen as 21.5 degrees and 24.5 degrees as the flap deflection angle, and 31.5 and 36.5 degrees are chosen as the calculation deflection angle. Figure 3.2.1 and Fig. 3.2.2 show the variation of the lift drag coefficient versus angle of attack at different deflection angles.

It can be seen that the trailing edge flaps are deflected 24.55 degrees, the lift coefficient the same maximum angle of attack; angle less than 24.5 degrees, with the increase of deflection angle, the same attack angle the lift increases gradually; the deflection angle is greater than 24.5 degrees, the state of negative angle of attack and zero angle of attack angle the greater the corresponding lift flap the smaller the positive attack angle state deflection angle of trailing edge flap is corresponding to lift more. As for the drag coefficient, the deflection angle is less than 24.5 degrees, the drag coefficient increases with the deflection angle; angle of 31.5 degree, the drag coefficient increases smaller, but the maximum negative attack angle, angle of 4 degrees but less than 24.5 degrees and 36.5 degrees angle. When the
deflection angle is 36.5 degrees, the resistance is the maximum. Comprehensive analysis, for the study of multi wing, the recommended take-off stage flaps the best deflection angle of 24.5 degrees, the landing phase recommended the best deflection angle of 36.5 degrees.

![Figure 13. Sketch of variation of lift coefficient with angle of attack at different flap angles](image)

![Figure 14. Sketch of variation of resistance coefficient of flap with angle of attack](image)

5. Conclusion
The Reynolds averaged Nervier-Stokes equations, structural grid technique and geometric modeling method based on using Spalart-Allmaras turbulence model, the influence of DLR-F11 wing, wing flap angle on aerodynamic characteristics.

(1) The aerodynamic performance prediction accuracy has reached the advanced level at the present stage by using numerical calculation method and grid method, and it is in good agreement with the experimental data. It is feasible to predict the aerodynamic characteristics of the multi section wing.

(2) The aerodynamic characteristics of multi section wings vary with the angle of attack. The variation of aerodynamic characteristics calculated by the deflection angle is basically the same as the values and trends of the experimental results.

(3) For the study of the multi section wing, the optimum deflection angle of the flap at the takeoff stage is 24.5 degrees, and the optimum deflection angle is 36.5 degrees at the landing stage. The results provide a useful reference for the study of flap deflection.

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