DETACHED EDDY SIMULATION OF AIRCRAFT MASSIVELY SEPARATED FLOWS

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Abstract

Numerical simulation of aircraft massively separated Flows is always CFD's difficulty. This paper adopts DES method based on SA turbulence model to simulate and analyze aerodynamic force and flow characteristics of SDM standard model at high angle of attack. It turns out that when the angle of attack is less than 40 degrees, RANS and DES methods for aerodynamic force are similar; while DES method reflects a clear advantage when the angle of attack is greater than 40 degrees. When the model leeward side is massively separated flows, primary vortex which is induced by the strake wing and the main wing separates into many small vortex structure, even induces lateral aerodynamic force which is diametrically opposed compared to RANS calculation method, reflects the complexity of flow when the aircraft is in high angle of attack on the leeward side.

1 General Introduction

This sample Aircraft with abilities of post-stall maneuver which achieve high maneuver ability by high angle of attack flight could obtain tactical advantages of rapid occupation, aim prior to enemy, avoid attack effectively. Unsteady massively separated flows might be generated on upper surface of aircraft wings at a high angle of attack which result in stall, sharp drop of lift, or even suddenly out of control. Therefore, aerodynamic characteristics and stability analysis of high angle of attack become key issue of modern high-performance flight vehicle design. In recent years, CFD prove to be a valid method to study aerodynamic. In the methods of CFD, RANS method obtain satisfactory results in attached and weak separation flow calculations, however it could not simulate massive separation accurately. With the enhanc4ement of numerical simulation capability, one kind of new method to describe unsteady turbulent flow —RANS/LES mixed method develops rapidly. In RANS/LES mixed method, Detached Eddy Simulation (DES) method which is presented by Spalart is representative. DES method calculates attached flow region under control of small-scale motion by turbulent model and use LES method to simulate unsteady separated flow which is involved large-scale motion, and combine both of them appropriately.

The paper simulates the aerodynamic characteristics of SDM with RANS and DES method in subsonic speed region. The integral aerodynamic forces, flow characteristics of aircraft configuration are calculated in low mach number region at high angle of attack. The comparison and analysis of RANS and DES calculation results can provide an effective and experimental reference to simulate aircraft configuration massive separated flow.

2 Numerical Methods

Special discrete is FDS-Roe format bases on MUSCL interpolation method, which has excellent viscosity resolution. Second-order central difference scheme is adopted to viscous term. Time advancement is implicit LUSGS method to ensure high computational efficiency and precision.

The current program module developement mainly use Spalart-Allmaras turbulence model. SA model is a one-equation model, solving single partial differential equation of turbulent transport, it meants to slove turbulent eddy viscosity activities, $\tilde{\upsilon}_t$. Derivation of this equation applied empirical formulas, dimensional analysis, Galileo invariant, molecular viscosity etc. The mathematical model comprising turbulence generating items, destroy items, and diffusion, namely:

RANS turbulence simulation method is accomplished by turbulence models, it can't resolve any details just the average flow changes, but the efficiency and robustness of the RANS method endows it great application in industry. LES has very good accuracy in stimulating turbulent details and flow separation, but current computer can't afford the calculation amount of the surface flows at high Reynolds number, so the distance between the project application and the modern times are quite far away. In order to apply the advantages of RANS and LES, hybrid LES / RANS model has been put forward, that is to apply RANS model near the surface, LES model away from the surface in separate region to discribe turbulence. Spalart and others complete DES format design by modified SA model as follows, which is also commonly known as the DES97 format.

The last item from SA-RANS model equations represents that $\tilde{\upsilon}_t$ depends on the surface distance, Spalart use $C_{des}\Delta$ to replace this item and physical length scale d which is involved in generating items. Thus, SA model transformed into LES equation's SGS model , reducing the length scale to increases the damage item, thereby reducing the eddy viscosity.The length scale of SGS choosen by the author is as follows:

$$\Delta = \max\{\Delta_x; \Delta_y; \Delta_z\}$$

Model parameters $C_{des} = 0.65$ *is* obtained by isotropic turbulence example's calibration, the literature indicates that the numerical results of the study parameters are not very sensitive.

Spalart create a "detached eddy simulation" (Detached Eddy Simulation-DES) term to name this method, their main purpose is to mix the flow field's solving methods, apply LES in external flow area, utilize LES mode to resolve detached eddy that is away from all boundaries, at the same time apply RANS models in the near-wall flow zone. Object RANS model meant to get a reasonable description of the near-wall flow in the statistical sense, the computational grid only need to normal refinement in surface, and apply relatively coarse grid in tangential. In addition, the switch between this two methods is by an automatic criterion, thereby avoiding the specified in advance by users.

3 Results and Analysis

3.1 Configuration and Mesh

The Standard Dynamics Model (SDM) is a test configuration designed loosely on the F-16 aircraft, including wing leading-edge extensions, horizontal and vertical stabilizers, ventral fins, a canopy, and a blocked-off inlet section. Further details on the geometry of the configuration can be found in Refs. [1].

Figure 1 shows the mesh distribution of symmetry planeand surface. Cell count of grid is 14 million, and the distance between far-field boundary from the surface is 15-20 times larger than the reference length. Full mesh which is refined in leeward region utilize C-H-type mesh topologyto describe the massively separated flow. Calculation conditions: Ma= 0.3, α = 0 ° - 80 °, β = 5 °, the longitudinal reference length is mean aerodynamic chord length, lateral reference length is wingspan, the reference area is the wing area, center of mass Xcg= 0.584.

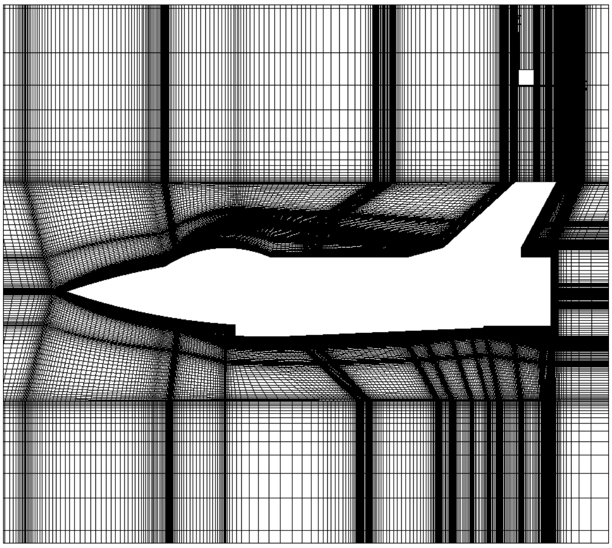

Fig.1. Symmetry Plane Grid Distribution

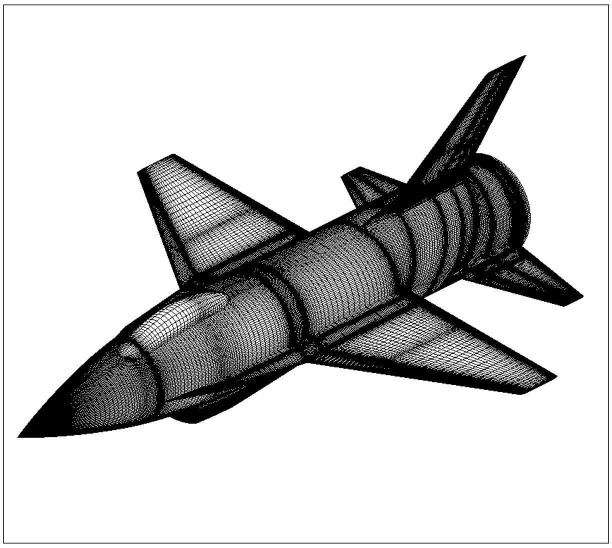

Fig.2. Surface Grid Distribution

3.2 Detached Eddy Simulation of SDM

In this paper, aerodynamic force and flow characteristics of SDM standard model are calculated and analyzed with RANS and DES method. The following figures are normal force and pitching moment with the angle of attack, and compared with experimental values [2]. What can be seen from the figure is that when the angle of attack is smaller than 40 degrees, the aerodynamic with angle of attack is a more linear trend, the change of pitching moment with angle of attack is small, and the simulation effect of RANS and DES method is quite similar. When the angle of attack increases to 40 degrees, the leeward side of model will be stall, and the aerodynamic force and pitching moment can be closer to the experimental value, which reflect the advantage of DES method in massively separation flows.

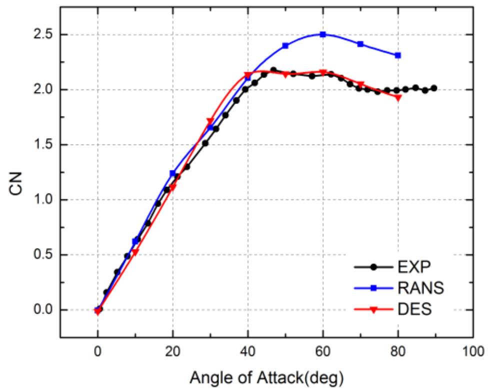

Fig.3. CN Results with Experimental Data

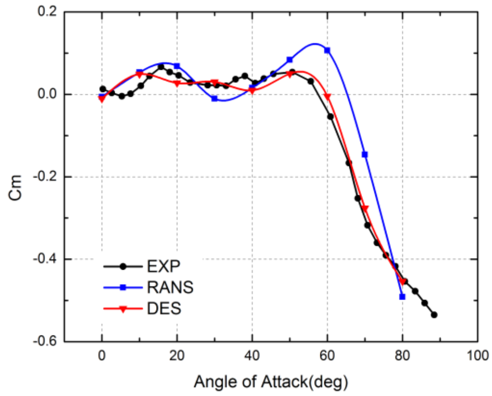

Fig4 Cm Results with Experimental Data

Figures 5 and 6 are the leeward side of the Mach number contours with RANS method and DES method individually, α = 50 °. From Figure 6, since the DES method can simulate smaller vortex structures, thus greatly reduces the flow velocity of the aircraft on the leeward side, increases the the surface pressure of leeward side, decreases normal force which is effected by the leeward side, and induces smaller normal force compared to RANS calculation method.

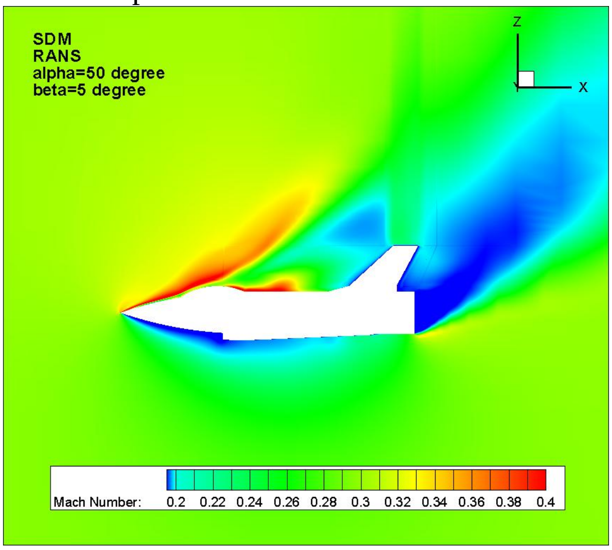

Fig.5. Ma Contour with RANS，α=50°

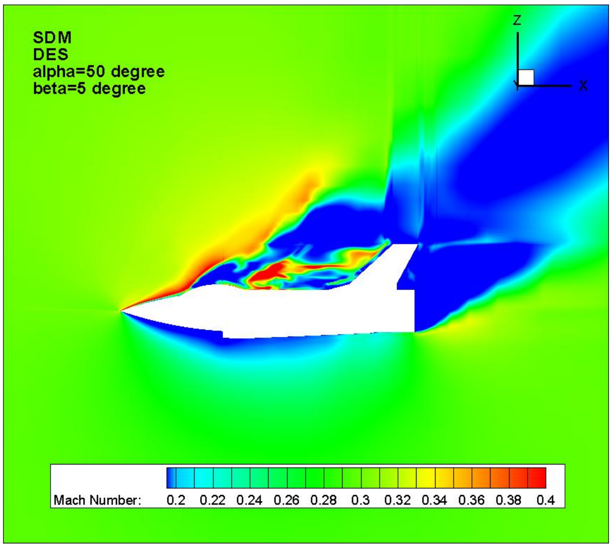

Fig.6. Ma Contour with DES，α=50°

Figure 7 are curves reflect yawing force Cy with the angle of attack, experimental value at the angle of attack range of α = 40-60 °is negative, which in good agreement in trends and magnitude with DES method simulation results, while RANS method has simulated the opposite yawing force. Figure 8 is a characteristic change in the rolling moment with the angle of attack, which is similar to the simulation of yawing force, the symbols are opposite when adoptes DES method and RANS method to simulate rolling moment at α = 40-60 °range, simulates rolling moment by DES method is much closer with experimental value, reflecting the advantage in simulate lateral\directional aerodynamic with DES method.

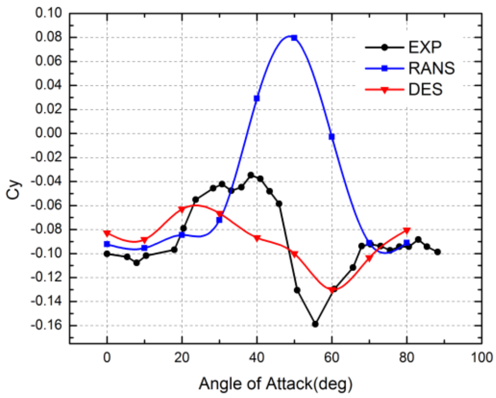

Fig.7. Cy Results with Experimental Data

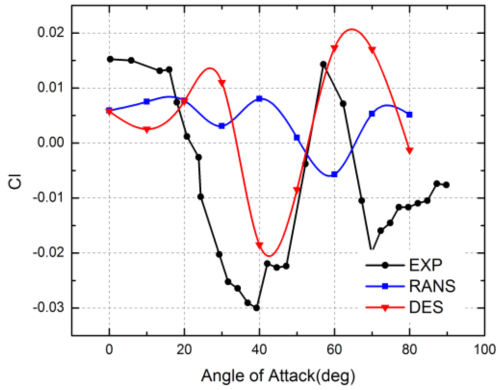

Fig.8. Cl Results with Experimental Data

Figures 9 and 10 are density contours of leeward side with RANS and DES method , α = 50 °. Seen from Figure 9, the model had a large separation vortex at the strake wing. the separation vortex contributes great to the yawing force, due to the strengeth of the separation vortex's right side is larger than the left side, which induces a positive directional force. What can be seen from Figure 10, the separation vortex of the right side crushing into many small separation vortex which results in significantly weakness of vortical suction, but still stronger separation vortex on the left side, so inducing a negative side force.

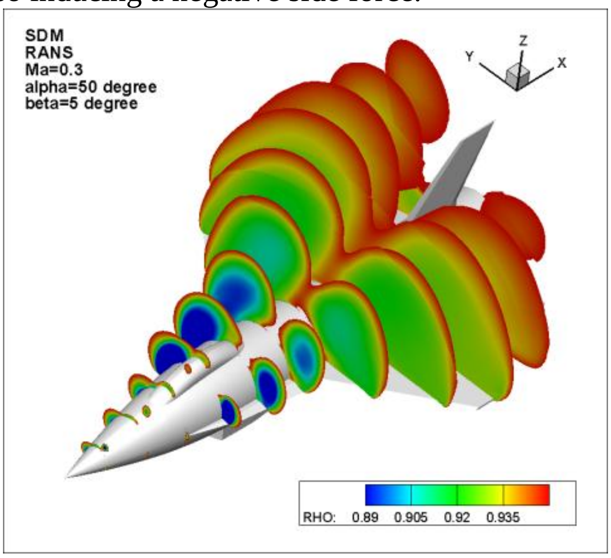

Fig.9. Density Contour with RANS，α=50°

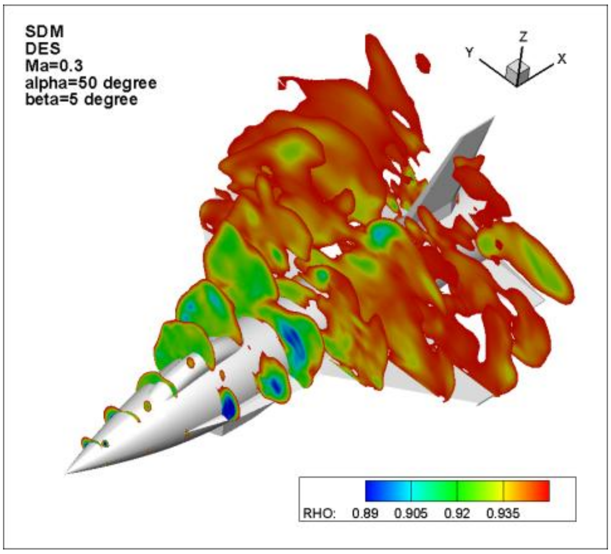

Fig.10. Density Contour with DES，α=50°

Fig. 11 and 12 are aircraft leeward side space streamline with RANS and DES , α= 20 °, what can be seen from the figure, since the angle of attack is small, the distance between vortex induced by strake wing and surface is quite near, the two methods of flow simulation of the effect is similar.

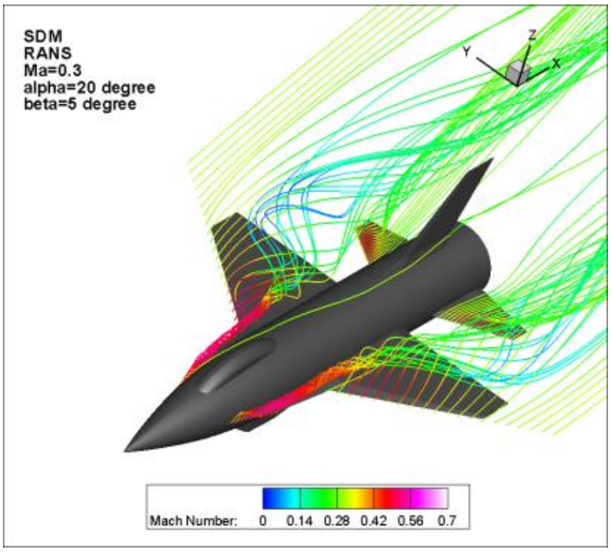

Fig.11. Streamline with RANS，α=20°

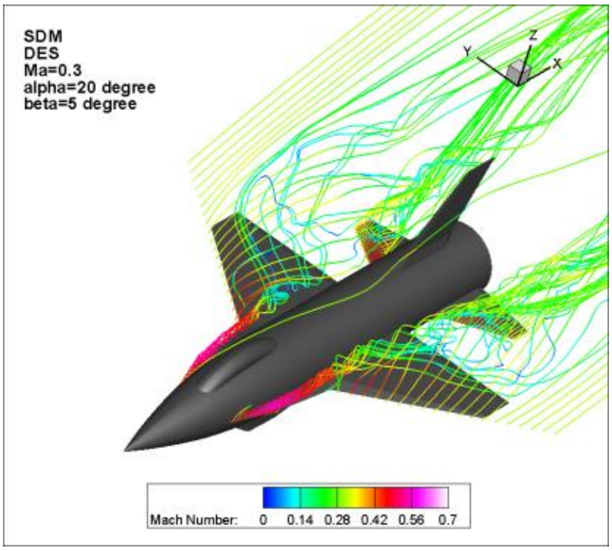

Fig.12. Streamline with DES，α=20°

When the angle of attack increased to 50 °, figure 13 and 14, what can be seen from the figure, the vortex flow is moving away from the surface, the difference between RANS method and DES methods begin to emerge. Primary vortex induced by strake wing is still strong which provide vortical suction, and making the wing leading edge vortex is also stable. The simulation results show the primary vortex induced by strake wing is broken into small vortex structures, vortical suction weakened. This kind of small vortex structure does not bring more energy to the wings flow so that leading edge vortex induced by main wing is also weak, leeward side is mainly.

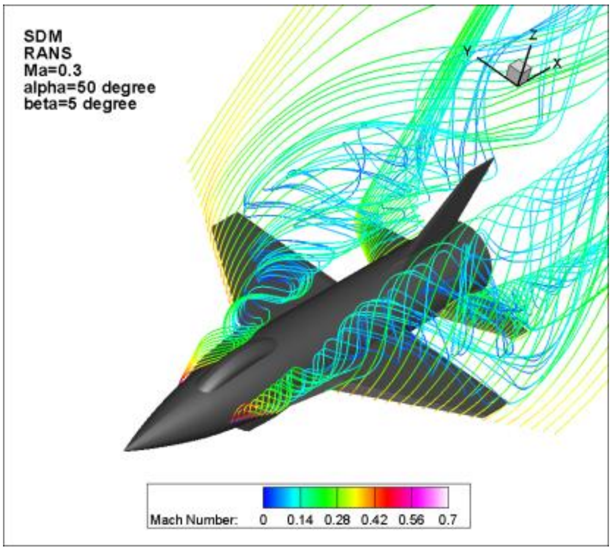

Fig.13. Streamline with RANS，α=50°

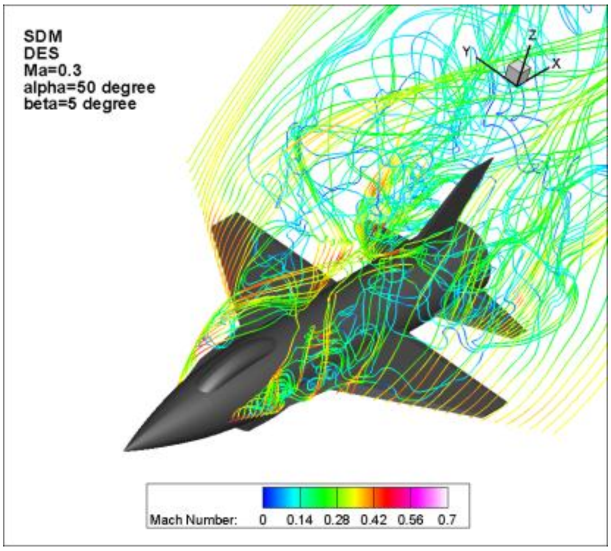

Fig.14. Streamline with DES，α=50°

4 Conclusion

What can be found in this study is that at less than 40 degrees angle of attack, RANS and DES methods for aerodynamic simulation is quite similar, when the angle of attack is greater than 40 degrees, DES method reflects a clear advantage. When simulating massively separation flow, since DES method for vortex flow higher resolution will make the primary vortex flow induced by strake wing and main wing broken into small vortex flow, so that the suction vortex weakened, resulting in different aerodynamic and flow characteristics from RANS.

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