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Detached Eddy Simulation of Complex Separation Flows Over a Modern Fighter Model at High Angle of Attack

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Abstract. This paper presents the simulation of complex separation flows over a modern fighter model at high angle of attack by using an unstructured/hybrid grid based Detached Eddy Simulation (DES) solver with an adaptive dissipation second-order hybrid scheme. Simulation results, including the complex vortex structures, as well as vortex breakdown phenomenon and the overall aerodynamic performance, are analyzed and compared with experimental data and unsteady Reynolds-Averaged Navier-Stokes (URANS) results, which indicates that with the DES solver, clearer vortical flow structures are captured and more accurate aerodynamic coefficients are obtained. The unsteady properties of DES flow field are investigated in detail by correlation coefficient analysis, power spectral density (PSD) analysis and proper orthogonal decomposition (POD) analysis, which indicates that the spiral motion of the primary vortex on the leeward side of the aircraft model is highly nonlinear and dominates the flow field. Through the comparisons of flow topology and pressure distributions with URANS results, the reason why higher and more accurate lift can be obtained by DES is discussed. Overall, these results show the potential capability of present DES solver in industrial applications.

AMS subject classifications: 76F99, 76M12, 65L80

Key words: Detached eddy simulation, hybrid grid, adaptive dissipation, separation flow, high angle of attack.

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1 Introduction

For modern fighter aircrafts, delta wing, double delta wing or diamond wing are often used in order to gain larger stall angles and generate higher lift, which is conducive to enhancement of the maneuverability of fighters. These benefits are mainly due to the leading edge vortex which dominates the flow field, but the sudden occurrence of vortex breakdown will lead to a sharp decline in aircraft performance, and even endanger flight safety, thus it is very important to accurately predict the vortical flow structures over modern fighters. With the rapid development of numerical algorithm and the rapid increase in computer power, Computational Fluid Dynamics (CFD) has been playing a more and more important role in the prediction of aerodynamic characteristics of complex modern aircrafts. Compared with experiments, numerical simulations can provide richer flow field information and meanwhile there are no influencing factors such as support interference and wind tunnel wall interference in the numerical results. However, so far it is still a great challenge for CFD to accurately simulate such large-scale separation flow. One reason is that this kind of flow belongs to the complex high Reynolds number turbulence flow, which requires a better capability of the model/solver combination to resolve turbulent structures. Another reason is that the computational cost for this kind of unsteady flow is so large that the simulations are often limited by the capacity of available computing resources [1].

To further optimize the present CFD methods in predicting complex vortex flows, three key factors need to be paid more attention, i.e., the turbulence modeling approaches, numerical schemes and mesh generation. Currently, the main methods used for numerical simulation of turbulent flows include Reynolds-Averaged Navier-Stokes (RANS) methods [2], Large-Eddy Simulation (LES) [3], Direct Numerical Simulation (DNS) [4] and RANS/LES hybrid methods [5]. Taking into account comprehensively factors such as computational cost and numerical performance, RANS/LES hybrid methods are the most potential turbulence simulation approaches in complex engineering applications at current stage and in the next period of time until LES and DNS become manageable [1]. Detached Eddy Simulation (DES) [6] is one of the most popular RANS/LES hybrid methods, because its model formulation is simple and easy to implement. Although RANS/LES hybrid methods are superior to (U)RANS methods in resolving small scale turbulent structures, low dissipative schemes are still needed in the LES region, because the excessive dissipation will prevent the methods from taking full advantage of the grid provided [7]. The central schemes without numerical dissipation seem to be more suitable for LES, but lack of computational stability is a bottleneck for their industrial applications. On the other hand, the traditional upwind schemes show good computational stability and widely used in complex engineering applications, but they are commonly considered to be too dissipative for LES [8], so high-order schemes (third order and higher) are suggested to reduce the numerical dissipation. However, the computational cost is very expensive in unsteady turbulent flow simulations with high-order schemes, especially for unstructured grids. Therefore many efforts have been made,