The Influence of Grid Scale on the Tail Vortex Capture of Aircraft

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Abstract. The grid has appreciable impact on the simulation of the wake vortex. There is a big difference between the traditional aerodynamic estimation grid and the grid used for capture the main parameters of the trailing vortex in the far field. This paper compares the similarities and differences between these two kinds of grids. The main parameters of the coarse grid are quite different from those of the refined grid simulation in the far field. Sufficient quantity grids are required to simulate the flow field in the parameters of wake vortex prediction. Otherwise, it may draw the reverse conclusions with the physical truth.

1. Introduction
The wake vortex is an important research object of aircraft flow field. The existence of vortex in the air will make the nearby aircraft tilting, rolling, stalling, sharp pitching and other dangerous situations that affect flight safety. Therefore, in the field of civil aviation, the prediction of wake vortex is an important factor affecting aircraft taking-off and landing.

In general, the methods of studying the wake vortex are through experiments and wake vortex measurements [1], by establishing the aircraft model and numerical simulation, and building a simplified wake model [2] to predict the development of the wake vortex. Aircraft wake vortex measurements could acquire primary source data, but the measurements maybe very costly. The simplified vortex model can accurately predict some key parameters such as the position and vorticity magnitude of the wake, but no more specific description of the shape and details of the wake. The numerical simulation is quite an economical method that could not only preserve the details of the wake vortex, but also avoid affected by many outdoors factors.

STUMPF, E. Rudnik, R., & Ronzheimer [3] have investigated the relationship between the wake vortex formation and the mesh mass in the near field of an airliner by euler equations. Misaka, T [4] has studied the DLR-F6 wake vortex with large-eddy simulation and found that the overall vorticity distribution is not very sensitive to the grid resolution at the initial phase of the wake. Jimenez [5] and Tabor [6] have studied the effects of boundary conditions and grid resolution on the scale of the wake vortex.

2. The Mesh and Model
2.1. The Simulation Model and State
The simulation model is the simplified A320 [7] as shown in Figure 1. This model is the most common passenger aircraft. The aircraft is a classified medium-sized aircraft according to ICAO [8], with a length of 37.57 m, a wingspan of 34.1 m, a height of 11.76 m, a sweep angle of 25° and a body
width of 3.95 m. The model is simplified with the main parts of the residual fuselage, wings, horizontal tail, and vertical tail and so on. Considering the main sources of vortices in the wake are the wing and the horizontal tail, the model is simplified without the undercarriage. The winglet is removed from the wing section in order to highlight the wingtip vortices dragged by the wing clearly.

![Figure 1. A320 model.](image)

At the height of 60m during the approach, the effect of the ground is not obvious and the grid don’t need to be enhanced near the ground, which could save the computing resources. The touchdown speed of A320 is about 60-70m/s in most approaching condition and the selected speed is 63m/s.

2.2. The Detail of Mesh and Boundary Conditions
As shown in Figure 2, the graph on the left is the coarse grid for calculating aerodynamic forces. The main performance and influence area of the wake vortex is the section A, in addition, the wake vortex may also spread to the B area in the wake flow field away from the aircraft as it sinking. Therefore, according to the general range of Wake Development, the refined grid is divided into more detailed blocks, and the areas of A1, A2, B1 and B2 in Figure 2(right) are especially densified.

![Figure 2. The block of coarse (left) and refined (right) grid.](image)

The number of grids is 9.21 million (the coarse grid) and 27.50 million (the refined grid), respectively. The plane and symmetry refined mesh are shown in Figure 3. Both mesh got the grid Y + = 50, so the wall function should be added to the near wall simulation. The turbulence model SST (Stress Shear Turbulent Model) [9] is selected for the good performance in flow separation calculation. In addition, we have also chosen the second-order upwind scheme for convection discrete momentum equations. The far field in all directions are free stream, and lower surface of the far field represent ground is set as the moving floor with the same velocity of free stream.
3. The simulation Results

3.1. The Aerodynamic Results

Table 1. The mesh and nodes information for the A320 configuration.

| Grid number (million) | Y+ | Xr | Y   | Z   |
|-----------------------|----|----|-----|-----|
| 9.21                  | 50 | 35 | 169 | 142 |
| 27.5                  | 50 | 89 | 261 | 263 |

The Xr in the Table 1 represents the block nodes of the flow field behind the aircraft, which is the main direction of enhance for the simulation of the refined grid.

Table 2. Aerodynamic results of two meshes.

| Grid number (million) | Cl  | Cl (%) | Cd   | Cd (%) |
|-----------------------|-----|--------|------|--------|
| 9.21                  | 0.8344 | - | 0.0554 | - |
| 27.50                 | 0.8348 | 0.048 | 0.0552 | -0.36 |

Table 2 showed the aerodynamic results of two meshes. Since the minimum scale of the surface grid has not changed, the infill of the wingspan to scale has little effect on the aerodynamic coefficients. The lift coefficient increased by 0.048% and the drag coefficient decreased by 0.36%. The aerodynamic coefficients are almost same between the two different kinds of grids.

3.2. The Wake Vortex Results
Figure 4. Vorticity profiles for two different mesh.

By comparing the viscosity contour results of two different grids in Figure 4, it can be seen that the shape and strength of the wake are similar in the near field. However, the far-field wake is affected by the grid nodes distribution. The intensity of the wake is much different considering the shape near the vortex core is similar.

The wake near the wing tip got huge similarity among two viscosity contour profiles in Figure 5(a). So did the intensity of the wake core. At 6 times characteristic length, the refined grid got more high viscosity section than the coarse grid gradually, which indicated the numerical dissipation of the coarse grid is more prominent. For the Figure 5(c), the simulation of coarse one could not fully and clearly presented the influence range of the wake vortex. In contrast, the refined grid simulation results could still show the influence range of the wake core completely.

(a) X/b=1.0
Figure 5. Vorticity of different profiles on the flow direction for the different mesh (left for the coarse mesh).

As shown in Figure 6, there is a small difference between the wake parameters of the two grids within the double length of flow direction, which coincided the previous contour graphs. In the spanwise direction (Z-axis), the difference of vortex core position begins to expand gradually. On the normal direction, the parameters shown in the two times of spanwise are very close. However, the performance became much different beyond that range. The wake of the coarse grid rises slowly, while the wake of the refined grid drops rapidly along the normal position (Y-axis). In the near flow field, the tip vortex could be induced to rise in the normal direction due to the greater influence of the homonymous horizontal wake. With the weakening energy of the horizontal wake vortex, the two wing tip vortices begin to induce each other to sink. The performance of coarse grid on normal data is very distorted.
4. Conclusion
Enhancing the flow field of the rear part of the aircraft would only influence the aerodynamic force little.

The grids used in aerodynamic simulation can hardly meet the needs of wake vortex capture. It only remained the same results with the refined mesh in about 3 times range of the wingspan. When the grid scale increases in the flow direction, the numerical dissipation gradually increases, which makes the grid unable to transfer the complete flow field information. The strength of the wake vortex decreases very seriously due to the former reason.

By properly increasing the grid nodes of each dimension, the wake vortex information can be well preserved in a certain range of simulation field.

The developing trend and the maximum vorticity between the coarse grid and the fine grid are consistent, while the difference increases with the flow direction. However, in the position, the coarse grid cannot capture more flow field information, which leads to the huge disparity normal position of vortex core very early.

Acknowledgments
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References

[1] Dougherty, R, Wang, F, Booth, E, Watts, M, Fenichel, N, and D'Errico, R 2004 Aircraft wake vortex measurements at Denver International Airport In 10th AIAA/CEAS Aeroacoustics Conference (2004, January) p 2880

[2] Segalini, A, and Alfredsson, P H 2013 A simplified vortex model of propeller and wind-turbine wakes Journal of Fluid Mechanics, 725, 91

[3] Stumpf, E, Rudnik, R, and Ronzheimer, A 2000 Euler computation of the nearfield wake vortex of an aircraft in take-off configuration Aerospace science and technology. 4(8), 535-543

[4] Misaka, T, Holzäpfel, F, Gerz, T, Manhart, M, and Schwertfirm, F 2011 Large-Eddy Simulation of wake vortex evolution from roll-up to vortex decay In 49th AIAA aerospace sciences meeting including the new horizons forum and aerospace exposition (2011, January) p 1003

[5] Jiménez, J, Hoyas, S, Simens, M P, and Mizuno, Y (2010) Turbulent boundary layers and channels at moderate Reynolds numbers Journal of Fluid Mechanics, 657, 335

[6] Tabor, G R, and Baba-Ahmadi, M H (2010) Inlet conditions for large eddy simulation: A review Computers and Fluids, 39(4), 553-567

[7] De Bruin, A C 2003 S-Wake Assessment of Wake Vortex Safety (Amsterdam: National Aerospace Laboratory NLR)

[8] ICAO, D 2016 Draft 2016-2030 Global Air Navigation Plan Doc 9750-AN/963, Fifth Edition (Montreal, Canada)

[9] Menter, F R 1994 Two-equation eddy-viscosity turbulence models for engineering applications AIAA Journal, 32(8), 1598-1605