Effect Analysis of the Hangar Rear Edge Curvature on the Ship Airwake

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Abstract. In order to examine the effects of hangar rear edge curvature on ship airwake, the SFS2 ship configuration is modified by changing rear vertical surface of hangar into curved surface. Airwake with different configurations subject to free-stream of 25.7m/s at headwind are simulated using commercial CFD solver ANSYS FLUENT, and the traditional Reynolds-average Navier-Stokes k-ε two equation turbulence model is applied. A very good agreement of experiment results in wind tunnel with predictions from the CFD demonstrate that both the FLUENT code and the meshes generated by ICEM perform well in simulating ship airwake. The comparison of different hangar rear edge curvatures shows that the curvature modifications improved airwake over the flight deck region of SFS2 by reducing mean downwash and turbulence intensity. 90° is the best angle corresponding to SFS2 hangar rear edge curved arc, which will reduce pilot workload during launch and recovery operations.

1. Introduction

The superstructure and the hangar of ship usually contain sharp corners, the airflow is blocked and creates flow separation, vortex shedding and attachment when crossing these structures. The blockage and viscosity are the driving force for flow separation and vortex shedding. For rear-flight deck ship with hangar, hangar shape is the key structure that affects the airwake in the helicopter operating area. By changing hangar shape, the pressure changes in the helicopter operating area can be slowly and smoothly, avoid the strong vortex and shear layer caused by the speed jump, so as to optimize the ship design. In 2002，Kumar[1] conducted subscale wind tunnel experiments to assess the effectiveness of passive control involving a porous surface and cavity underneath for reducing the level of surface pressure fluctuations in reattaching flows, and it demonstrated the design can significantly reduce the peak surface pressure fluctuations in the reattachment zone, a maximum reduction of as much as 35% has been observed; in 2003, Tai[2] modified the SFS ship configuration by adding a rounded bow section at the front end to avoid complete separation along the side walls, the concluding remarked that the complete separation along the hull surface is avoided; in 2005, Shafer[3] explored both active and passive flow control techniques on airwake improvement in the final decent of helicopter onto the flight deck, results show that it would cause a reduction in unsteadiness in the landing region of 6.6% at 0° wind-over-deck (WOD) and 8.3% at 20° WOD by injecting air through the porous surfaces; in 2010, Forrest[4] found that it could decrease the adverse pressure gradient and the turbulence at the hangar edge by installing a 30° flap at the hangar edge of starboard side or applying a chamfer with an angle of 30°; in 2013, the midshipman LaSalle[5] of the United States Naval Academy examined the effects of passive flow control techniques on the ship airwake of YP, and the investigation showed that the particular passive flow control fence produce a less favorable ship airwake for helicopter launch

and recovery operations due to an increase in shear, turbulent kinetic energy density, and mixing within the helicopter landing region.

The work presented in this paper relates to a number of curved geometric modifications which have made to the vertical hangar rear edge of SFS2 in an attempt to alter the airwake characteristics over the flight deck for headwind. Airwake for different modifications are measured with computational fluid dynamics (CFD) simulations to provide analysis for effects of the curvatures on the SFS2 airwake.

2. Aerodynamic Design and Meshing

As shown in figure 1, the rear vertical surface of the hangar is modified to curved surface. The top view of 13 different kinds of curvatures of hangar rear edge is shown in figure 2. Different curvatures are expressed by the center angle α corresponding to the arc. The α ranges from 0° to 180°, and the interval is 15°, actually when $\alpha>150°$ the mesh quality around the arc degraded severely, which will result in calculation divergence, so the upper limit of α in this paper is 150°.

（a）$\alpha=0°$ （b）$\alpha=60°$ （c）$\alpha=120°$
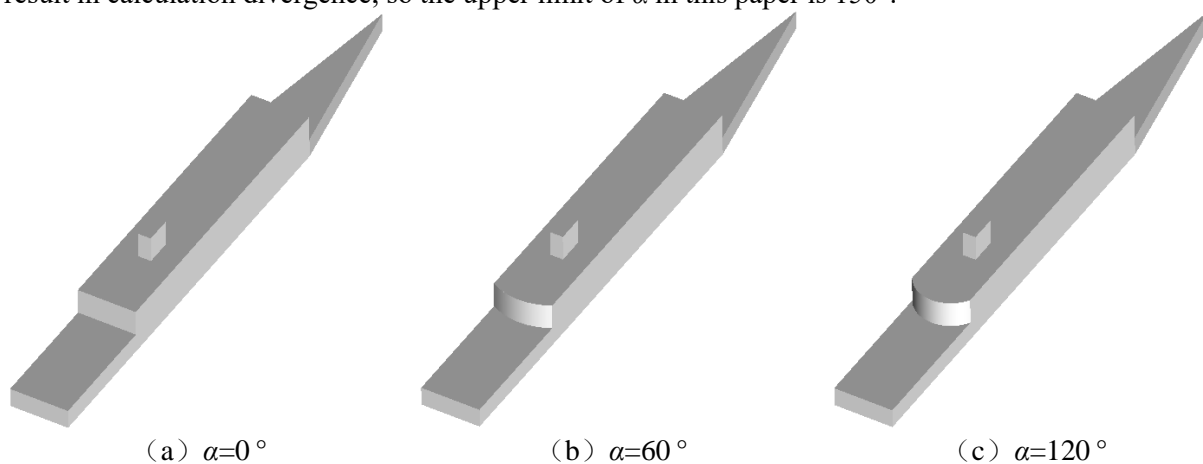
Figure 1. Schematic of the different curvatures of hangar rear surface for SFS2
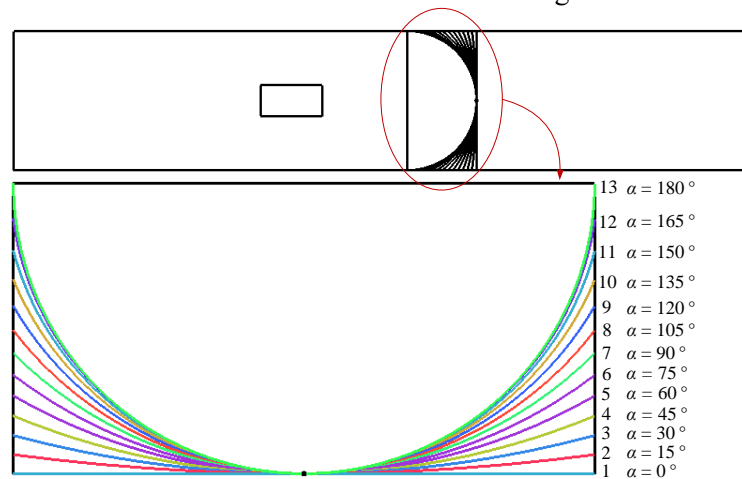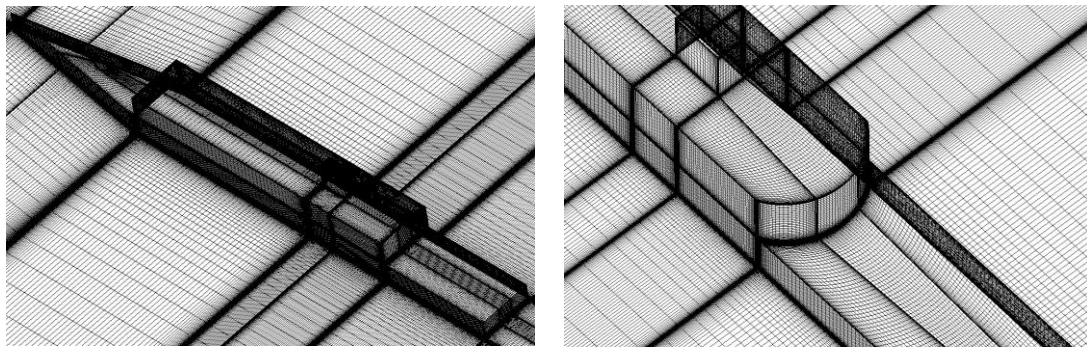

Figure 2. Top view of different curvatures of hangar rear edge for SFS2

The SFS2 models were imported into the ANSYS ICEM mesh generation software to generate structured meshes. Original SFS2 and the modified SFS2 structured mesh are shown in figure 3, after verifying the grid independence, both the original and modified SFS2 mesh number used for numerical computation is 1.89×10^7.

（a）mesh for original SFS2 mesh   （b）mesh for modified SFS2 mesh

Figure 3. Top view of mesh distribution for different SFS2 models

3. Flow Solver and Boundary Conditions

The steady-state airwake of SFS2 is simulated using commercial CFD solver ANSYS FLUENT, and the traditional Reynolds-average Navier-Stokes k-ε two equation turbulence model is applied.

The boundary conditions for the FLUENT solver are:

(1) free-stream of 25.7m/s for upstream;

(2) pressure far field for downstream;

(3) viscous nonslip flow at the surface of the SFS2 ship;

(4) frictionless surface at stationary water surface.

4. Method Validation

The validation study was performed to gain confidence in the accuracy of the CFD modelling by comparing the experiment results obtained from the Chinese Aeronautical Establishment (CAE). The experiment was conducted in the 4.5m×3.5m low-speed wind tunnel as shown in figure 4. Particle Image Velocimetry (PIV) was used to obtain the mean velocities over the SFS2 deck. In order to simulate uniform flow condition, the 1:60 scale SFS2 model was mounted on a plate about 1.45m above the wind tunnel floor. The outlet wind speed of wind tunnel is 25.7m/s.
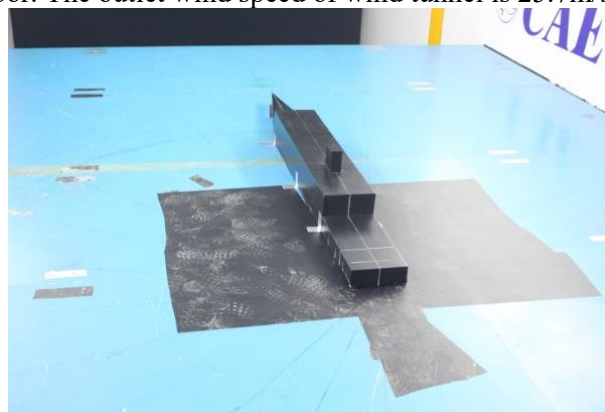

Figure 4. SFS2 model in the test section of the wind tunnel

Figure 6 shows a comparison of CFD and wind tunnel experiment velocity. The comparison contains the x-velocity and z-velocity of L_S plotted in figure 5. These two data sources are referred to in figure legends as 'CFD' and 'EXP' respectively. CFD and wind tunnel experiment predict the same wake pattern, with the CFD velocities a factor of approximately 0.1 lower than the wind tunnel results outside the separation, while inside the separation the velocities profiles almost overlap. The overlapped zero points of A and B indicate that the CFD and wind tunnel predict the same separation. In summary, the comparison of the detailed CFD results with data obtained from wind tunnel experiment show excellent agreement. This agreement holds not only for the velocity profiles but also

for the velocity magnitude. These results demonstrate that both the FLUENT code and the meshes generated by ICEM perform well in simulating ship airwake.
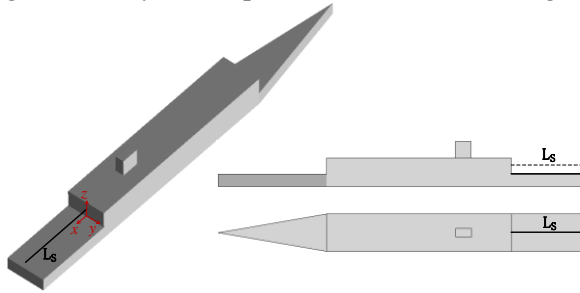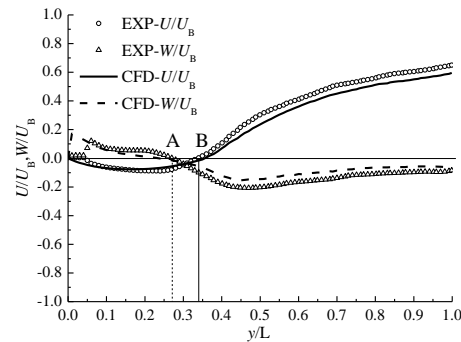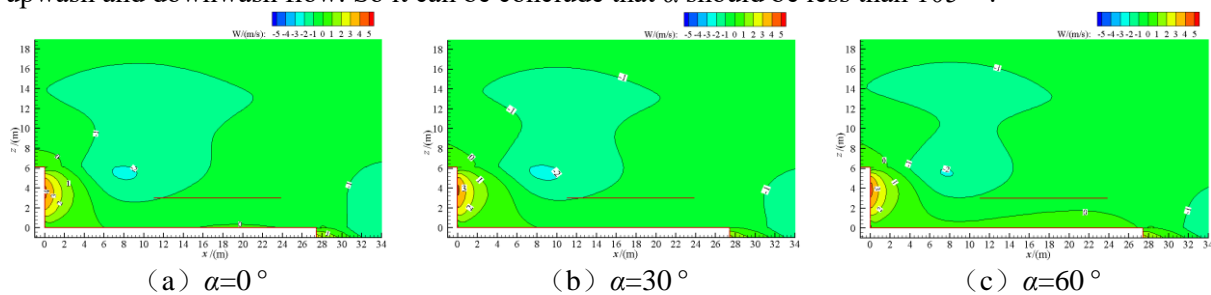

Figure 5. Coordinate and location of L_S

Figure 6. Comparison of CFD and experiment for SFS2

5. Results and comparison

The early publications of Lee and Zan [6,7] already revealed that both the turbulence intensity and the downwash mainly affect the helicopter in the ship airwake, the turbulence intensity mainly affect the pilot workload, and the downwash affect the rotor performance. This paper will analyse the airwake focused on the parameters mentioned above.

The z-component velocity contours on SFS2 symmetry plane for different α are shown in figure 7, with the increasing of α, the downwash around the flight deck hangar increases gradually, while the upwash shows the opposite trend; for the airwake around the rotor(the red line above the flight deck), both the downwash magnitude and the affect range reduced. When α is equal to 90°, the downwash velocity contour of 2 m/s disappears; and when α is greater than 120°, upwash appears around the rotor centre. The streamlines on SFS2 symmetry plane for different α shown in figure 8 indicate that with the increasing of α, the recirculation behind the hangar gets smaller and smaller; when α is equal to 90°, the helicopter almost escape the effect of the recirculation. Due to the limitation of mesh quality, it does not simulate the conditions when α is bigger than 150°, while based on the trend of existing data, it can be inferred that as α continue to increase, both the downwash and the recirculation zone will further decrease. It is beneficial to improve the stability of helicopter in the ship airwake.

Figure 9 gives the downwash and the turbulence intensity contours predicted by CFD for the rotor disk of a Westland Lynx helicopter sitting on the flight deck for different α. The results show that as α increases, the airwake changes obviously, both the downwash and the turbulence intensity decrease sharply. Similar to the results in figure 7, when α is greater than 105°, upwash appears around the rotor centre. Which may cause a rollover danger for the helicopter located in airwake with both upwash and downwash flow. So it can be conclude that α should be less than 105°.
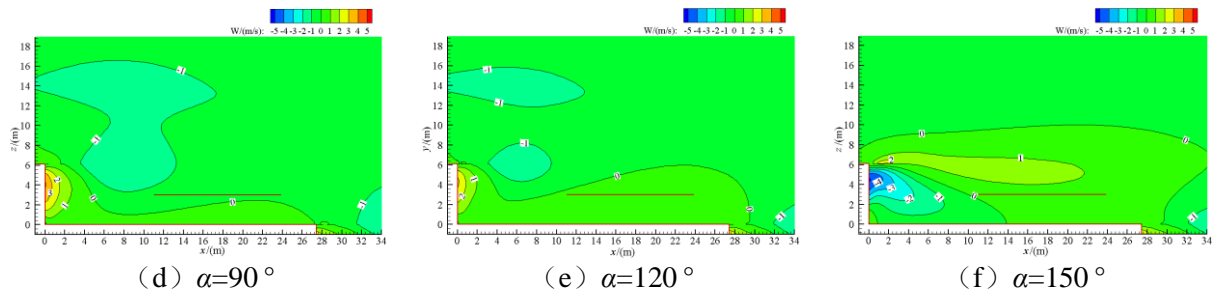

（a）$\alpha=0°$

（b）$\alpha=30°$

（c）$\alpha=60°$

（d）α=90°   （e）α=120°   （f）α=150°

Figure 7. *z*-component velocity contours at SFS2 symmetry plane of different α for headwind

（a）α=0°   （b）α=30°   （c）α=60°

（d）α=90°   （e）α=120°   （f）α=150°

Figure 8. Streamlines at SFS2 center deck of different degrees of circular hangar transition for headwind

（a）α=0°   （b）α=15°   （c）α=30°   （d）α=45°   （e）α=60°

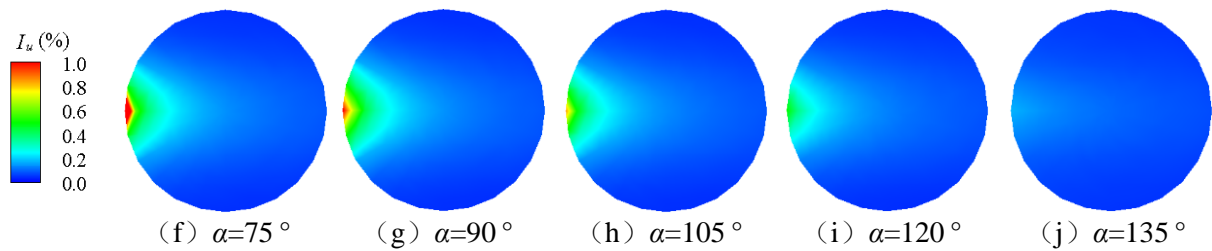（f）α=75° 　（g）α=90° 　（h）α=105° 　（i）α=120° 　（j）α=135°

Figure 9. *z*-component velocity, pressure and turbulence intensity contours at Westland Lynx rotor plane of SFS2 different degrees of circular hangar transition for headwind

The *z*-component velocity profiles on the vertical line passing ITDP with different α shown in Figure 10 indicate that, it only exists upwash above the ITDP(Ideal touchdown point) when α is less than 30°, while when α is greater than 30°, helicopter will be subjected to the downwash firstly and then the upwash during the landing process. And as α increases, the upwash velocity increases while the downwash velocity decrease in opposite.
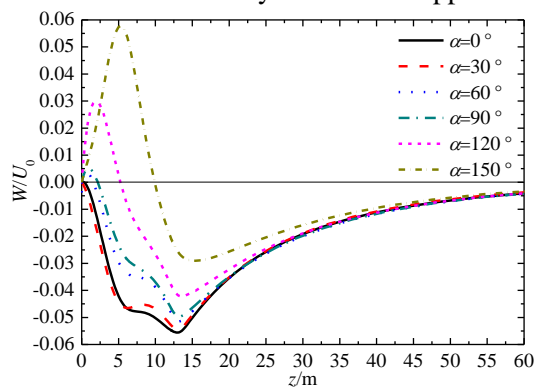

Figure 10. *z*-component velocity on the vertical line passing ITDP of SFS2 different degrees of circular hangar transition for headwind
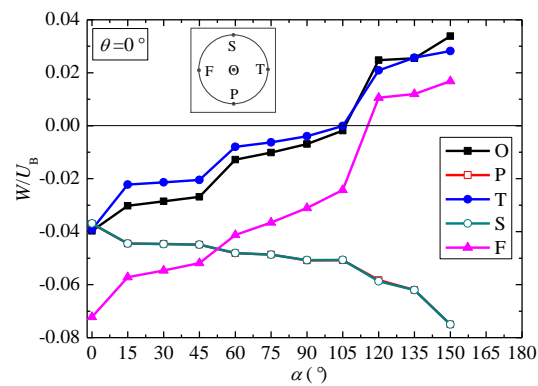

Figure 11. *z*-component velocity at point O,P,T,S and F of SFS2 different degrees of circular hangar transition for headwind

Figure 11 gives the z-component velocity profiles of the key points labelled as O, F, T, P and S with different α. Compared to the contours the velocity profiles show clearer trend, as α increases, the downwash velocity at points O, F and T decreases gradually, and when α=105°, the velocity magnitude drop to the minimum, then it turns to upwash and increases as α increases on. For the symmetrical points P and S, the downwash velocity profiles coincide completely, and the velocity magnitude increases as α increase from 0° to 90°, while from 90° to 105° the velocity magnitude keep as a constant, and when α is equal to 105° the downwash velocity gradient increases significantly.

The numerical simulation results provide details of the flow around SFS2 hangar rear edge curvatures. Analysis demonstrates that by changing the curvature of SFS2 hangar can significantly optimize the ship airwake around the helicopter, while when α is greater than 90°, it may cause a rollover danger with both upwash and downwash load on the rotor and fuselage, and the downwash velocity gradient increases significantly when α is greater than 105°, so 90° is the best angle corresponding to the SFS2 hangar rear edge curvature arc.

6. Conclusions
A methodology for testing the effect of ship hangar rear edge curvature on ship airwake has been presented, featuring steady CFD ship airwakes validated with PIV wind tunnel experiment. A very good agreement of the mean flow measured in experiments with predictions from the CFD data is demonstrated. The comparison of different hangar rear edge curvatures simulation results showed that the curvature modifications improved airwake over the flight deck region of SFS2 by reducing mean downwash and turbulence intensity in the local flow. With increasing of α (The centre angle

corresponding to the arc of curvature), the improvement effect is more and more obvious when α is less than $90°$; the curvature modification more than $90°$ could potentially lead to the rollover of helicopter with both upwash and downwash load on the rotor and fuselage, and the downwash velocity gradient increases significantly when $\alpha>105°$, thus $\alpha=90°$ is the best angle corresponding to the SFS2 hangar rear edge curvature arc, which will reduce pilot workload during launch and recovery operations.

For future investigations, the PIV should be applied to validate the effects of curvature modification on SFS2 ship airwake.

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