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Research Article

The Influence of Turbulence Models on the Numerical Modelling of a 3D Wing in Ground Effect

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Abstract

This paper deals with the influence of different RANS turbulence models on the numerical modelling of a 3D rectangular symmetrical wing in ground effect. Travelling near a solid surface, so-called ground effect, considerably alters the aerodynamic characteristics of a wing. This paper aims to investigate the performance of the widely used eddy viscosity turbulence models while predicting the changing aerodynamic behavior due to the ground effect. Three different RANS turbulence models, realizable $\kappa-\varepsilon$, $\kappa-\omega$ SST and Spalart-Allmaras models are taken into consideration. The effectiveness of the turbulence models were tasted in comparison with the experimental data in different angles of attack and ground heights. Results reveals that, the effect of the turbulence models on the numerical accuracy of the ground effect aerodynamics calculations are related to the altitude and the angle of attack. The choice of the turbulence model becomes important when the wing travels in very close proximity to the ground and the angle of attack is low or negative. The discrepancy of the calculated results mainly comes from the pressure distribution variations on the lower side of the wing. For high angles of attack, or relatively larger ground heights, the difference between the predictions of the turbulence models become negligible.

Keywords: Ground effect, Rectengular wing, Aerodynamics, CFD, Turbulence models, RANS.

Türbülans Modeli Seçiminin Zemin Etkisindeki 3B Bir Kanatın Sayısal Modellemesine Olan Etkisi

Öz

Bu çalışma, farklı RANS türbülans modellerinin Zemin etkisinde çalışan 3B simetrik bir kare kanatın sayısal modellemesindeki etkisini incelemektedir. Katı bir Zemin yakınında hareket etme, ya da bilinen ismiyle yer etkisi, bir kanatın aerodinamik karakteristiğini öenmli oranda etkiler. Bu makalede amaç, farklı eddy viskozitesi türbülans modellerinin yer etkisi esnasındaki aerodinamik davranışı modelleme yönünden performansının araştırılmasıdır. Üç farklı türbülans modeli, realizable $\kappa-\varepsilon$, $\kappa-\omega$ SST and Spalart-Allmaras modelleri incelemeye dahil edilmiştir. Türbülans modellerinin etkinlikleri farklı hücum açıları ve kanat yükseklikleri için deneysel verilerle karşılaştırmalı olarak test edilmiştir. Sonuçlar göstermektedir ki, türbülans modellerinin yer etkisi aerodinamiği hesaplamaları konusundaki başarısı irtifa ve hücum açısı ile doğrudan ilişkilidir. Türbülans modeli seçimi kanat yere çok yakın hareket edşyorken ve hücum açısı düşük ya da negatifken önemli hale gelmektedir. Elde edilen sonuçların birbirlerinden farklılığı temel olarak kanat alt yüzeyindeki basınç dağılımından kaynaklanmaktadır. Yüksek hücum açıları ve irtifalarda farklı türbülans modelleri ile elde edilen tahminler arası fark ihmal edilebilir düzeyde kalmaktadır.

Anahtar Kelimeler: Zemin Etkisi, Kare Kanat, Aerodinamik, HAD, Türbülans modelleri, RANS.

1. Introduction

Operating in the vicinity of the ground provides several benefits to the objects by enhancing the aerodynamic lift and efficiency. This advantage makes the ground effect an important phenomena for various present or experimental practical applications.

Many researchers have been dealing with the ground effect aerodynamics for several years with the aim of understanding the flow physics of the ground effect or to obtaining the best performance from it. Zerihan and Zhang (2012) carried out experimental wind tunnel measurement to analyze the performance of a single element wing close ground proximity. He et al. (2014) performed shape optimization of NACA4412 in order to evaluate the performance in WIG craft applications. Jia et al. (2016) numerically investigated the aerodynamics of a banked wing in ground effect. They studied different configurations like the use of rectangular wing, delta wing endplates, ailerons..etc. Qu et al. (2016) investigated the flow physics of a multi element wing working in ground effect. Zaheer et al. (2019) evaluated the performance of different airfoil geometries in ground effect by the aid of computational fluid dynamics (CFD) . Qu et al. (2015) conducted a series of numerical analyses with 2D NACA4412 airfoil in ground for wide range of angles of attack. Ozden et al. (2020) revealed the features of a low-aspect-ratio wing in ground effect by performing wind tunnel measurements. Nirooei (2018) conducted CFD analyses to study the aerodynamic and stability characteristics of modified NACA4412 airfoil in extreme ground effect. Lee and Han (2020) experimentally investigates the high angle of attack ground effect aerodynamics of the low-aspect ratio modified NACA0012 wing.

There are also a group of studies focused on the accuracy of the numerical simulations concerning to the ground effect aerodynamics. Schmid et al. (2009) tested different modelling approaches for the trustworthy numerical modelling of airfoils and wings in ground effect. Doig and Barber (2012) investigates different numerical features like tunnel walls and turbulence model for the numerical simulations of a 2D airfoil in ground effect. Jithin et al. (2021) evaluated the performance of different turbulence models in the numerical modelling of 2D NACA4412 airfoil in ground effect. Firooz and Gadami (2006) assessed the effect of ground boundary condition and turbulence models on the accuracy of the numerical simulation of a 2D airfoil concerning ground effect.

Present paper covers the CFD modelling of a 3D wing in ground effect using different RANS turbulence models. NACA0012 rectangular wing is used for simulations. The effect of the turbulence models on the lift predictions were provided in comparison with the available experimental data from the literature. Pressure distributions are also investigated to analyze the discrepancy between the results.

2. Material and Method

In this study, the flow over a 3D rectangular wing with NACA0012 section was investigated with the aid of CFD. The main dimensions of the wing is given in table 1. A commercial Navier-Stokes solver, Simcenter Star-CCM+ was utilized in the calculations. The solution numerical configuration is similar to the experimental work of Moore et al.(Moore, Wilson, & Peters, 2002) for validation purposes. The computations were carried out in a Cartesian coordinate system with the center on c/3 and positive –x axes pointing flow direction.

Table 1. The main dimensions of the wing

Chord, c	0.317 m.
Span, s	0.96 m.
Aspect Ratio, *AR*	3.02 m.
Area , A	0.303 m2

The wing is located at 10c from the inlet, 20c from the outlet boundary and 3.3c from the sidewalls. The distance from the bottom wall (ground height) was equal to h/c=0.1 and h/c=0.3. The angle of attack (AoA) for each wing height was varying in the range of $-3^\circ < \alpha < 5^\circ$. The geometrical description of the problem is shown in fig.1. Uniform velocity condition is applied to the inflow boundary. No-slip boundary condition was spplied to the wing surface, while the ground was treated as moving wall, for better representation of the real flow physics (Schmid et al., 2009). The free stream velocity at the inlet is 38m/s, which corresponds to the Reynolds number of Re=8x10^5 ($\mathrm{Re} = Uc/\nu$, where u is free stream velocity, c is chord length and ν is kinematic viscosity)

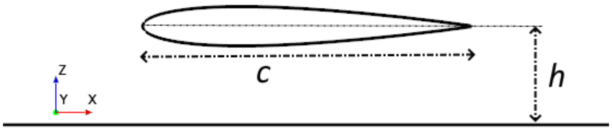

Fig. 1 Description of the problem

The solution domain was constructed using hexahedral elements. The view of the mesh structure close to the wing is given in fig.2. there are several refinement regions located around the wing and the wake region. Addition mesh refinement was applied to the region between wing and the ground to capture the high velocity and pressure gradients. Prismatic mesh layers was constructed along the wing surface for the better representation of the boundary layer. The first mesh point was located to ensure the y+ ($y+ = u_\tau y/\nu$, where u_τ is friction velocity and y is the height of the first mesh point) is about 30-100. The grid structure was systematically refined and the change of the lift coefficient was observed to investigate the mesh dependency of the results.

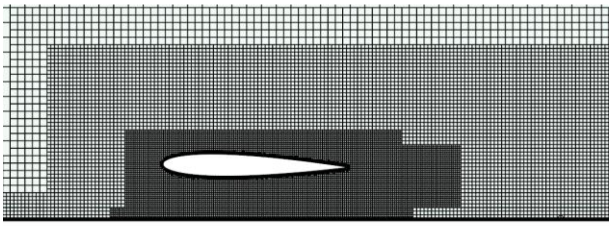

Fig. 2 Mesh structure around the wing

The solver implements finite volume method for the discretization of the governing equations. A second order scheme was applied for spatial and temporal discretization. The time step was 10^{-4} for all simulations. the details of the turbulence models can be found in the solvers manual (Siemens, 2019).

3. Results and Discussion

The flow around the wing for varying altitudes and AoAs are numerically calculated using different RANS turbulence models. In fig.3, the lift vs. AoA results for the wing height at h/c=0.3 are presented in comparison with the experimental data of Moore et al. (Moore et al., 2002). As can be shown in the figure, the choice of the turbulence model has no considerable influence on the lift coefficient predictions. all results are in very good agreement with the experimental data for all AoAs in the investigated range.

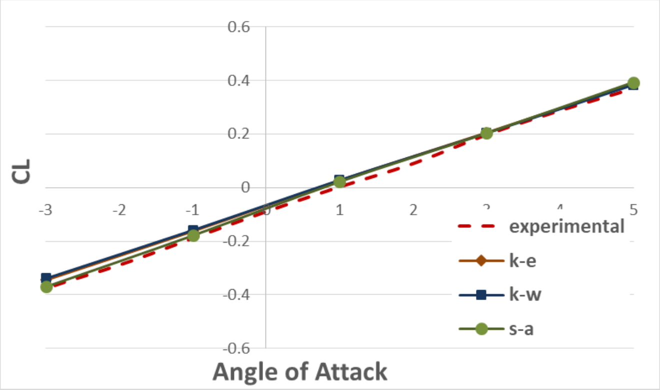

Fig. 3 Comparison of turbulence models for lift at h/c=0.3

For the clearer understanding of the agreement/ discrepancies between the lift force computations of different turbulence models, pressure coefficient results are depicted in comparison. Fig. 4 shows the pressure distribution along the mid-section of the wing at h/c=0.3 and $\alpha = 5^\circ$. The figure shows a typical pressure distribution of a positive lift generating foil: higher pressure at the lower surface. The similarity between the lift calculations of different models can be also seen in the pressure predictions.

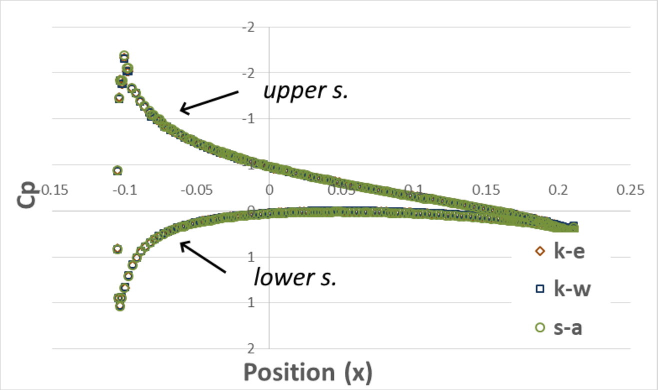

Fig. 4 Pressure distribution along the wing at h/c=0.3 and a=5

Same pressure coefficient calculations in fig.4 are also investigated for a negative AoA. Fig.5 gives the pressure distribution along the mid-section of the wing at h/c=0.3 and $\alpha = -3^\circ$. The predictions of different models are still similar, but the pressure balance along the wing changes for the negative AoA. The pressure coefficients along the lower surface of the wing are higher compared to those of upper surface. Thus, for this scenario, the wing generates negative lift.

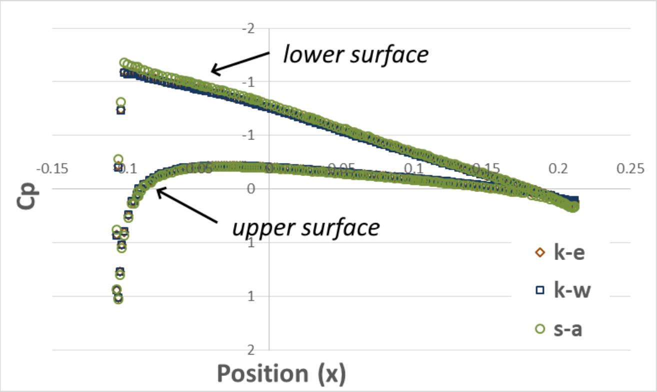

Fig.5 Pressure distribution along the wing at h/c=0.3 and a=-3

The lift calculation results in the fig.3 are repeated for a lower wing height. In fig.6, the lift vs. AoA results for the wing height at h/c=0.1 are presented in comparison with the experimental data. The lift force predictions of different turbulence models are not in agreement for this case. The discrepancy between the results become notable as the AoA decreases. Among the three, Spalart-Allmaras turbulence model produces lowest lift coefficient values for all AoAs, while $\kappa - \omega$ SST model produces the highest ones. Realizable $\kappa - \varepsilon$ model seems to provide the best performance in the manner of the agreement with the experimental data.

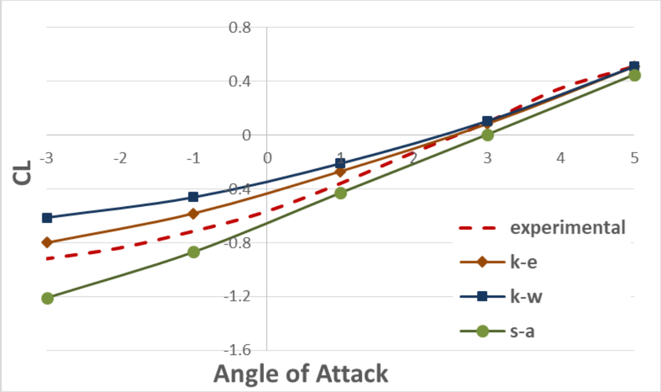

Fig. 6 Comparison of turbulence models for lift at h/c=0.1

The pressure distribution along the wing is provided to seek for the ground of the discrepancy between turbulence model predictions. Fig. 7 shows the pressure results for h/c=0.1 and . For this high AoA, the calculated pressure coefficients do not show a considerable difference as in the lift results in fig.6. As seen from the figure, near the trailing edge pressure values at the lower surface become comparable to those of upper surface. However, in the first half of the chord length in the stream-wise direction, the pressure values along the lower surface are higher due to the air cushion effect of the close ground proximity.

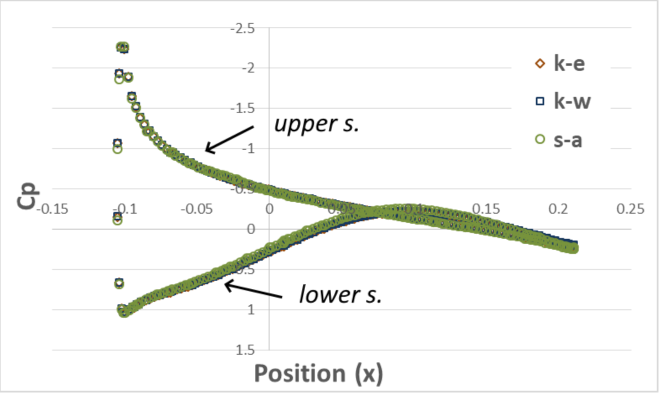

Fig. 7 Pressure distribution along the wing at h/c=0.1 and a=5

Fig.8 gives the pressure distribution along the mid-section of the wing at h/c=0.1 and $\alpha = -3^\circ$. For this case, the difference between the calculated pressure coefficient results are notable. In general, lower surface of the wing produces higher pressure values compared to those of upper surface, thus the wing generates negative lift. All turbulence models captures this behaviour in success. The magnitude of the calculated peak pressure values in the lower surface are in agreement with the amount of the discrepancy of the lift values in fig.6. There are no significant difference between the pressure coefficients along the upper surface.

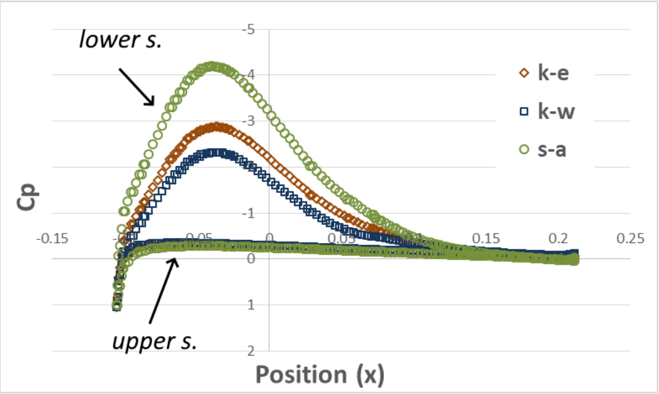

Fig. 8 Pressure distribution along the wing at h/c=0.3 and a= -3

4. Conclusions and Recommendations

Present paper aims to investigate the effect of the turbulence model choice on the numerical accuracy of the ground effect aerodynamics calculations of a rectangular wing. The flow around the 3D wing with a NACA0012 cross section is numerically modelled using three different turbulence models which are realizable $\kappa - \varepsilon$, $\kappa - \omega$ SST and Spalart-Allmaras models. Two different ground height is tested as h/c=0.1 and h/c=0.3, while the AoA is varying in the range of -3°< α <5°.

The results show that the effect of the turbulence models on the accuracy of the numerical results are depending on the wing height and the AoA. All turbulence models provides very close results for high (h/c=0.3) altitude. However, when the wing height is low, there is a discrepancy between the results of the different turbulence models and this discrepancy becomes notable as the AoA decreases. Realizable $\kappa - \varepsilon$ performs slightly better than the others in negative AoAs. It is also seen that, the difference between the pressure calculations on the lower surface of the wing results in the discrepancy in the lift predictions.

References

Doig, G., & Barber, T. J. (2012). Considerations for Numerical Modeling of Inverted Wings in Ground Effect. *AIAA Journal*, *49*(10), 2330–2333. https://doi.org/https://doi.org/10.2514/1.J051273

Firooz, A., & Gadami, M. (2006). Turbulence Flow for NACA 4412 in Unbounded Flow and Ground Effect with Different Turbulence Models and Two Ground Conditions : Fixed and Moving Ground Conditions. *Int. Conference on Boundary and Interior Layers*.

He, Y., Qu, Q., & Agarwal, R. K. (2014). Shape optimization of an airfoil in ground effect for application to WIG craft. *Journal of Aerodynamics*, *2014*. https://doi.org/https://doi.org/10.1155/2014/931232

Jia, Q., Yang, W., & Yang, Z. (2016). Numerical study on aerodynamics of banked wing in ground effect. *International Journal of Naval Architecture and Ocean Engineering*, *8*(2), 209–217. https://doi.org/10.1016/j.ijnaoe.2016.03.001

Jithin, P. N., & Arumugham-Achari, A. K. (2021). Shape Optimisation of NACA4412 In-Ground Effect- Selection of a Turbulence Model. *ASME 2021 Fluids Engineering Division Summer Meeting*, *1*. https://doi.org/https://doi.org/10.1115/FEDSM2021-65600

Lee, S. H., & Han, Y. O. (2020). Experimental Investigation of High-Angle-of-Attack Aerodynamics of Low-Aspect-Ratio Rectangular Wings Configured with NACA0012 Airfoil Section. *International Journal of Aeronautical and Space Sciences*, *21*(2), 303–314. https://doi.org/10.1007/S42405-019-00215-Z/FIGURES/15

Moore, N., Wilson, P. A., & Peters, A. J. (2002). An investigation into wing in ground effect aerofoil geometry. In *RTO-MP-095; NATO RTO.11; NATO RTO* (p. 20). Washington DC, USA.

Nirooei, M. (2018). Aerodynamic and static stability characteristics of airfoils in extreme ground effect. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, *232*(6), 1134–1148. https://doi.org/10.1177/0954410017708212

Ozden, K. S., Karasu, I., & Genc, M. S. (2020). Experimental investigation of the ground effect on a wing without/with trailing edge flap. *Fluid Dynamics Research*, *52*(4), 045504. https://doi.org/10.1088/1873-7005/ABA1D8

Qu, Q., Ju, B., Huang, L., Liu, P., & Agarwal, R. K. (2016). Flow physics of a multi-element airfoil in ground effect. *54th AIAA Aerospace Sciences Meeting*, *0*(January), 1–16. https://doi.org/10.2514/6.2016-0856

Qu, Q., Wang, W., Liu, P., & Agarwal, R. K. (2015). Airfoil Aerodynamics in Ground Effect for Wide Range of Angles of Attack. *AIAA Journal*, *53*(4), 1048–1061. https://doi.org/10.2514/1.J053366

Schmid, S., Lutz, T., & Krämer, E. (2009). Impact of Modelling Approaches on the Prediction of Ground Effect Aerodynamics. *Engineering Applications of Computational Fluid Mechanics*, *3*(3), 419–429. https://doi.org/10.1080/19942060.2009.11015280

Siemens. (2019). *Star-CCM+ User Guide version 14.02*.

Zaheer, Z., Reby Roy, K. E., Nair, G. S., Ragipathi, V., & Niranjan, U. V. (2019). CFD analysis of the performance of different airfoils in ground effect. *Journal of Physics:*

Conference Series, *1355*(1). https://doi.org/10.1088/1742-6596/1355/1/012006

Zerihan, J., & Zhang, X. (2012). Aerodynamics of a Single Element Wing in Ground Effect. *Journal of Aircraft*, *37*(6), 1058–1064. https://doi.org/https://doi.org/10.2514/2.2711