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Effect of Geometric Parameters on Aerodynamic Parameters of Wings in Ground Effects

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A B S T R A C T

This manuscript investigates the aerodynamic performance of wing-in-ground-effect vehicles, focusing on the influence of key geometric parameters, specifically twist angle, sweep angle, and taper ratio. A three-dimensional computational fluid dynamics (CFD) model has been developed to analyze the aerodynamic behavior associated with these parameters under ground-effect conditions. The RNG k-ε turbulence model is used to simulate turbulent flow. The numerical results demonstrate that variations in the lift coefficient and lift-to-drag ratio (L/D) are strongly influenced by the angle of attack, twist angle, and ground clearance. In contrast, the sweep angle minimizes the lift coefficient for the given wing section. Additionally, the analysis reveals that the taper ratio plays a beneficial role in enhancing aerodynamic performance, particularly in the trailing condition, where it contributes to improved lift and reduced drag. These findings underscore the critical role of geometric design in optimizing the aerodynamic efficiency of wing-in-ground-effect vehicles.

Keywords: Ground Effect, Aerodynamics, CFD, RNG, Parameters Of Wings.

Introduction

Ground-effect vehicles are vehicles that operate at a relatively small altitude above the water or ground. Theoretical and experimental studies (Belavin N.I, Wieselsberger C, M. R. Ahmed, R. D. Irodov) show that, when flying close to the ground, the air is compressed in the space between the wing and the ground, leading to an increase in pressure on the underside of the wing, forming a cushion, high-pressure gas. This air cushion will increase the lift force acting on the wing. The ground also prevents wing-tip vortices from developing, the wing-tip vortex intensity is reduced, leading to a reduction in induced drag.

Several numerical studies have been performed on model wings. Using numerical and experimental methods, (Ranzenbach and Barlow, 1996) found that the highest lift force occurred at a height of 0.08 c from the bounding surface. The aerodynamic properties of two-dimensional smart flaps in the area affected by ground effects have been studied using numerical methods (Djavareshkian et al., 2011). The authors compared smart flaps and conventional flaps and found that the pressure coefficient distribution in smart flaps is smoother than the pressure coefficient of conventional flaps at a connection point. The aerodynamic properties of flying vehicles using ground effects near curved limit surfaces have been studied (Yang et al., 2010a, 2010b). Numerical simulations show that the curvature effects of the bounding surface are represented by the variation of cyclic aerodynamic forces and the variation of pressure effects under the wing. The purpose of Wang's articles is to study aerodynamic characteristics and stability characteristics, such as the aerodynamic center of height (ACH) and the aerodynamic center of angle (ACP). of pitch) of profile NACA4412 (NACA4412 airfoil) in background effect. The authors found that within the range of heights and tilt angles studied, the ACH of profile NACA 4412 was only a function of the tilt angle, while the ACP was only a function of height (Wang et al., 2013) (Wang et al., 2013).

(Vogt et al. 2012) studied the phenomenon of background effects on profiles, often conducted in an upright or inverted conFigureuration, in which case the mechanisms of influence of the background effect act differently on Each conFigureuration is highlighted and explained. Numerous numerical efforts are conducted to describe the lifting properties of three-dimensional swept and dihedral wings operating in the vicinity of a free surface. Interestingly, for high Froude numbers, the free surface effectively becomes rigid, and it can safely be treated as a solid surface. The aerodynamic characteristics of compound wings during the ground effect were numerically investigated by (Jamei et al. 2012). In his study, the principal aerodynamic properties of compound wings as well as rectangular wings are computed for various ground clearances. (Firooz and Gadami, 2006) described the turbulent fluid flow around a two-dimensional wing NACA4412 for different angles of attack, near and far from the ground, and fixed and moving ground conditions. They also concluded that considering the moving ground condition, the drag coefficient decreases as it approaches the ground.

The article (Juhee Lee, et al) studied the influence of the wing conFigureuration with the Glenn Martin 21 type profile on the aerodynamic characteristics of the wing in the Ground Effect. However, the content of the article is only limited to considering the influence of the angle of inclination and the shield at the wing tip. The influence of other geometrical parameters of the wing has not been mentioned.

Continuing to approach the problem according to (Juhee Lee, et al), the author further investigated the influence of other geometric parameters such as the influence of different tilt angles, the influence of arrow angle, and wing twist angle, the elongation to the aerodynamic parameters of the wing in the background effect.

Method

The wing model studied in this article has a square shape, with a Glenn Martin 21 style profile that has been modified so that the underside of the wing is relatively flat, a typical wing shape for aircraft that use surface effects land.

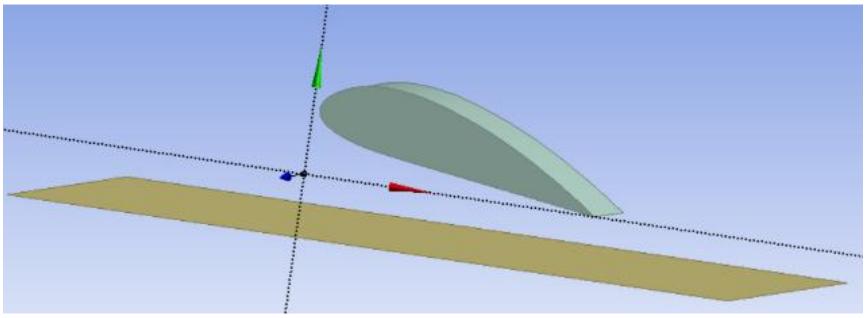

Figure.1 Wing model

The geometrical characteristics of the wings and fairings are given in Table 1:

Table 1. Geometric characteristics of the wing model

Numerical order	**Geometric characteristics**	**Values**
1	Profin	Glenn Martin 21 MOD.
2	chord length	c = 12 in = 0,3048 m
3	Wingspan	L = 12 in = 0,3048 m
4	wing with span	$\lambda = 1$

The wing model was investigated at $R_e = 0{,}49.\,10^6$, corresponding to a speed of 23.478 m/s, angle of attack varying from $0^o - 8^o$, relative altitude (equal to the distance from the trailing edge of the wing to the ground). divided by wingspan ($\bar{h} = \frac{h}{b}$) varies from 0,1 to 0,35. Due to the geometric symmetry of the wing, only half of the wing is simulated. When simulating in ANSYS/FLUENT, the survey domain is built in a rectangular shape, with dimensions (length, height, width) = $(40b \times 10b \times 10c)$.

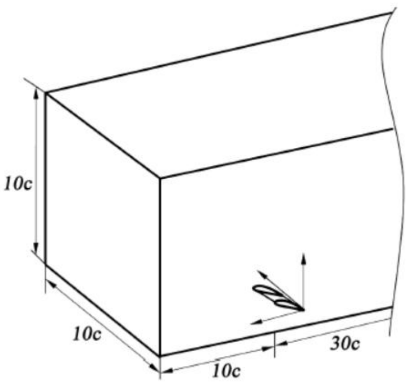

Figure.2 Setting up the survey area in the shape of a rectangular box

The computational space surrounding the wing is divided in ANSYS/Meshing software, by an unstructured point grid with 1,794,642 nodes and 4,403,355 elements. The mesh is divided thicker near the wing surface as well as close to the limit surface (**Figure. 3**).

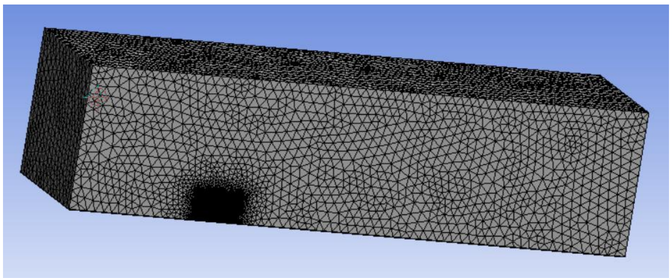

Figure.3 Grid of points in the computational space domain

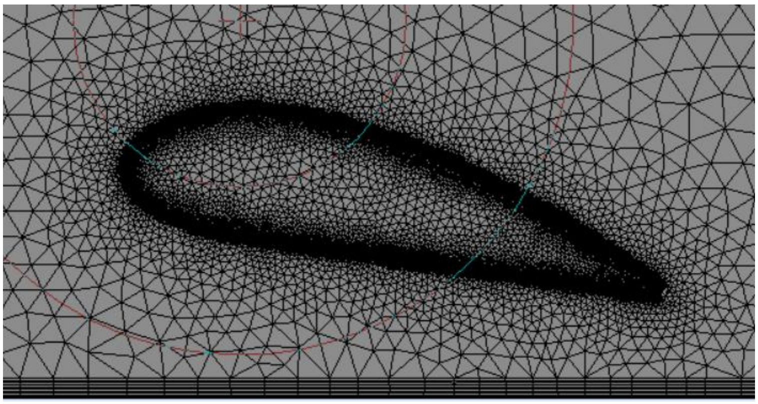

Figure.4 Side-by-side area and background

Air is assumed to be stable and incompressible. The flow is turbulent, simulated by the RNG k-ε model, and the flow near the wall is calculated by the wall function. To accurately simulate the interaction between the ground and the wing, the ground must be considered a wall moving at the same velocity as the airflow. To test the calculation model, the authors calculated and compared with (Juhee Lee, et al).

Table 2. In this case, the wing has an angle of attack of 2 degrees, at different relative heights

h/c	0,1	0,2	0,3	0,5
Calculate	0,440886	0,419642	0,415236	0,3999661
According to [5]	0,435	0,415	0,405	0,4
Error %	1,335039	1,106181	2,465104	−0,008476

Table 3. In this case, at a relative height $h/c = 0{,}3$ and at different angles of attack

The angle of attack, deg	0	2	4	6	8
Calculate	0,332901	0,415515	0,490025	0,573192	0,652045
According to [5]	0,325	0,405	0,5	0,58	0,67
Error %	2,373378	2,530595	−2,03561	−1,18773	−2,75364

Thus, the calculation results have small errors compared to [5] (maximum error is less than 3%). The computational model is highly reliable and can be used to determine the aerodynamic parameters of the wing in ground effects.

Results and Discussion

Effect of arrow angle

The authors evaluated the influence of the background effect on the arrow angle at the condition of the angle of attack of 4 degrees and relative height h/c = 0.1 using ANSYS software as shown in the Figureure below.

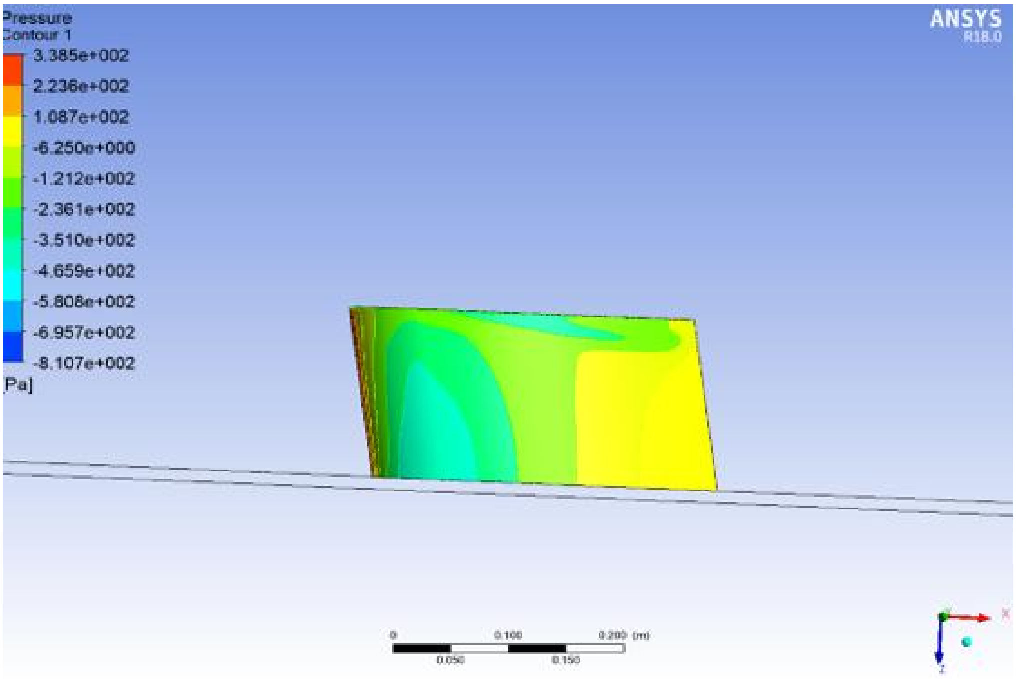

Figure.5 The influence of the ground effect on the inverted arrow angle

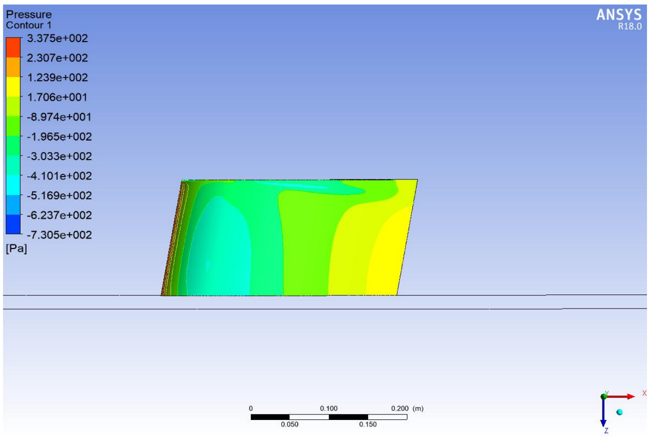

Figure.6 The influence of the ground effect on the forward arrow angle

Detailed results are shown in the table

Table 4. The value of the aerodynamic parameter when the arrow angle is at different values

The arrow angle, deg	-10	-5	0	5	10
C_y	0,540389	0,540361	0,543237	0,547138	0,54943
C_x	0,085832	0,085968	0,086296	0,086882	0,087223
K	6,295878	6,285598	6,295057	6,2975	6,299407

From the above results, it can be seen that in the background effect, the wing's arrow angle has little effect on the wing's aerodynamic parameters. However, using the arrow angle will change the position of the center of gravity of the wing and reduce the moment arm of the forces acting on the wing relative to the longitudinal axis of the ground effect aircraft.

Effect of aspect rations

To study the effect of the elongation on the aerodynamic parameters of the wing in the ground effect, the authors consider the wing at a height of $h/c = 0{,}1$ and at different angles of attack. The results show that the lift coefficient and aerodynamic quality of the wing both increase with increasing wing elongation.

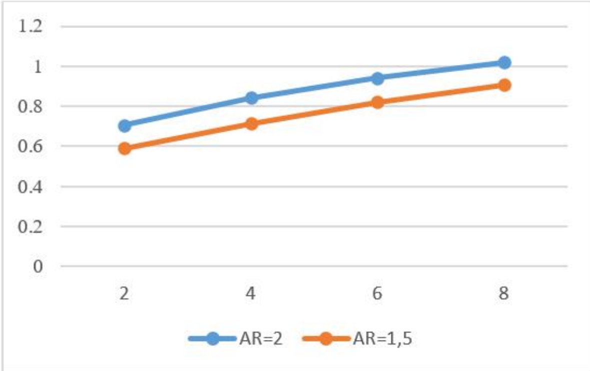

Figure. 7 The influence of the elongation on C_y

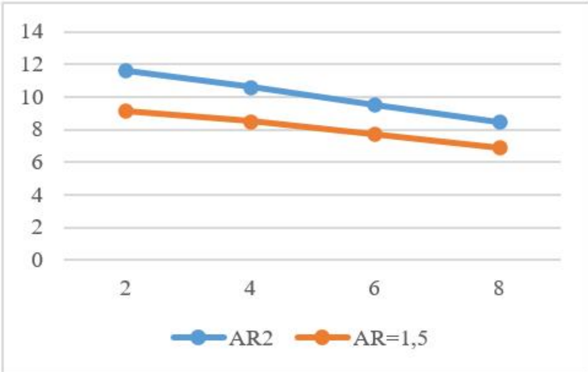

Figure.8 The influence of the elongation on K

Effect of twist angle

The twist angle is used to improve the lift distribution on the wing. There are two types of torsion angles: geometric torsion and aerodynamic torsion. Within the scope of the article, the authors consider the aerodynamic twist angle. The wing has a negative twist angle (Figure 9)

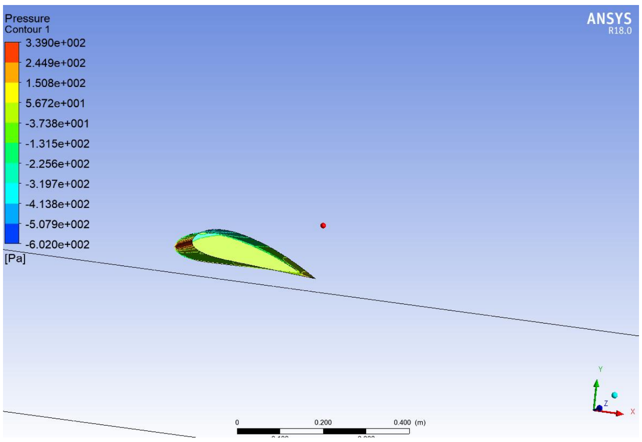

Figure.9 The influence of the ground effect on the negative twist angle and the wing has a positive twist angle (Figure 10)

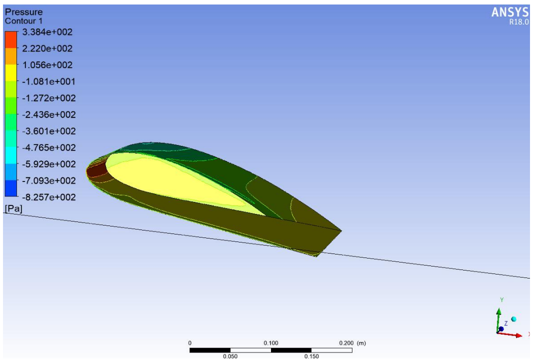

Figure.10 The influence of the ground effect on the positive twist angle

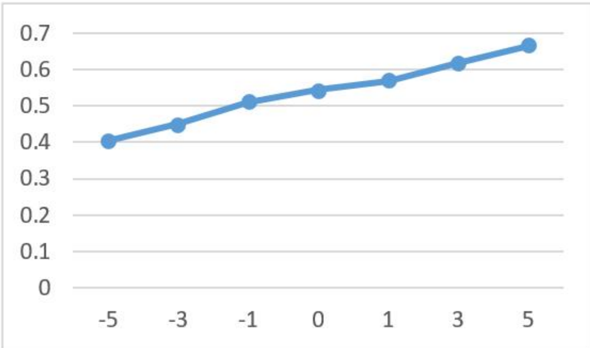

Figure.11 The influence of the twist angle on C_y

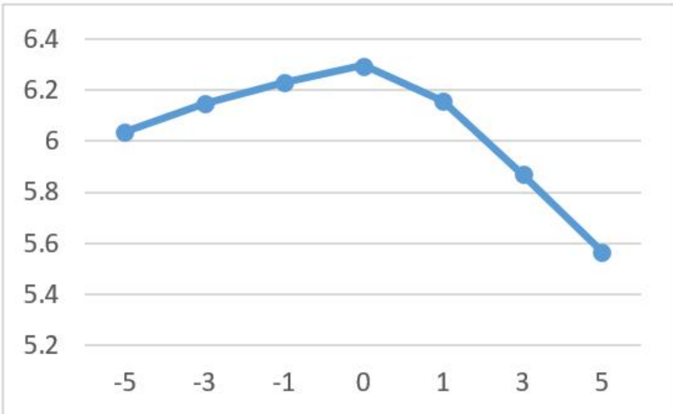

Figure.12 The influence of the twist angle on K

Thus, in the ground effect, increasing the twisting angle increases the lift coefficient and at the same time increases the drag coefficient. The greatest aerodynamic quality is achieved in wings without twist angles. This means that, as the twist angle increases, the wing will benefit in terms of lift coefficient, but will negatively affect aerodynamic quality.

Delta wing influence

When studying the influence of the Delta wing, the authors study the influence of the positive Delta wing (**Figure. 13**)

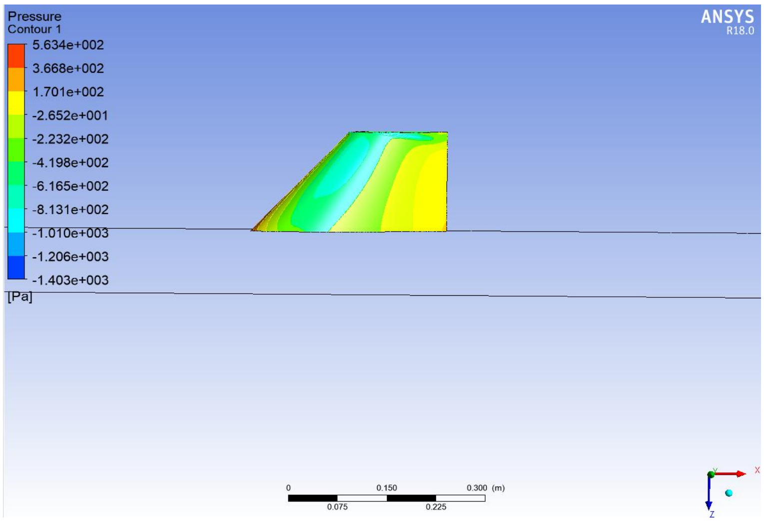

Figure.13 The influence of the ground effect on the positive Delta wing and inverted Delta wing (Figure.14)

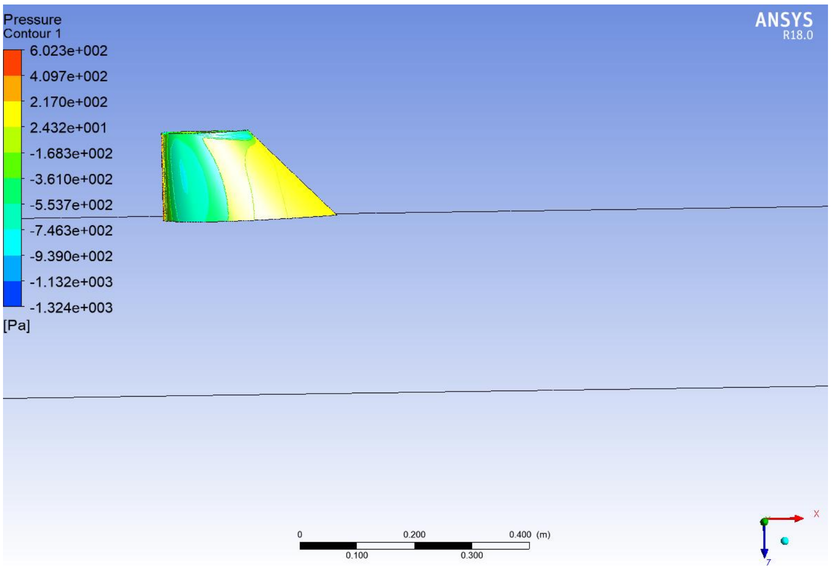

Figure.14 The influence of the ground effect on the inverted Delta wing under the condition h/c= 0,1 and angle of attack 4 degrees.

The results show that

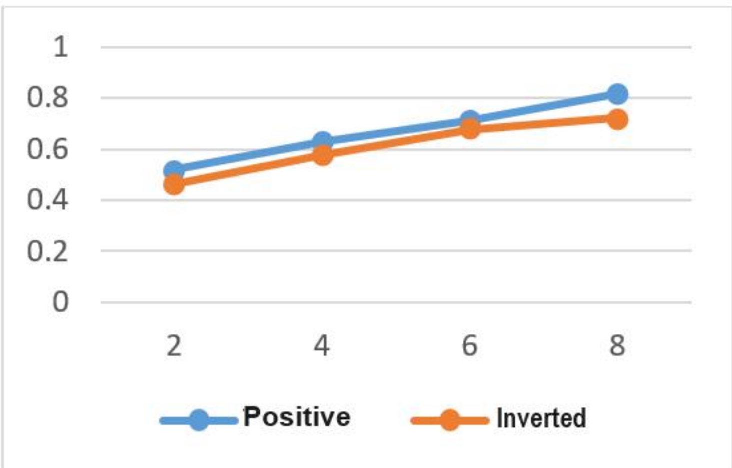

Figure.15 The influence of the Delta wing on C_y

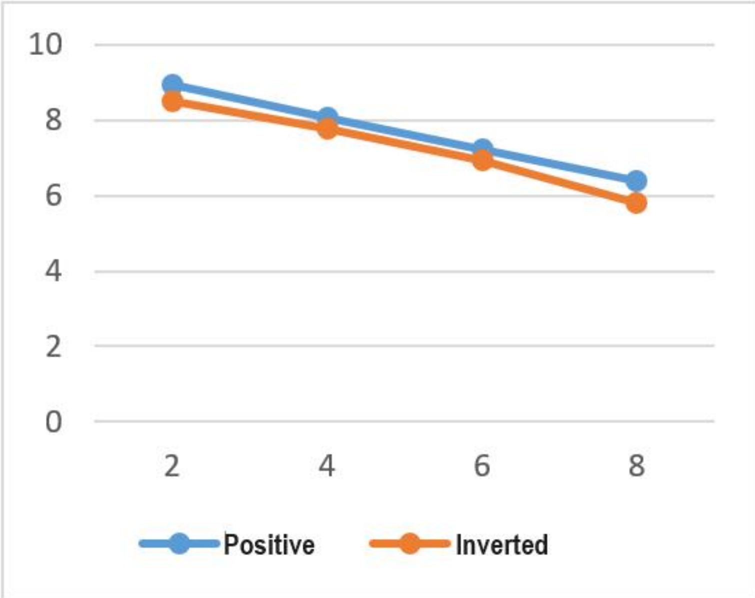

Figure.16 The influence of the Delta wing on K

That is, a positive Delta wing will increase the lift coefficient and aerodynamic quality of the wing in the ground effect. However, in reality, there are still many vehicles flying in ground effect that use inverted Delta wings because although the aerodynamic parameters of inverted Delta wings are worse than those of forward Delta wings, the stability and control characteristics of the wings This type is better than the positive Delta wing. This will be presented by the authors in the next article.

The established calculation model is highly reliable and can be used to calculate other cases.

The influence of geometric parameters on aerodynamic parameters is very large. When calculating and designing low-flying instruments in background effects, it is necessary to determine the aerodynamic advantages to be achieved to choose the structure wing shape accordingly.

Calculation results show the dependence of lift coefficient and aerodynamic quality on angle of attack, twist angle, and distance from the limiting surface. On the other hand, the arrow angle does not greatly affect the lift coefficient of the wing section under consideration. In addition, aerodynamic properties increase with increasing wing elongation.

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