Aerodynamic Characteristics of Wing of WIG Catamaran vehicle During Ground Effect

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Abstract: In this paper, the aerodynamic characteristics of wing with NACA 6409 section from WIG Catamaran vehicles with the influence of twin hull and ground effect was numerically studied. The simulation of WIG Catamaran was performed by Three Dimensional (3D) Computational Fluid Dynamic (CFD). The k-ω SST turbulent model was used for turbulent flow in CFD mode. In order to validate the numerical results, the CFD simulations of only wing with NACA 6409 section were compared with experimental data published by previous researcher. Next, Lift coefficient and, drag coefficient and lift to drag ratio of wing with twin hulls of WIG catamaran were determined on various of angle of attacks and two ground clearances (h/c=0.3 and infinity). The results of the CFD simulation indicate a reduction on lift and drag coefficients but there is an increment lift to drag ratio of wing which is caused by twin hulls of WIG Catamaran, as well as there are enhancement on lift coefficient and decreasing on drag coefficient, hence lift to drag ratio increases when flying in proximity to the ground.

Key-words: WIG Catamaran, Wing In Ground effect, Aerodynamic characters, NACA 6409, CFD analysis.

1 Introduction

Wing-In-Ground effect (WIG) craft takes a category of an intermediate configuration between ship and aircraft. Many researchers have had some successful attempts to develop WIG crafts that fly near sea surface. The initial development with success of WIG vehicles was done in Finland, Russia, Sweden and the United States. Ollila [1] provided a review of Experimental and proposed designs at various time. Rozhdesvensky [2] has reviewing research and development of win-in-ground effect technology. Now days, research on developing of WIG crafts because of its application takes a place in R&D (research and development) of many countries, the efficiency fuel savings and speed advantages over other types of sea transport providing the impetus. In research and development of the aerodynamic characteristics over the wings and other lifting surfaces of WIG craft is required from both numerical and experimental work. Many experimental have been as well as theoretical studies on influence of aerodynamic condition and different wing configurations on the aerodynamic characteristics.

One of the intermediate vehicles that operate using water and air motion is WIG craft. WIG craft concepts are different among other vehicles since it can be categorized as an intermediate level between ships and airplane. WIG craft is one of high speed low altitude flying vehicle which could take off and land on any relatively flat surface such as land, water, snow, and ice. It could fly just a few meters above the sea level. Ground effect at this craft is resulted from cushion high pressure air created from interaction between wings and the surface. This effect will give two advantages to the operation of WIG craft which are significant augmentation on lift coefficient and substantial reduction in drag. The phenomenon about WIG craft could be discovered in nature like a birds and flying fish which are carrying less energy when fly near ground surface (water).

Jung et al. [3] carried out widely tests in the closed-type wind tunnel. Lift and drag forces and the pitch moment of NACA6409 were measured as several aerodynamic parameters such as the aspect ratio (AR), angle of attack (α), ground clearance (h/c) and endplate shape were varied. In addition, the smoke trace technique was employed to visualize the flow pattern around the wing during the ground effect. They illustrated the ground effect caused a reduction in the tip vortex and the wake following the wing, as shown by the smoke trace test. The lift increases due to the ground effect at low ground clearance when the endplate is not present. Because of the boundary layer that develops on the ground, the lift could be slightly dropped when it is measured at ground clearances smaller than h/c = 0.1. Also they showed by smoke trace test, the endplate kept the flow passing under the pressure side and reduced the tip vortex caused by the pressure difference between the pressure and suction sides of the wing. The use of an endplate with smaller

Nomenclature

A	Aspect Ratio *(= 2b/c)*
b	Wing Span [m]
c	Chord length [m]
C_L	Lift Coefficient $(=L/0.5\rho AU^2_\infty)$
C_D	Drag Coefficient $(=D/0.5\rho AU^2_\infty)$
D	Drag Force [N]
G_k	Production of turbulence kinetic energy of mean velocity gradients
G_ω	Production of ω
h	height of trailing edge above the ground [mm]
h/c	Ground clearance
k	Turbulent kinetic energy
L/D	Lift to drag ratio
S_k	User-defined source term for k
S_ω	User-defined source term for ω
Y_k	Dissipation of k due to turbulence
Y_ω	Dissipation of ω due to turbulence
α	Angle of attack [^{0}]
ω	Turbulence frequency
Γ_k	Effective diffusivity of k
Γ_ω	Effective diffusivity of ω

AR wing gave more of an improvement in the lift force than when a larger AR wing was used. They presented that endplates help to reduce the wave effect on the wing surface due to the higher ground clearance up to the wing as much as the endplate height. The drag force is decreased by the ground effect as the wing approaches the ground. The reason for this is that the induced drag decreases due to the reduction of the tip vortex at the wing tip. Another finding of Jung et al. [3] is that when the angle of attack and the AR increased, the center of pressure moved forward to the leading edge of the wing. The presence of an endplate at the wing tip shifted the center of pressure to the leading edge. As the ground clearance of the wing decreased, the center of pressure also moved to the leading edge.

Ahmed and Sharma [4] studied on the pressure distribution over the wing surface at different ground clearances and angles of attack for measuring the lift and drag forces and the mean flow over the surface of the wing and to follow the flow in the wake region for mean and fluctuating velocities. They observed a suction effect on the lower surface at certain ground clearances at angles of attack up to 5˚, because of a convergent–divergent passage between the airfoil and the ground, causing a local drop in lift force. The lift force could be high by small ground clearances, due toram pressure on the lower surface of the airfoil. They found pressure distribution on the upper surface of airfoil did not have more variation with ground clearance. Therefore, the higher lift force was mainly due to modification of pressure distribution on the lower surface. Also they showed a reduction in pressure on the suction surface at higher angles of attack, causing an adverse pressure gradient on the upper surface and a thick wake region. Because of merging the airfoil and the ground plate boundary layers at very low ground clearances, was found an increasing drag for higher angles of attack.

Aerodynamic characteristics of three-dimensional wings in ground effect for Aero-levitation Electric Vehicle (AEV) are numerically investigated for various ground clearances and wing spans at the chord-length based Reynolds number of 2.0×10^6 by Moon et al.[5]. They designed an AEV system that with small wing span for reduction costs of the construction and manufacturing of cruising channel. This system for making high lift force uses tandem-wing arrangement. Static and dynamic stability conditions are derived from the longitudinal motion equations of the WIG crafts by Chun and Chang [6]. They simplified ground condition by a rigid wall and ignored the sea surface variation. Ahmed et al. [7] studied the flow characteristics over a NACA4412 airfoil in a low turbulence wind tunnel with moving ground simulation at a Reynolds number of 3.0×10^6 by varying the angle of attack and ground clearance. They recorded a loss of upper surface suction when the airfoil decreased the ground clearance for all angles of attack. Also they illustrated, the lift decreased with dropping ground clearance for angle of attack less than 4˚, whereas for 6-8 angles, it reached due to a higher pressure on the lower surface. Another observing of their experiment was the drag force increased close to the ground for all angles because of the modification of the lower side pressure distribution.

Chawla et al. [8] studied experimentally on a NACA4415 section from a wind-tunnel respect wing-in-ground effects. They used a wing model had a 20%-chord, full-span, adjustable flap and removable end and center plates. The principal terms during ground effects were angle of attack, flap angle, wing height above ground, and use and size of end and center plates. They showed ground effects are presented till one mean chord or less of airfoil to heights above the ground. Surface effect aerodynamic-hydrodynamic and its application were briefly described by Cui [9]. He discussed on some important such as, high lift/drag configuration, power augmented ram (PAR) and etc. The extensive experimental of Cui research group showed that PAR can provided static lift may 4-6 times higher than the trust of engine. They illustrated lift/thrust ratio affect of geometry and the deflected angle of flap at the trailing edge of the wing, condition of propeller of PAR, angle of guide van, and the configuration of end plate.

Ockfen and Matveev [10] researched numerically on aerodynamic characteristics of NACA4412 airfoil section with flap in extreme ground effect. The numerical method consisted of a steady–state, incompressible, finite volume method using Spalart-Allmaras model of the Navier-stokes equations for turbulent flow. They performed their research for various flap configurations and different ground effect height, Reynolds number, and angle of attack. They showed favorable trailing-edge flap configuration that improve aerodynamic characteristics of NACA4412 wing section. Chun and Chang [11] numerically analyzed turbulent flow around two-dimensional wings in ground effect with incompressible Reynolds Average Navier-Stokes (RANS) equations which are approximated using finite difference methods. The main objective of their study was to clarify the two-dimensional ground effect and its aerodynamic characteristics for two ground boundary conditions, i. e., moving and fixed bottom boundary. According to their computational results, the different bottom condition did not significant influence on the lift force and moment, but the drag force simulated by the moving bottom is greater than that by the fixed one. Zhang et al. [12] reported the influence of tip vortex characteristics on the aerodynamic performance of a cambered airfoil during ground effect. They showed vortex breakdown occurred as the wing approached to the proximity ground, causing to a slow down in the force enhancement. Zhang and Zerihan [13] equipped wing with end plats and operated in ground effect for showing the influence of edge vortices generated on force behavior.

The lift to drag ratio just for wing with ground effect can be large. When the other parts of vehicle are added to wing this ratio drops significantly [2]. Kirillovikh [14] reported the lift-to-drag ratio of a wing of aspect ratio 2–3 flying at ground clearance around (h/c) 0.2 could be around 35–45 that it is acceptable for creating an efficient transport platform. When other part of crafts integrated to wing, the losses of lift-to-drag ratio occur due to presence of the hull (40%) and pylons (15%) holding PAR engines and the (non-lifting) tail (5%).

Richard Selescu [15] tries to adapt a blowdown type wind tunnel for ground simulation test. The main part of his adapting solution was the moving belt system. This modification is useful for aerodynamic tests with a ground effect. Hee Jung Kim et al [16] tried to optimize a Wing In Ground effect (WIG) configuration which could reach the maximum lift and high stability. The influences parameters for this optimization are aspect ratio, position of tail wing and wing section. They used the vortex lattice method to calculate aerodynamic coefficients with inviscid and potential flow approximation.

The design of WIG crafts request a unique technology problem because they operate in water and air. The configuration of WIG craft should consist the aerodynamic and hydrodynamic condition. The present a high drag during take off of WIG craft demands a high power that it is the principal challenge in concept design of WIG craft. The design of hull plays an important role in solving this problem. There is several of hulls shape that has been developed related to WIG craft. The monohull shape is used for most designing. In this paper, double hull shape will be used on WIG craft as shown in Fig.1. A main wing of this craft is applied with NACA6409 section with total wing span of 60 cm which is divided into two parts, namely middle wing (20 cm) and two side wings (2.6 m) and summarized in Table 1.

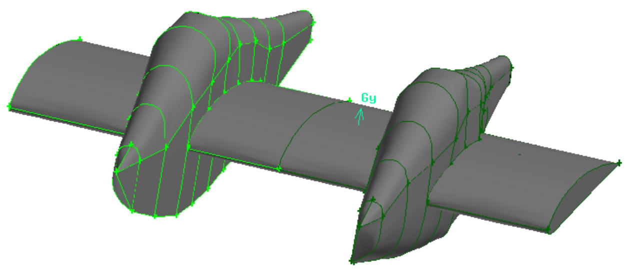

Fig.1 WIG Catamaran Vehicle.

Table 1 Principle dimension of WIG Catamaran.

Length over all (LOA)	70 c m	
Breadth over all (BOA)	60 c m	
Hull breadth (B)	7 cm	
Wing Span (b)	Middle Wing	20 m
	Side Wing	13 cm
Chord length (c)	Middle Wing	30 cm
	Side Wing	30 cm

Recently, researchers understood that the ground effect (GE) contribute in the increasing of the lift to drag ratio when an aircraft flying near the ground surface. Two phenomenon which are span dominated (h/b) and chord dominated (ground clearance h/c) are effecting on aerodynamic characters [117]. The results of them during fly proximity of ground are an increasing of lifting and reduction of drag then lift to drag ratio would grow. Lift to drag ratio is defined as efficiency for aircraft [18], higher ratio leads to lower consumption fuel with a same weight of aircraft in cruise flight.

The aim of this paper is aerodynamic characteristics of wing of WIG catamaran with NACA6409 section in proximity and infinity to the ground surface that they are numerically studied. The simulation is performed by three dimensional (3D) CFD model. The k-ω SST turbulent model has been used for turbulent flow. Lift coefficient, drag coefficient and lift to drag ratio were assigned for wing only and wing with the hulls for two ground clearance (h/c=0.3 and infinity).

2 CFD Numerical Study

This numerical simulation applied a model of WIG Catamaran and wing section of NACA 6409 with chord length 30 cm. Table 1 shows the principle dimension of WIG Catamaran. All CFD models were performed using FLUENT Software on wing only and wing with hull of WIG Catamaran which have different angle of attack (α = 0°, 2°, 4° , 6° and 8°). Simulation were performed with two ground clearance (h/c=0.3 and h/c=∞) and velocity of airflow 20.5 m/s(40 knots). Ground clearance (h/c) is defined of the distance ratio between wing trailing edge and ground surface (h) to wing chord length (c). The CFD simulation is defined using k-ω SST model for turbulence airflow around the wing. The transport equations for the turbulent kinetic energy (k) and turbulent dissipation energy (ω) are expressed as follows.

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\Gamma_k \frac{\partial_k}{\partial x_j}\right] + G_k - Y_k + S_k \qquad (1)$$

$$\frac{\partial}{\partial t}(\rho \omega) + \frac{\partial}{\partial x_i}(\rho \omega u_i) = \frac{\partial}{\partial x_j}\left[\Gamma_\omega \frac{\partial \omega}{\partial x_j}\right] + G_\omega - Y_\omega + D_\omega + S_\omega \qquad (2)$$

The number of elements for each simulation is around 1,200,000 for wing only and 1,550,000 for wing with hull of WIG Catamaran. The number of mesh has acceptable convergence for aerodynamic characters. Current simulation uses symmetry plane as shown in Fig. 2 for wing only and Fig. 3 for wing with hulls of WIG Catamaran. This is to shorten the simulation time while the results obtained will be the same.

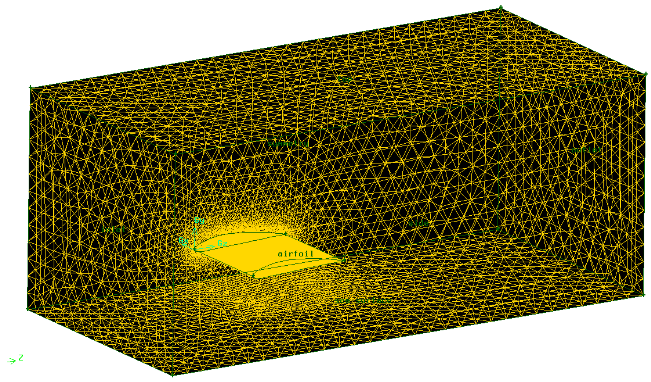

Fig. 2 The meshing of simulation for wing only.

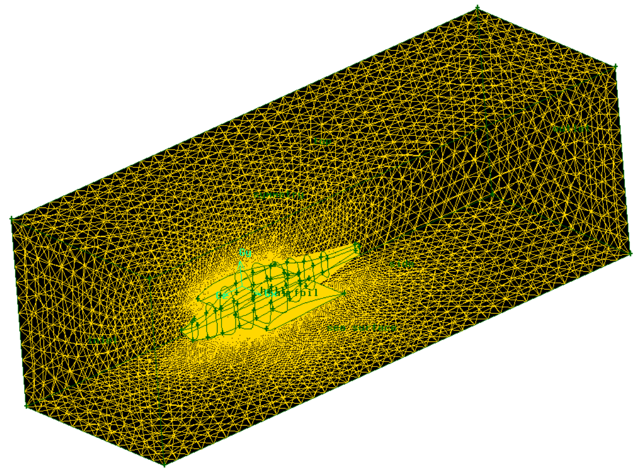

Fig. 3 The meshing of simulation for wing with hulls of WIG Catamaran.

3 Validation of CFD Simulations

3.1 Lift Coefficient (C_L)

Fig. 4-6 shows the comparison results of lift coefficient (C_L) between CFD simulation and experimental data for wing only [3]. The validation is summarized in Tables 2-4. The lift coefficient varied with angle of attack for three Aspect Ratios (ARs) 1, 1.5, and 2. The influence of aspect ratio on lift coefficient in CFD models would be declared on experimental simulation. The magnitude of lift coefficient increases with increment of AR and angle of attack.

Table 2 Lift coefficient versus angle of attack for h/c = 0.3, AR = 1 based on experimental and numerical result.

Angle of attack	AR = 1	
	Numerical	Experimental
0	0.233	0.200
2	0.316	0.280
4	0.395	0.340
6	0.477	0.420
8	0.560	0.510

Table 3 Lift coefficient versus angle of attack for h/c = 0.3, AR = 1.5 based on experimental and numerical result.

Angle of attack	AR = 1	
	Numerical	Experimental
0	0.323	0.270
2	0.432	0.380
4	0.510	0.470
6	0.620	0.540
8	0.723	0.640

Table 4 Lift coefficient versus angle of attack for h/c = 0.3, AR = 2 based on experimental and numerical result.

Angle of attack	AR = 1	
	Numerical	Experimental
0	0.367	0.320
2	0.492	0.450
4	0.612	0.580
6	0.727	0.690
8	0.836	0.800

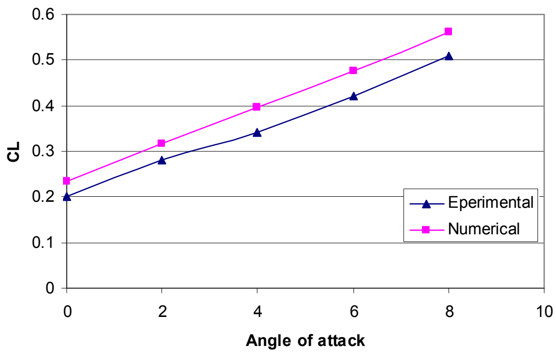

Fig.4 Lift coefficient versus angle of attack for h/c = 0.3 and AR = 1.

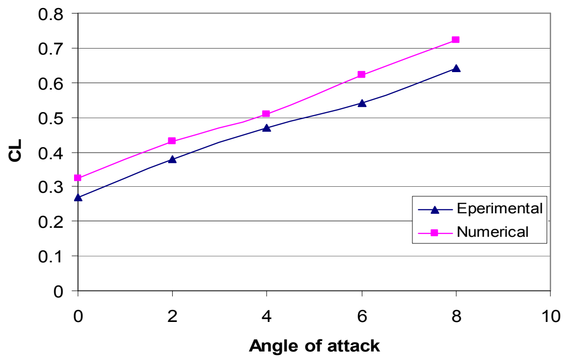

Fig.5 Lift coefficient versus angle of attack for h/c = 0.3 and AR = 1.5.

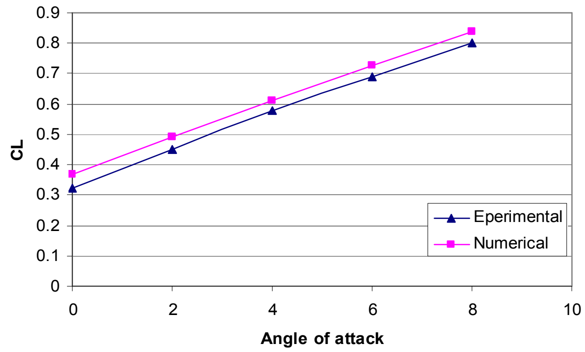

Fig.6 Lift coefficient versus angle of attack for h/c = 0.3 and AR = 2.

3.2 Drag Coefficient (C_D)

The numerical and experimental drag coefficients are showed in fig. 7-9 and tables 5-7 for only wing. The magnitude of drag coefficient varied with angle of attack and three different aspect ratio (AR = 1, 1.5, and 2). Generally, trend of drag coefficient from CFD model is similar with experiment [3] but the numerical result demonstrates 30-50 deviation from experimental data. Figures 7-9 presents drag coefficient as a function angle of attack for three aspect ratios (AR 1, 1.5, and 2). It explained that drag coefficient have linear coherence with angle of attack but reverse to aspect ratio. It is happened as when friction drag increase so induced drag consequently decrease and makes total drag remains approximately constant.

Table 5 Drag coefficient versus angle of attack for h/c = 0.3, AR = 1 based on experimental and numerical result.

Angle of attack	AR = 1	
	Numerical	Experimental
0	0.046	0.036
2	0.054	0.039
4	0.065	0.049
6	0.081	0.060
8	0.101	0.080

Table 6 Drag coefficient versus angle of attack for h/c = 0.3, AR = 1.5 based on experimental and numerical result.

Angle of attack	AR = 1	
	Numerical	Experimental
0	0.042	0.030
2	0.051	0.036
4	0.062	0.045
6	0.085	0.059
8	0.103	0.075

Table 7 Drag coefficient versus angle of attack for h/c = 0.3, AR = 2 based on experimental and numerical result.

Angle of attack	AR = 1	
	Numerical	Experimental
0	0.043	0.025
2	0.052	0.030
4	0.066	0.040
6	0.085	0.055
8	0.106	0.075

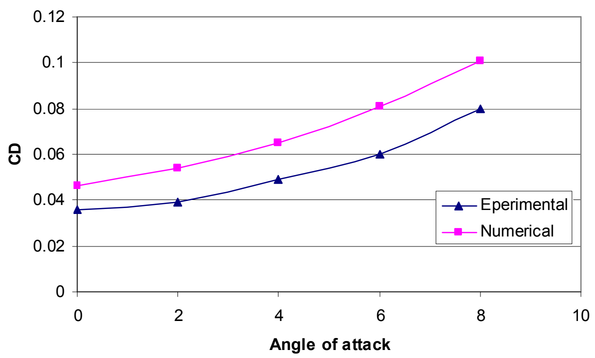

Fig.7 Drag coefficient versus angle of attack for h/c= 0.3 and AR = 1.

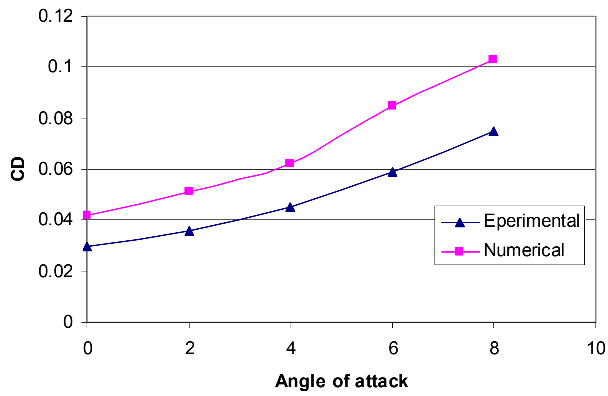

Fig.8 Drag coefficient versus angle of attack for h/c= 0.3 and AR = 1.5.

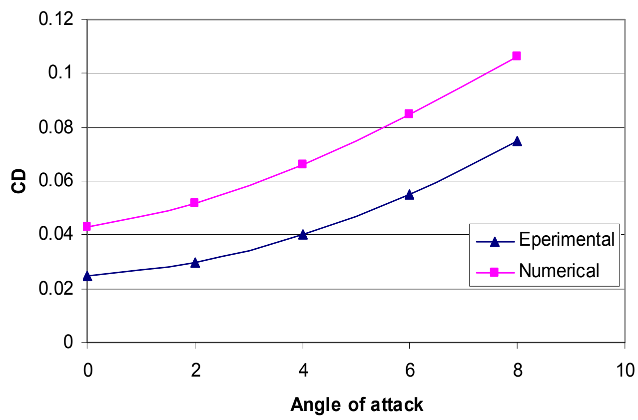

Fig.9 Drag coefficient versus angle of attack For h/c = 0.3 and AR = 2.

3.2 Lift to drag ratio (L/D)

Lift to drag ratio from numerical simulations and experimental data [3] are showed in Figure 10-12 and table 8-10. The numerical variation of lift to drag ratio from three aspect ratios and two ground clearances have similar trend relative to experimental simulation. For all aspect ratios, lift to drag ratio has a moderate increasing between 0 and 2 degrees after that it decreases slightly. The maximum deviation of numerical result relative to experimental data is around 30% at 2^0 in aspect ratio 2. Lift to drag ratio is efficiency of wing that it is higher between 2-4 angle of attack for both simulations. Also, It increases relatively to aspect ratio as shown in figure 10-12.

Table 8 lift to drag ratio versus angle of attack for h/c = 0.3, AR = 1 based on experimental and numerical result.

Angle of attack	AR = 1	
	Numerical	Experimental
0	5.065	5.556
2	5.852	7.179
4	6.077	6.939
6	5.889	7.000
8	5.545	6.375

Table 9 lift to drag ratio versus angle of attack for h/c = 0.3, AR = 1.5 based on experimental and numerical result.

Angle of attack	AR = 1	
	Numerical	Experimental
0	7.690	9.000
2	8.471	10.556
4	8.226	10.444
6	7.294	9.153
8	7.019	8.533

Table 10 lift to drag ratio versus angle of attack for h/c = 0.3, AR = 2 based on experimental and numerical result.

Angle of attack	AR = 1	
	Numerical	Experimental
0	8.535	12.800
2	9.462	15.000
4	9.273	14.500
6	8.553	12.545
8	7.887	10.667

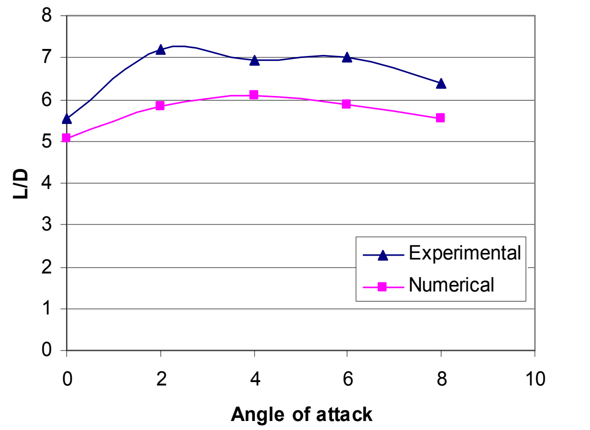

Fig.10 LIFT TO DRAG RATIO versus angle of attack for h/c= 0.3 and AR = 1.

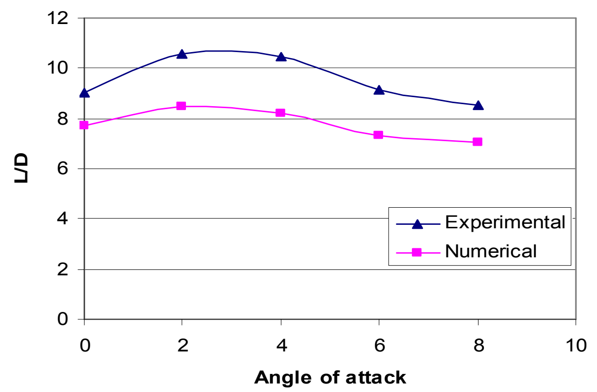

Fig.11 LIFT TO DRAG RATIO versus angle of attack for h/c= 0.3 and AR = 1.5.

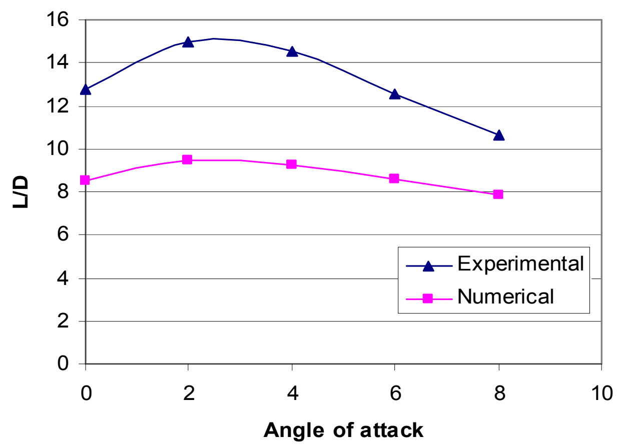

Fig.12 LIFT TO DRAG RATIO versus angle of attack for h/c= 0.3 and AR = 2.

4 Results and Discussion

Fig. 13-15 show comparison of result of lift coefficient , drag coefficient and lift to drag ratio of wing only and wing with influence twin hull in proximity of ground surface (h/c=0.3). The validation is summarized in Table 11-13. There is a reduction in lift coefficient for wing of WIG Catamaran when twin hulls added to wing as a compare with wing only (Fig.13). This reduction drops when the angle of attack is increased. The reduction is calculated using Eq.3.The maximum reduction of lift coefficient (C_L) is around 27.9 % at angle of attack 0°. The influence of hull on lift coefficient with higher angle of attack becomes small, where the reduction is only 19.1% (Table 11). Drag coefficient of wing decreases as twin hulls integrated to wing (fig.14). This reduction is determined by Eq.3 with replacing CL by CD (Table 12). Both lift and drag coefficients decrease with applying twin hulls but the gain of lift is grater than drag, hence lift to drag ratio grows (Fig 15). The increasing is calculated using Eq.4. This growth has a moderate increasing from 0° angle of attack until 4° after that it drape slightly (Table 13).

$$Reduction\ (\%) = 1 - \frac{C_{L(wing+hulls)}}{C_{L(wing)}} \quad (3)$$

$$Increment(\%) = \frac{L/D_{(wing+hulls)}}{L/D_{(wing)}} - 1 \quad (4)$$

Table11 Lift coefficient for wing only and wing with influence twin hulls of WIG catamaran versus angle of attack for h/c = 0.3.

Angle of attack	Wing only	Wing with hulls	Reduction of CL %
0	0.269	0.194	27.9
2	0.400	0.309	22.8
4	0.524	0.418	20.2
6	0.649	0.515	20.6
8	0.759	0.614	19.1

Table12 Drag coefficient for wing only and wing with influence twin hulls of WIG catamaran versus angle of attack for h/c = 0.3.

Angle of attack	Wing only	Wing with hulls	Reduction of CD %
0	0.0295	0.0204	30.8
2	0.0373	0.0255	31.6
4	0.0488	0.0343	29.7
6	0.0646	0.0459	28.9
8	0.0829	0.0608	26.7

Table13 Lift to drag ratio for wing only and wing with influence twin hulls of WIG catamaran versus angle of attack for h/c = 0.3.

Angle of attack	Wing only	Wing with hulls	Increment of L/D %
0	9.113	9.491	4.1
2	10.726	12.097	12.8
4	10.751	12.179	13.3
6	10.043	11.210	11.6
8	9.164	10.112	10.3

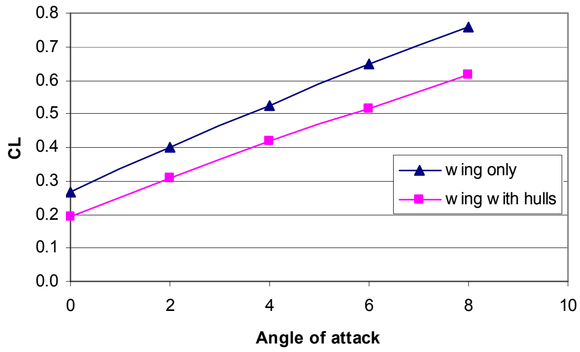

Fig.13 Lift coefficient versus angle of attack for h/c=0.4 for wing only and wing with influence twin hulls of WIG Catamaran.

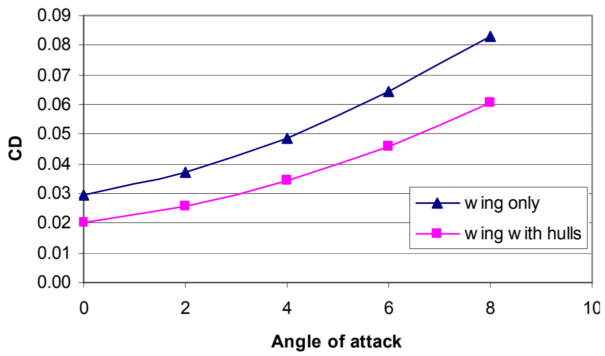

Fig.14 Drag coefficient versus angle of attack for h/c=0.4 for wing only and wing with influence twin hulls of WIG Catamaran.

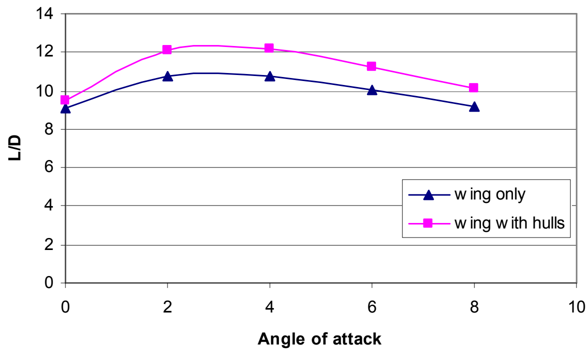

Fig.15 Lift to drag ratio versus angle of attack for h/c=0.4 for wing only and wing with influence twin hulls of WIG Catamaran.

The influence of ground effect on lift coefficient, drag coefficient and lift to drag ratio for wing with affect twin hulls of WIG catamaran for two ground clearance (h/c=0.3 and h/c= infinity) are summarized in Table 14-16. The results are presented in Fig. 16-18 for comparisons. There is augmentation on lift coefficient (C_L) related to ground clearance of h/c =0.3 when it is compared with h/c = infinity as shown in Fig. 16. The increment of lift coefficient between h/c= infinity and h/c=0.3 is calculated by Eq5. It is found that the higher of wing angle of attack increases the increment of lift coefficient (C_L) (Table 14). Drag coefficient of wing of WIG catamaran due to ground effect decreases (Fig. 17). This reduction is determined by Eq.6. The higher reduction in drag is between 2-4 angle of attack (Table 15). Both increment lift coefficient and reduction drag coefficient make a growth in lift to drag ratio as shown in Fig 18. This increment can calculate by Eq.5 with replacing CL by L/D. There is a high increasing in lift to drag ratio between 0-2 angle of attack after that it has a small fluctuation (Table 16).

$$Increment(\%) = \frac{C_{L_{(h/c=0.3)}}}{C_{L_{(h/c=\infty)}}} - 1 \qquad (5)$$

$$Reduction\ (\%) \quad = 1 - \frac{C_{D_{(h/c=0.3)}}}{C_{D_{(h/c=\infty)}}} \qquad (6)$$

Table14 Lift coefficient for wing with influence twin hulls of WIG catamaran versus angle of attack with h/c = 0.3 and h/c = ∞.

Angle of attack	h/c = 0.3	h/c = infinity	Increment of CL %
0	0.194	0.191	1.6
2	0.309	0.272	13.6
4	0.418	0.353	18.4
6	0.515	0.434	18.7
8	0.614	0.521	17.9

Table15 Drag coefficient for wing with influence twin hulls of WIG catamaran versus angle of attack with h/c = 0.3 and h/c = ∞.

Angle of attack	h/c = 0.3	h/c = infinity	Increment of CL %
0	0.0204	0.0217	6.0
2	0.0255	0.0281	9.3
4	0.0343	0.0374	8.3
6	0.0459	0.0491	6.5
8	0.0608	0.0645	5.7

Table16 Lift to drag ratio for wing with influence twin hulls of WIG catamaran versus angle of attack with h/c = 0.3 and h/c = ∞.

Angle of attack	h/c = 0.3	h/c = infinity	Increment of CL %
0	9.5	8.8	8.0
2	12.1	9.7	24.7
4	12.2	9.4	29.8
6	11.2	8.9	25.8
8	10.1	8.1	24.7

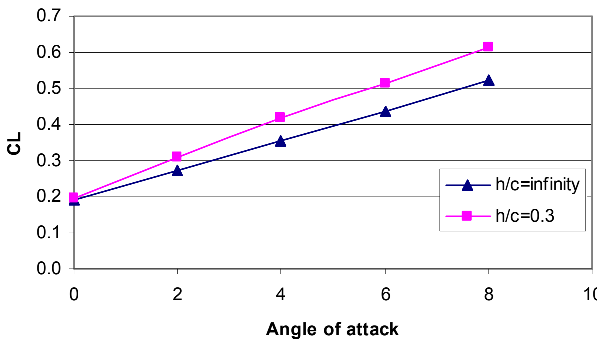

Fig.16 Lift coefficient for wing with influence twin hulls of WIG Catamaran versus angle of attack for h/c = 0.3 and infinity.

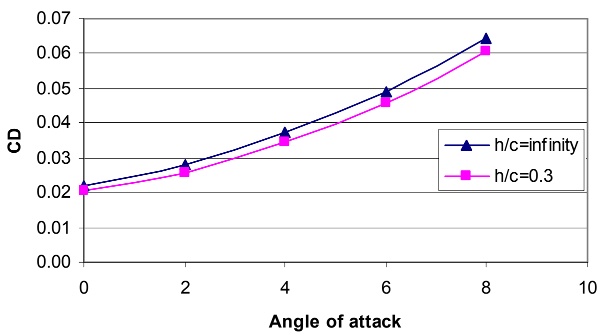

Fig.17 Drag coefficient for wing with influence twin hulls of WIG Catamaran versus angle of attack for h/c = 0.3 and infinity.

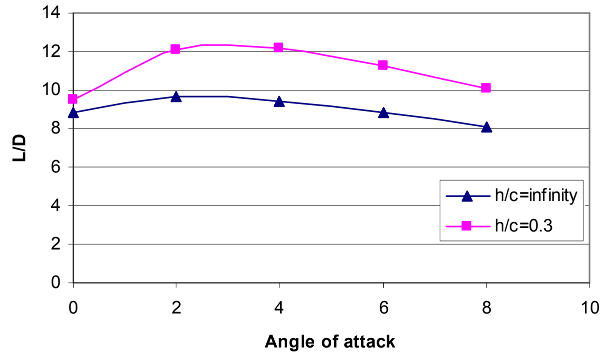

Fig.18 Lift to drag ratio for wing with influence twin hulls of WIG Catamaran versus angle of attack for h/c = 0.3 and infinity. .

5 Conclusion

The aim of this paper is finding the influence of ground effect and twin hulls on aerodynamic characters of wing from WIG Catamaran vehicle. The hulls of WIG Catamaran have effects on aero dynamic characters of wing by reduction the lift coefficient and drag coefficient, whereas lift to drag ratio increases because the gain of reduction of drag is higher. It is found that the influence of ground effect has significant effects for wing of WIG catamaran vehicle, Based on the variation of aerodynamic characters of wing, the influence of twin hulls is more efficient than monohull of WIG vehicle. Hence WIG catamaran with twin hulls able to take more benefit of dynamic ground effect. For further research, all aerodynamic characters of wing form WIG catamaran vehicle would be numerically determined and compared with experimental data using UTM wind tunnel.

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