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NUMERICAL ANALYSIS OF INFLUENCE OF THE WING IN GROUND EFFECT ON AIRCRAFT LIFT COEFFICIENT AND ON CAR DOWNFORCE COEFFICIENT

The paper presents the mechanism of the wing in ground effect formation, also shows the structure of wing in ground craft, and race car, which uses wing in ground effect. Results of numerical analysis are as expected, which means, the lift coefficient is higher for positive angles of attack, and lower for negative angles of attack. The paper details also characteristics of lift and drag coefficients in the angle of attack function. The numerical research was conduct in Ansys Fluent 15.0 academic license.

Keywords: airfoil, aircraft, wing in ground effect, numerical analysis

1. INTRODUCTION

The most common application of airfoil is aircraft construction. Regular aircraft fly at high altitude, but there is an experimental [Moore, Wilson, Peters 2002] prove that shows positive influence of ground proximity to airfoils lift coefficient on positive angles of attack, also when airfoil in nearby ground with a negative angle of attacks the downforce is increasing too. Wing in ground effect could be useful to build fast on-water crafts, which can fly like regular aircraft, but only in proximity of ground or water. Wing in ground crafts could take more cargo than a traditional plane. Wing in ground effect is also useful for F1, where front wing generates high downforce, so WIG effect increased downforce, but also the safety of all drivers in F1.

The mechanism of wing in ground formation is simple, and it is based on reducing space between aircraft and ground. First, WIG effect leads to increase pressure on the lower surface of the airfoil, what causes the rise of lift coefficient higher than in the case of wing in free air stream. Secondly, vortices created by differ-

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ential pressure above upper and lower surfaces in case of WIG effect moves aside of wing tips, what decreases resistance and induced drag, also increases effective aspect ratio.

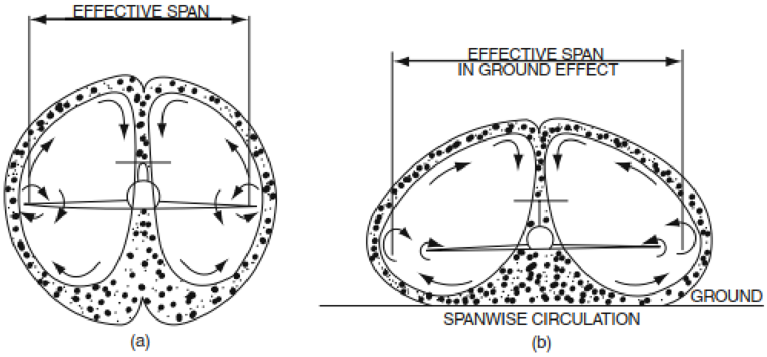

Fig. 1. Influence of WIG effect on vertices formation [Yun, Bliault, Doo 2010]

Wing in ground crafts are mostly seaplanes, so the canopy in its construction is similar to a boat, wings are producing more lift force in wing in ground effect than in free air stream flight. Thanks to the construction of WIG craft there is no need to use traditional runway. The most common construction of WIG craft is shown in Fig. 2. below Table 1. presents a comparison of biggest WIG craft (Caspian Sea Monster – 1966), biggest cargo airplane An-225, well-known Boeing 747-400F, and cargo version of Airbus A380F, which is biggest passenger airplane.

Fig. 2. The biggest WIG craft ever built, Caspian Sea Monster [3]

Table 1. Comparison of technical parameters of traditional airplanes and WIG craft

Aircraft	Caspian Sea Monster	Boeing 747-400F	Airbus A380F	Antonov An-225
Length [m]	92	70,6	72,72	84
Wing span [m]	37,6	64,4	79,75	88,4
Wing area [m²]	662,5	560	845	905
Max. Takeoff weight [kg]	544000	396890	590000	640000
Empty mass [kg]	240000	178,800	252200	285000
Max. payload [kg]	130000	112630	149800	253820
Operating speed [km/h]	430	978	945	800
Engines	10 × Dobrynin VD-7	4 × PW4062	4 × GP7277	6 × ZMKB D-18
Total thrust [kN]	1275,3	1128	1360	1377

In automotive, wing in ground effect mostly is used in race cars, such as F1 or Indy Car. In 1970s Lotus 79b was the first car which uses wing in ground effect, what gave the Lotus Team world championship. The biggest influence on the car downforce in wing in ground effect, has the height of car suspension. Smaller height gives higher downforce, what is shown in Fig. 3.

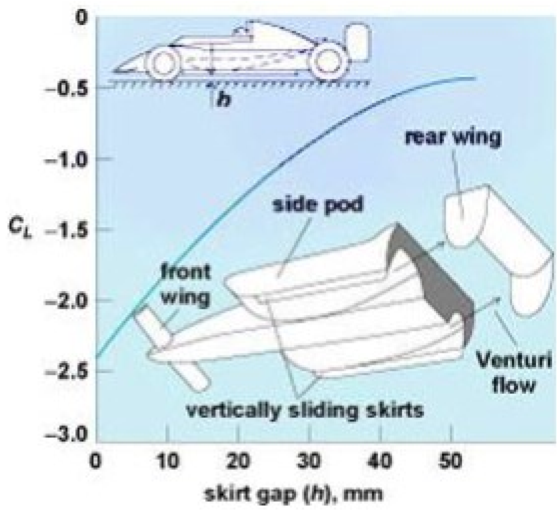

Fig. 3. Dependency of lift coefficient and height of car suspension [Katz, 2006]

For the positive influence of wing in ground effect for planes, what means increasing of lift force, there is a specific coefficient (1) $\overline{h}$ [Rozhdestvensky 2000], which is the ratio of the height of fly and chord length. For best results, this coefficient value should be near 0.1 [Moore, Wilson, Peters 2002].

$$\overline{h} = \frac{h}{c} \tag{1}$$

where:
h – height of flight or car suspension,
c – airfoil chord length.

2. CONDITIONS OF NUMERICAL ANALYSIS

The parameters of mesh designed for numerical analysis of wing in ground effect on NACA 0015 airfoil profile with chord length equal to 0.0625 m are as follows:

– element sizing on airfoil surface is equal to 0,0005 m
– for wing in ground effect, sizing of elements on ground (surface below airfoil) is equal to 0,0005 m
– the maximum size of the element for whole domain is equal to 0,002 m
– to correct imitate the boundary layer on airfoil surface there were used inflation condition with 8 layers and with a growth rate equal to 1.2, inflation is pointed in Fig. 4 with mesh for wing in ground effect case.

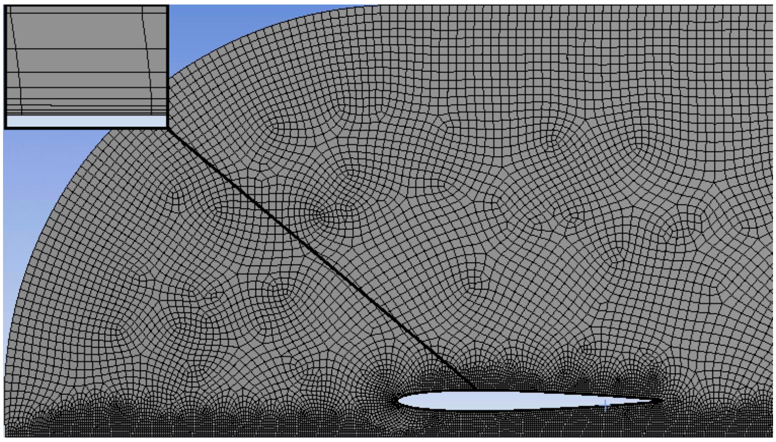

Fig. 4. View of mesh created in Ansys Mesher [Rojewski 2015]

Simulation conditions for all cases:
- solver set as density-based,
- pressure value set as 1 atm what is equal to 101325 Pa,
- energy equation set on,
- turbulence model set as k-epsilon, and it contains two equations in it, first the turbulent kinetic energy k, and second dissipation rate equation,
- gas property set as ideal-gas,
- for every case edges of domain sets as far-field condition, with one exception for surface below airfoil in wing in ground effect cases, where ground condition was set as moving wall, with the speed of movement of air stream velocity,
- standard initialization for semicircle at the left side of the domain,
- air stream velocity set as 35.056 m/s, in Ansys Fluent set as Mach number equal to 0.0101.

3. RESULTS OF NUMERICAL ANALYSIS

Ansys Fluent software as result of calculations can plot graphs of lift and drag coefficients, but also can print values of lift force and drag force in Newtons [N], with the second path it is necessary to use equation (2) for lift/drag coefficient, which is derived the equation of Jukowski:

$$C_L = \frac{L}{\frac{\rho \cdot V^2}{2} \cdot S} \tag{2}$$

where:
L – lift force [N] or D – drag force,
C_L – lift coefficient or C_D – drag coefficient,
ρ – fluid density (for air on the sea height 1,225 kg/m^3),
S – wing area [m²] or for drag force calculation – surface of airfoil projection on plane perpendicular to air stream direction [m²],
V – velocity of body relative to air flow [m/s].

Negative angles of attack as expected provide to increase of downforce, unfortunately also to increase of drag force. It is worth to notice that after exceed –8 ° angle of attack and lower, lift coefficient remains still when drag coefficient is still growing. It should explain why spoilers in automotive should not exceed under –8 ° angle of attack, it would raise fuel consumption without positive effect.

Positive angles of attack provide to increase of lift coefficient. The biggest increase was reached for 13 ° angle of attack and it is rise by over 116%. Drag coefficient is raised by almost 3 times, but thanks to wing in ground effect there is no stall. For 5 ° angle of attack rise of drag is almost unnoticeable, so it is possible to determine the most efficient angle of attack for WIG effect, to connect all positive aspects of this phenomenon. Results of simulations are shown in Table 2, also the characteristics of lift coefficient and drag coefficient are shown in Fig. 6.

Table 2. Results of numerical analysis [Rojewski 2015]

Angle [°]	Lift coefficient (free stream)	Lift coefficient (WIG effect)	Change [%]	Drag coefficient (free stream)	Drag coefficient (WIG effect)	Change [%]
–13	–0,7	–1,3	87,01	0,58	0,9	55,26
–12	0,83	–1,31	58,33	0,57	0,83	44,71
–11	–0,78	–1,32	68,21	0,5	0,8	61,29
–10	–0,82	–1,33	61,29	0,46	0,76	64,38
–9	–0,76	–1,32	73,01	0,39	0,74	89,94
–8	–0,71	–1,28	82	0,34	0,72	111,24
–7	–0,64	–1,35	110,08	0,32	0,73	127,45
–6	–0,58	–1,24	113,88	0,3	0,68	123,64
–5	–0,52	–1,07	106,16	0,32	0,66	104,99
–4	–0,4	–0,89	122,91	0,32	0,63	95,73
–3	–0,29	–0,7	140,66	0,25	0,6	138,54
–2	–0,2	–0,55	173,7	0,34	0,56	63,66
–1	–0,1	–0,32	220,8	0,35	0,51	45,32
Angle [°]	Lift coefficient (free stream)	Lift coefficient (WIG effect)	Change [%]	Drag coefficient (free stream)	Drag coefficient (WIG effect)	Change [%]
0	0	–0,15	0	0,35	0,44	27,36
1	0,1	0,09	–14,16	0,35	0,39	12,32
2	0,2	0,28	41,17	0,34	0,36	6,56
3	0,29	0,45	54,51	0,25	0,34	35,49
4	0,4	0,61	52,08	0,32	0,32	0
5	0,52	0,75	45,85	0,32	0,33	1,83
6	0,58	0,85	47,33	0,3	0,34	12,8
7	0,64	0,95	47,95	0,32	0,4	23,92
8	0,71	1,03	45,79	0,34	0,5	47,57
9	0,76	1,1	44,15	0,39	0,77	99,88
10	0,82	1,19	43,76	0,46	1,13	145,83
11	0,78	1,3	66,21	0,5	1,33	167,37
12	0,83	1,41	69,9	0,57	1,47	156,45
13	0,7	1,51	116,52	0,58	1,59	173,14

The reason of drag coefficient rise can be aerodynamic trace produced by airfoil in wing in ground effect flight, because of the higher speed of air above the airfoil, than in free stream flight (Fig. 5), also rise of drag force can be caused by higher static pressure under airfoil.

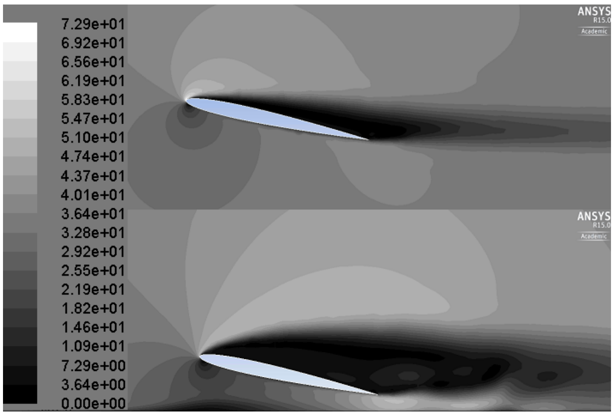

Fig. 5. Distribution of air stream velocity for angle of attack equal to 12 °, from the top for free air stream flight, and below for wing in ground effect [Rojewski 2015]

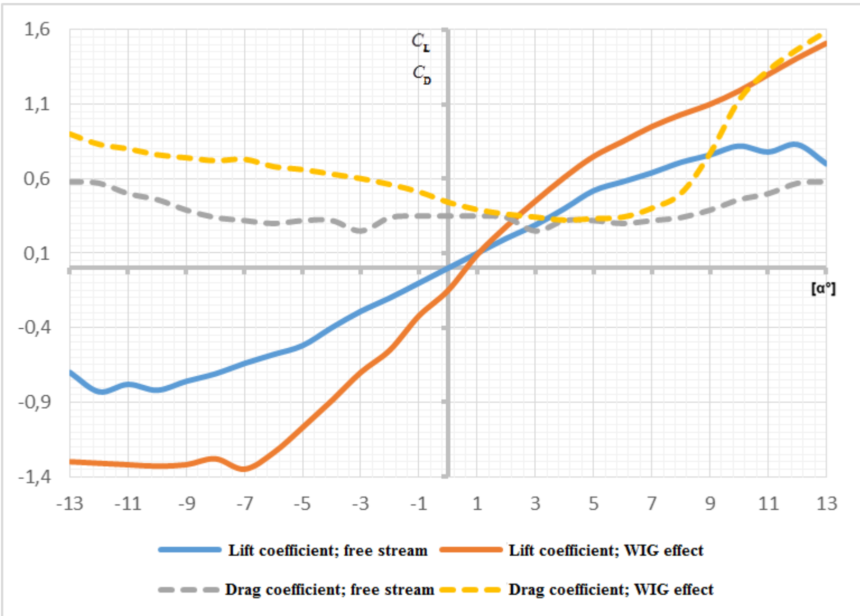

Fig. 6. Characteristics of lift and drag coefficients in function of angle of attack for NACA 0015 airfoil

4. CONCLUSION

Based on results of calculation from numerical analysis of NACA 0015 in two cases, first free air stream flight and second wing in ground effect flight, as expected there is a rise of lift force, but also down force, depends on the angle of attack, and probably it depends on airfoil profile. For a low angle of attacks can be noticed that below –8 ° lift coefficient is almost constant, opposite to high angles of attack. Positive angles of attack mostly create higher lift force, but for positive angles of attack near the value of 0 °, lift force decreases due to the shape of the canal which creates airfoil and ground, it seems to look like a convergent-divergent nozzle. Of course for another shape of airfoil values would be different. Aircraft should avoid negative angles of attack near ground because it could provide to a sudden loss of lift force and next to crash. Results of drag force for negative angles of attack explains why in an F1 front wing of the car is not simple airfoil, but many airfoils in other angles relative to each other, it could solve the problem of drag increase, also should produce more downforce.

REFERENCES

N. Moore, P A. Wilson, A. J. Peters, 2002, An investigation into wing in ground effect airfoil geometry, School of Engineering Sciences, University of Southampton, SO17 1BJ, UK, Qineqtiq Haslar.

L. Yun, A. Bliault, J. Doo, 2010, WIG Craft and Ekranoplan, Springer.

Russian Federation Navy, unknown author.

J. Katz, 2006, Aerodynamics of race cars, Annual Review of Fluid Mechanics, 38: 27–64, Annual Reviews.

K.V. Rozhdestvensky, 2000, Aerodynamics of a Lifting System in Extreme Ground Effect, 1st ed., Springer-Verlag, p. 63–67.

Rojewski A., 2015, Analiza numeryczna wpływu efektu przypowierzchniowego na siłę nośną profilu lotniczego NACA0015, Poznan University of Technology, Poznan [BEng Thesis].

ANALIZA NUMERYCZNA WPŁYWU EFEKTU PRZYPOWIERZCHNIOWEGO NA SIŁĘ NOŚNĄ SAMOLOTU I SIŁĘ DOCISKU POJAZDU DROGOWEGO

Streszczenie

W artykule przedstawiono zjawisko efektu przypowierzchniowego i powód jego powstawania. W pracy ujęto również opis konstrukcji samolotu korzystającego z efektu przypowierzchniowego jak i samochodu wyścigowego. Wyniki analizy numerycznej, tak jak przypuszczano, ukazały działanie efektu przypowierzchniowego zwiększającego współczynnik siły nośnej dla kątów natarcia większych od zera stopni oraz działanie odwrotne dla ujemnych kątów natarcia. Praca zawiera również charakterystyki przebiegu współczynnika siły nośnej I siły oporu w funkcji kąta natarcia dla badanego profilu. Analiza numeryczna została przeprowadzona w programie Ansys Fluent 15.0 academic license.

Słowa kluczowe: profil lotniczy, samolot, efekt przypowierzchniowy, analiza numeryczna