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FLAPS INFLUENCE ON WING IN GROUND EFFECT LIFT COEFFICIENT

Adam Rojewski, Jarosław Bartoszewicz

Poznan University of Technology, Chair of Thermal Engineering
Piotrowo Street 30, 61-138 Poznan, Poland
tel.: +48 791 450 322, +48 61 6652215
e-mail: adam.m.rojewski@doctorate.put.poznan.pl
jaroslaw.bartoszewicz@put.poznan.pl

Abstract

The main purpose of this article was to study flaps application influence on airfoil, which flies in the wing in ground effect with lift, and drag coefficients changes. Wing in ground effect occurs in the direct proximity of ground, it makes lift coefficient higher than in free stream flight, also decreases drag coefficient. WIG effect craft can be an alternative for traditional aircraft, but also for marine transportation. The article presents wing in ground effect creation mechanism description with height coefficient explanation, also presents experimental analysis of lift coefficient with reference to height coefficient. Airfoil with flaps simulation and for free stream flight. Application of flaps makes the wing in ground effect more efficient by lift coefficient rise, what provides also to drag coefficient rise. Flaps provide to absolute pressure rise under the airfoil. It allows to fly slower without lift force change or to make aircraft start shorter without risk of stall. The article shows also conditions and results of Ansys Fluent software simulation for NACA M8 airfoil for angles of attack equal to: 0°, 6°, 10° for three different cases: free stream flight, wing in ground flight with the clear wing, wing in ground flight with flaps, and conditions of analysis convergence.

Keywords: *transport, ground effect vehicle, numerical analysis, wing in ground effect, flaps*

1. Introduction

Airfoil, which flies in the wing in ground effect, produces up to 200% more lift force than in normal flight conditions. Wing in ground effect occurs when aircraft is close to the ground. This phenomenon is described by K. V. Rozhdestvensky [1] in his book "*Aerodynamics of a Lifting System in Extreme Ground Effect"* and shows the dependency of the height of flight and airfoil chord length, and named as height coefficient (1):

$$\overline{h} = h / c\,, \tag{1}$$

where: $\overline{h}$ – height coefficient, c – chord length, h – flight altitude.

Wing in ground effect mostly works for angles of attack higher than 0°. It is shown in Fig. 1, which present results of the wing in ground effect experiment on NACA 0012 airfoil, with six different angles of attack. There are two main conclusions, first, wing in ground effect makes lift coefficient higher for NACA 0012 when airfoil angle of attack exceed 3°, second, the highest value of lift coefficient achieved by an airfoil is when height coefficient is equal to 0.1.

Figure 2 shows NACA M8 profile, which is in authors' opinion the best choice from tests of ten different airfoils to use in the wing in ground effect. Plain flaps are commonly used in aircrafts, the cause of its simplicity. Flaps allow aircraft to decrease the speed of landing, and make the start of aircraft shorter or allow increasing maximum take-off weight.

2. Ansys Fluent simulations

All simulations were prosecuted in Ansys Fluent 17.2 academic research, with ICEM CFD mesh generator. Simulation conditions were the same for all cases:

- solver set as density-based, because velocity is set above 0.3 of Mach number, there is a need of considering flow as compressible,
- pressure value set as 1 [atm] (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, because the air in density based solver does not work with constant air density,
- edges of domain sets as pressure far-field condition, with exceptions, for surface below airfoil in the wing in ground effect, where the ground condition was set as moving wall, with the speed of movement of air stream velocity, standard initialization for pressure far-field,
- for every case airfoil angle of attack was set at 0°,6°,10°,
- for every angle of attack flaps angle was set in three different positions: 5°,15°, 30°,
- the height of flight set as 0.1 for the wing in ground effect simulation.

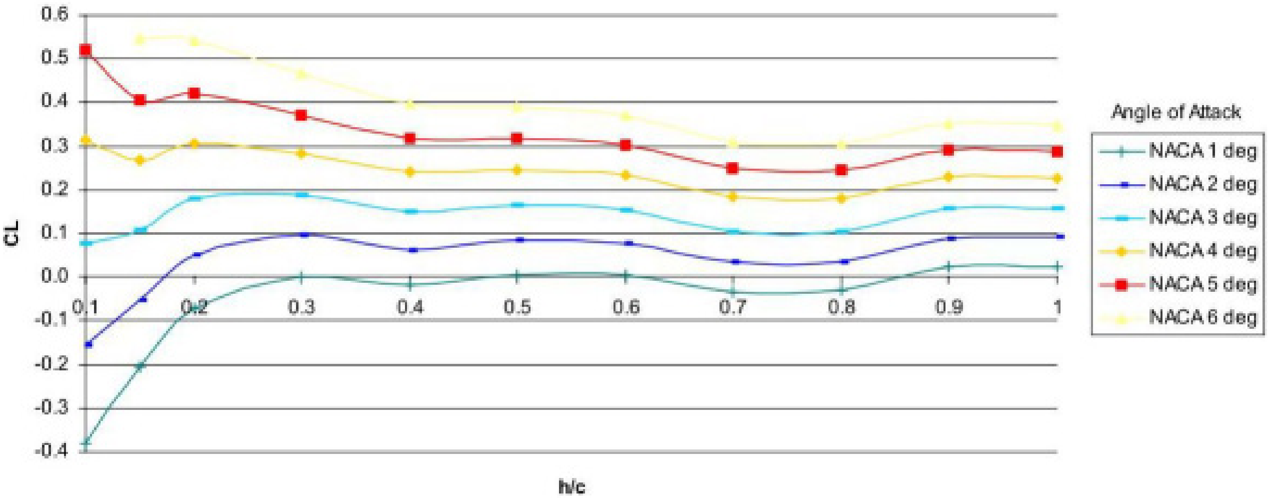

Fig 1. Influence of height coefficient change on lift coefficient for NACA 0012 [2]

Fig. 2. NACA M8 airfoil with plain flaps (30°)

Figure 3 shows mesh created for NACA M8 profile in ICEM CFD software. Ansys Fluent does not allow its user to use structural mesh, but ICEM CFD can change structural mesh to unstructural, what makes numerical analysis easier when computing power is small. Every mesh cells number for the wing in ground effect is similar and close to 35000 cells.

Every simulation has the main condition of results convergence, it is recognized by stabilization of lift and drag coefficients in numerical analysis. It is shown in Fig. 4. When graph remains still and it draws a straight line, it can be considered as a convergent result.

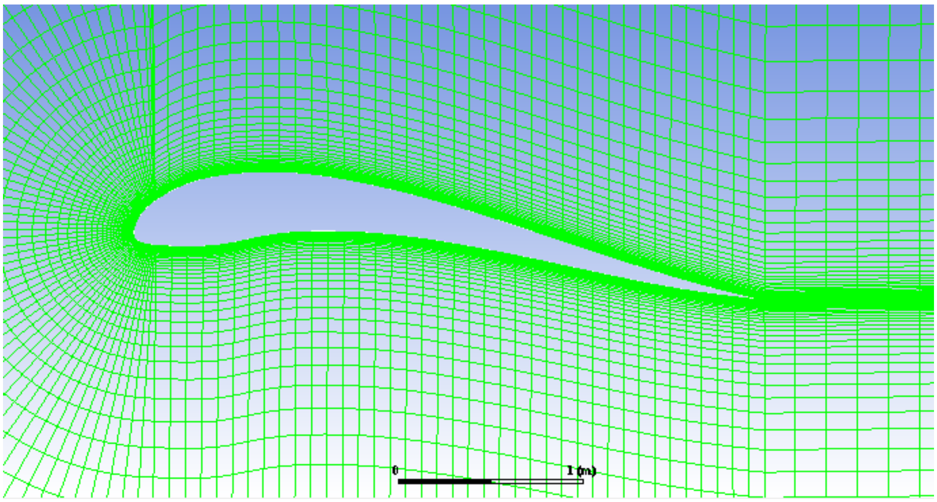

Fig. 3. Mesh for NACA M8 airfoil created in ICEM CFD software

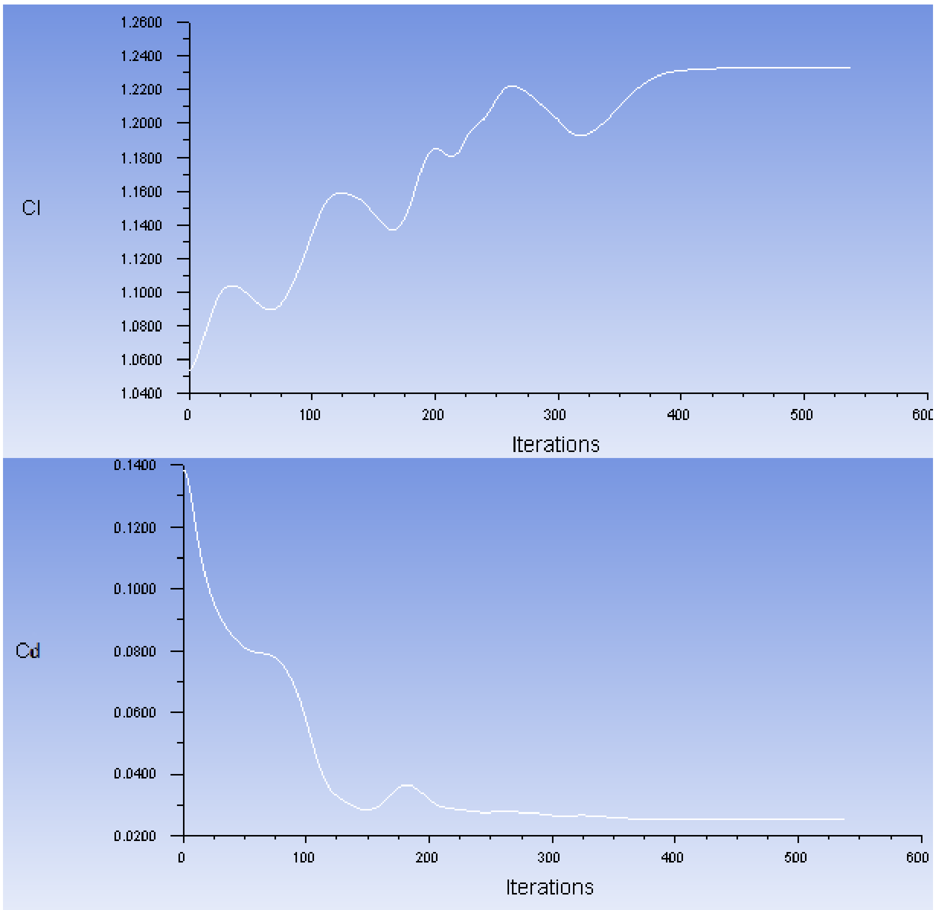

Fig. 4. Convergence of drag and lift coefficient

2. WIG effect simulation results

Authors choose NACA M8 profile from 10 different airfoils after conduct numerical analysis of wing in ground effect and free stream flight for these profiles, an article titled "Airfoil selection for the wing in ground effect craft" shows this comparison.

Table 1 present results of simulation in Ansys Fluent for lift coefficient. Wing in ground effect with clear wing makes lift coefficient almost two times greater than in free stream flight. Greater pressure under the wing in WIG effect flight produce more drag (Tab. 2) on higher angles of attack, but advantages which come from bigger lift force, like less fuel consumption per passenger or higher maximum take-off mass, are undisputed. As expected, flaps application with slight drag coefficient increase makes lift coefficient more than two times bigger for the wing in ground effect(6° angles of attack), depending on angle, and almost 5 times bigger (6° angle of attack) than in free stream flight. Mostly, wing in ground effect works above 0° angle of attack, but with flaps, this phenomenon can produce larger lift force even with angles of attack below this value.

Tab. 1. Comparison of lift coefficient for NACA M8 airfoil

α [°]	free stream flight	WIG effect flight without flaps	WIG effect flight with flaps (5°)	WIG effect flight with flaps (15°)	WIG effect flight with flaps (30°)
0	0.563	1.34	3.835	5.12	5.719
6	1.233	2.53	5.763	6.499	6.81
10	1.653	3.006	6.573	7.148	7.313

Tab. 2. Comparison of drag coefficient for NACA M8 profile

α [°]	free stream flight	WIG effect flight without flaps	WIG effect flight with flaps (5°)	WIG effect flight with flaps (15°)	WIG effect flight with flaps (30°)
0	0.0715	0.065	0.132	0.173	0.266
6	0.0253	0.186	0.249	0.335	0.439
10	0.0753	0.257	0.401	0.524	0.614

WIG effect provides to rise of drag coefficient, but there are few ways to reduce it. First, there is a need of height of flight steering to adjust pressure under the wing to requirements of flight. Second, WIG effect crafts have had small wingspan with much greater chord length than normal aircraft, what provides to aerodynamic drag reduction, also WIG effect moves out of the wing tips vortices produce by pressure differential pressure under and above the wing, and decrease induced drag.

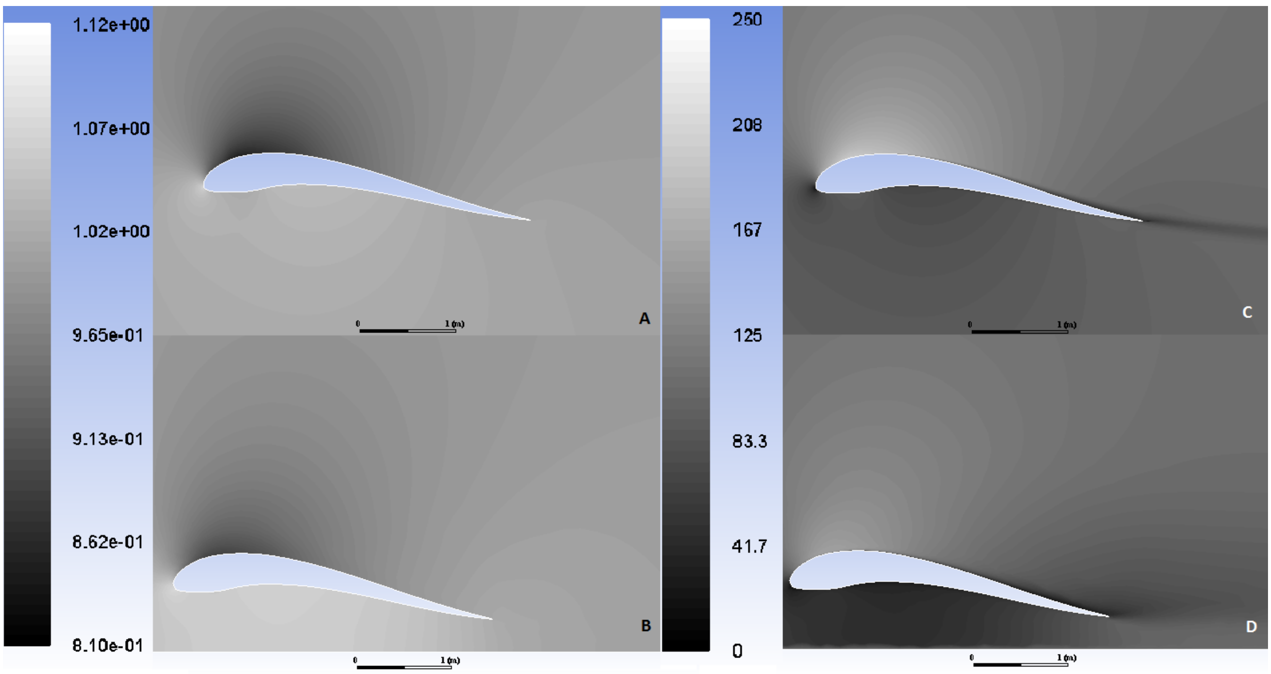

Fig. 5. Comparison of absolute pressure distribution (left scale in [atm]) for free stream flight (A) and wing in ground effect flight (B), and velocity distribution (right scale [m/s]) for free stream flight (C) and WIG effect flight (D)

Figure 5 presents results of simulation as absolute pressure distribution and air stream velocity distribution free stream flight and for WIG effect flight. Absolute pressure is measured relative to the absolute zero pressure. As shown in this figure, absolute pressure for WIG effect flight is higher below the airfoil than for normal flight, because of ground proximity air stream was stopped, what provides to this increase. In the course of research, authors noticed that drag increase could be due to aerodynamic trace above the airfoil in the wing in ground effect flight.

Figure 6 presents flaps influence on absolute pressure distribution under the NACA M8 airfoil in WIG effect flight. The height of flight remains still for every flaps angle, and it is equal to 0.1 of chord length. The length of flaps is equal to 0.2 of chord length. It is important to keep distance still on the wing in ground effect, because there is a risk of break off flaps. With higher flaps angle pressure under the wing rise, and due to an increase of speed above the wing, pressure on the upper surface decrease.

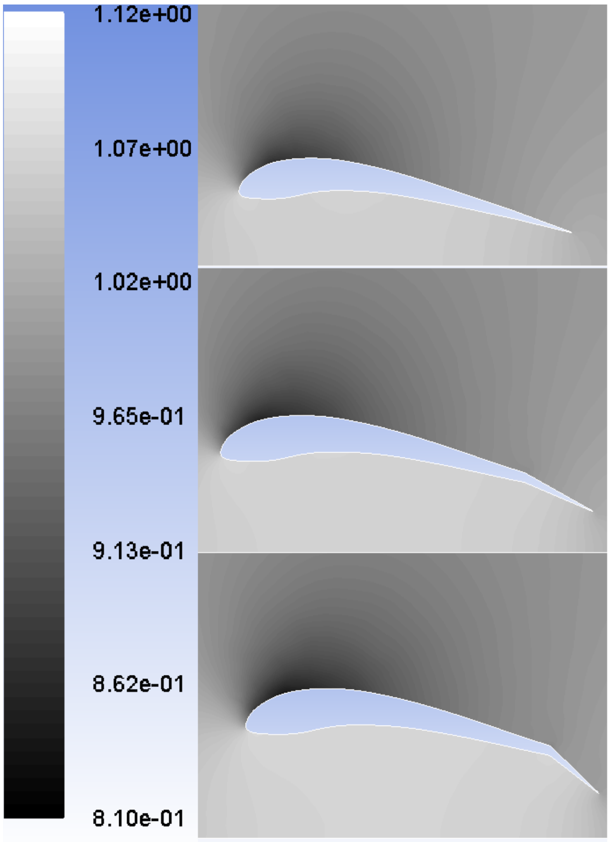

Fig. 6. Pressure distribution [atm] for NACA M8 airfoil in wing in ground effect flight with flaps; flaps angle from the top: 5°,15°,30°

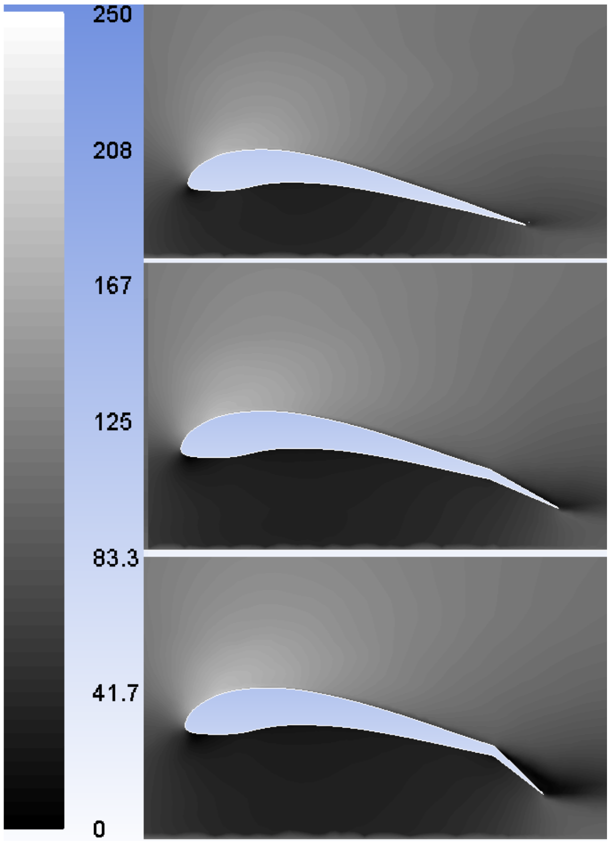

Fig. 7. Air stream velocity distribution [m/s] for NACA M8 airfoil in wing in ground effect flight with flaps; flaps angle from the top: 5°,15°,30°

In reference to Fig. 6, Fig. 7 presents air stream velocity distribution for the same cases of flaps usage. With the higher angle of flaps, more air was stopped under the wing, what provides to increase of lift force, but also to increase drag force. Due to air stagnation under the wing, air needs to flow above the wing with higher speed, thanks to that, the difference in pressure values under and above the wing is bigger.

3. Conclusion

This is obvious that wing in ground effect provides to a big growth of lift force, with few factors it can also increase or decrease drag force, depends on wing angle of attack, slots or flaps application. In further work, authors want to examine boundary layer blowing and suction in the wing in ground effect airfoil. For now, WIG effect with flaps application can make aircraft more efficient, and more environment-friendly.

References

[1] Rozhdestvensky, K. V., *Aerodynamics of a Lifting System in Extreme Ground Effect,* 1st ed., Springer-Verlag, pp. 63-67, 2000.

[2] Moore, N., Wilson, A., Peters, J., *An Investigation into wing in ground effect airfoil geometry*, RTO SCI Symposium on Challenges in Dynamics, System Identification, Control and Handling Qualities for Land, Air, Sea and Space Vehicles *Paris, France, NATO* RTO, pp. 11-20, 2002.