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AIRFOIL SELECTION FOR WING IN GROUND EFFECT CRAFT

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Abstract

The main purpose of this article was to select airfoil, which generates the biggest lift coefficient, with possibly smallest drag coefficient when the airfoil flies in the wing in ground effect. Wing in ground effect occurs in the direct proximity of ground, the article presents wing in ground effect creation mechanism description with automotive and aerospace examples.

The article shows also wing in ground conditions of Ansys Fluent software simulation for all cases with conditions of analysis convergence. The article contains results of the numerical analysis for ten airfoils in three different positive angles of attack in the wing in ground flight; ten airfoils for free stream flight in the same angles of attack as in wing in ground effect, results contains lift and drag coefficients with NACA M8 airfoil presentation as authors choice for wing in ground effect crafts airfoil with full simulation results for angles of attack from –5° to 15°, with profile characteristics.

The article shows physics of stall in the wing in ground effect, and a description why stall in WIG effect flight occurs only with drag coefficient rise without lift coefficient drop, and safety measures for aircraft landing with wing in ground effect influence.

Keywords: *transport, ekranoplan, numerical analysis, wing in ground effect, airfoil*

1. Introduction

Wing in the ground craft is special kind of aircrafts which flies in direct proximity of a ground, more often over the water. WIG craft is called ekranoplans from the Russian language. Russia it is where the history of ekranoplans starts, WIG craft can land on water, or on the conventional runaway, also ekranoplans can take more cargo on board or more passengers which mean that energy consumption of this aircraft per passenger is smaller than a traditional airplane. It is known that WIG effect generates more lift force when airfoil with positive angles of attack is near the ground, but it is also known that with negative angles of attack with WIG effect influence airfoil generates higher downforce, this phenomenon is widely used in Formula 1.

WIG effect phenomenon is simple. The first aircraft needs to fly at adequate altitude, with a smaller distance between lower airfoil surface and ground static pressure rises, leading to rising of lift force. When an airfoil is near the ground it also forces vortices on the wing tips to move aside, what reduces induced drag and rises effective wing span (Fig. 1). There is a dependency, determine by K.V. Rozhdestvensky [2] which is the height of flight to chord length ratio, called height coefficient (1). The second factor is the angle of attack, with positive angles of attack, the higher angle produces higher lift force until stall.

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

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

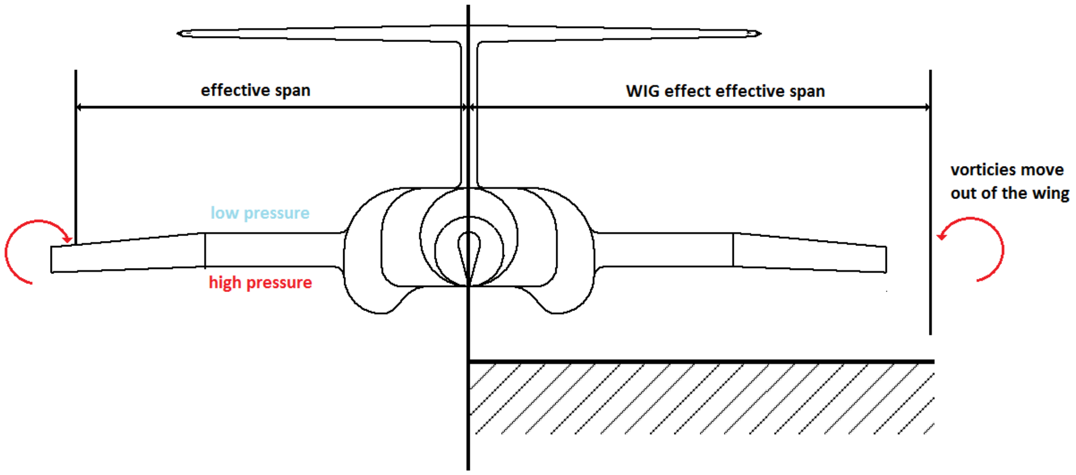

Fig. 1. Mechanism of WIG effect creation

2. Ansys Fluent simulations

All simulation were prosecuted in Ansys Fluent 17.2 academic research. Simulation conditions for all cases:

- solver set as density-based because velocity in this simulation is set above 0.3 of Mach number, above this value, there is need to consider flow as compressible,
- speed set as 0.35 of Mach number,
- 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,
- altitude above ground set as 0.1 of wing chord length.

In every simulation as the main condition of results, convergence is recognized by stabilization of lift and drag coefficients in numerical analysis. Fig. 2. When lift coefficient and drag coefficient remains still, as in Fig. 2, numerical analysis is succeeded.

3. WIG craft airfoil selection

To choose best airfoil geometry for the wing in ground effect craft, authors choose 10 different airfoils to compare. With ICEM CFD mesh and numerical analysis in Ansys Fluent 17.2 authors select airfoil with best values of lift coefficient, and also highest aerodynamic efficiency. To compare airfoils authors takes values of lift and drag coefficient for every airfoil for three different angles of attack: 0[°], 6[°], 10[°]. The values of lift coefficient are present in Tab. 1 for free stream flight and Tab. 2 for WIG effect flight, in Tab. 3 and 4 presents drag force coefficient for free stream flight and WIG effect flight.

As expected for WIG effect flight lift and drag coefficients are lower, what makes aerodynamic efficiency higher for almost every airfoil. Best results are obtained for NACA M8 (Fig. 3) airfoil, for free stream flight its aerodynamic efficiency is equal to 5.15, but for WIG flight it is equal to 16.56, it means that aircraft on 1 [km] altitude can fly without engines 16.56 [km] until it touches the ground. Full results of simulations for NACA M8 are presents in Tab. 5.

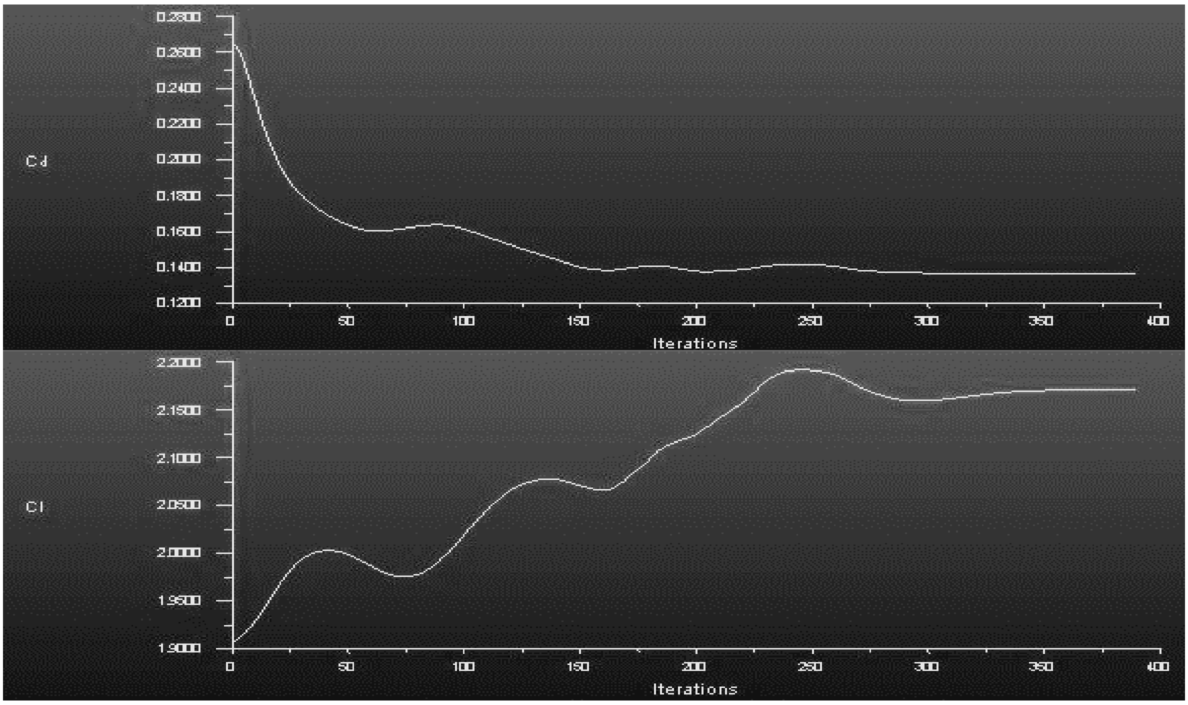

Fig. 2. Convergence of drag and lift coefficient [4]

Tab. 1. Comparison of lift coefficient for free stream flight [3]

α [°]	NACA 0015	NACA 2412	NACA M18	NACA 11H9	NACA M22	NACA M8	CHEN	CP 100 050 gn	Selig S1091	Selig S1210
0	0.00	0.23	0.19	0.20	0.29	0.53	0.40	0.45	0.60	0.97
6	0.61	0.87	0.83	0.81	0.93	1.16	1.00	1.19	1.21	1.60
10	0.97	1.22	1.20	1.17	1.28	1.52	1.34	1.49	1.53	1.91

Tab. 2. Comparison of lift coefficient for WIG effect flight [3]

α [°]	NACA 0015	NACA 2412	NACA M18	NACA 11H9	NACA M22	NACA M8	CHEN	CP 100 050 gn	Selig S1091	Selig S1210
0	–0.66	–0.07	0.02	0.26	0.52	0.76	0.53	0.45	0.83	1.04
6	0.84	1.23	1.24	1.26	1.39	1.60	1.45	1.48	1.52	1.77
10	1.44	1.64	1.63	1.57	1.52	1.91	1.43	1.79	1.79	2.06

Tab. 3. Comparison of drag coefficient for free stream flight [3]

α [°]	NACA 0015	NACA 2412	NACA M18	NACA 11H9	NACA M22	NACA M8	CHEN	CP 100 050 gn	Selig S1091	Selig S1210
0	0.07	0.09	0.09	0.11	0.16	0.13	0.06	0.24	0.21	0.23
6	0.14	0.19	0.17	0.17	0.20	0.23	0.18	0.29	0.29	0.39
10	0.21	0.26	0.24	0.24	0.29	0.30	0.26	0.37	0.36	0.47

Tab. 4. Comparison of drag coefficient for WIG effect flight [3]

α [°]	NACA 0015	NACA 2412	NACA M18	NACA 11H9	NACA M22	NACA M8	CHEN	CP 100 050 gn	Selig S1091	Selig S1210
0	0.12	0.10	0.10	0.09	0.09	0.09	0.08	0.22	0.10	0.08
6	0.09	0.10	0.09	0.09	0.10	0.10	0.10	0.11	0.10	0.11
10	0.12	0.14	0.13	0.18	0.40	0.15	0.48	0.14	0.17	0.15

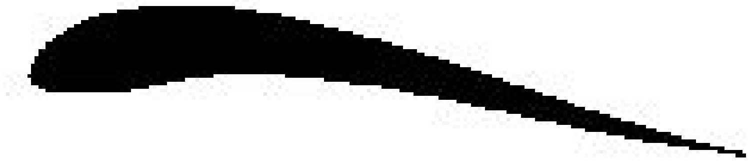

Fig. 3. NACA M8 airfoil

Tab. 5. Lift and drag coefficient values for NACA M8 profile [3]

Angle of attack α [°]	Free stream flight lift coefficient	WIG flight lift coefficient	Free stream flight drag coefficient	WIG flight drag coefficient
–5	–0.02	–0.36	0.13	0.31
–4	0.09	–0.21	0.12	0.25
–3	0.2	0	0.11	0.19
–2	0.31	0.25	0.10	0.14
–1	0.42	0.51	0.11	0.11
0	0.53	0.76	0.13	0.09
1	0.64	0.97	0.15	0.08
2	0.75	1.13	0.16	0.08
3	0.86	1.26	0.17	0.08
4	0.96	1.39	0.19	0.08
5	1.06	1.49	0.21	0.09
6	1.16	1.6	0.23	0.10
7	1.25	1.69	0.24	0.11
8	1.35	1.78	0.26	0.12
9	1.44	1.85	0.28	0.13
10	1.52	1.91	0.30	0.15
11	1.6	1.98	0.33	0.16
12	1.66	1.98	0.34	0.22
13	1.72	2.03	0.36	0.25
14	1.75	2	0.38	0.40
15	1.7	2.06	0.39	0.45

The characteristics of NACA M8 airfoil are presents in Fig. 4. In WIG effect flight there is no stall in traditional meaning. When the angle of attack is too high, there is no loss of lift force, but an only sudden increase of drag coefficient, what makes WIG effect craft safer than traditional aircraft. With almost every positive angle of attack, the drag coefficient is smaller than for a traditional flight, what means that WIG effect craft can fly with the same speed as normal aircraft with smaller specific fuel consumption rate.

Figure 5 presents distribution of air stream velocity for NACA 0015 airfoil simulation. Fig. 5 shows why there is an increase of drag coefficient after cross maximum angle of attack. The reason for this phenomenon is aerodynamic trace produced by airfoil in the wing in ground effect flight, because of the higher speed of air above the airfoil than in free stream flight also rise of drag force can be caused by higher static pressure under airfoil, what also provides to maintain lift force.

4. Conclusion

With obtained results, there is a chance to use it in WIG effect craft concept model to study WIG effect in aerospace. NACA M8 is promising as a WIG effect craft airfoil. WIG craft in the past were military planes, but now we can use it as a form of cargo or people transport, which could be cheaper and safer than traditional aircraft. WIG craft does not need a regular airport,

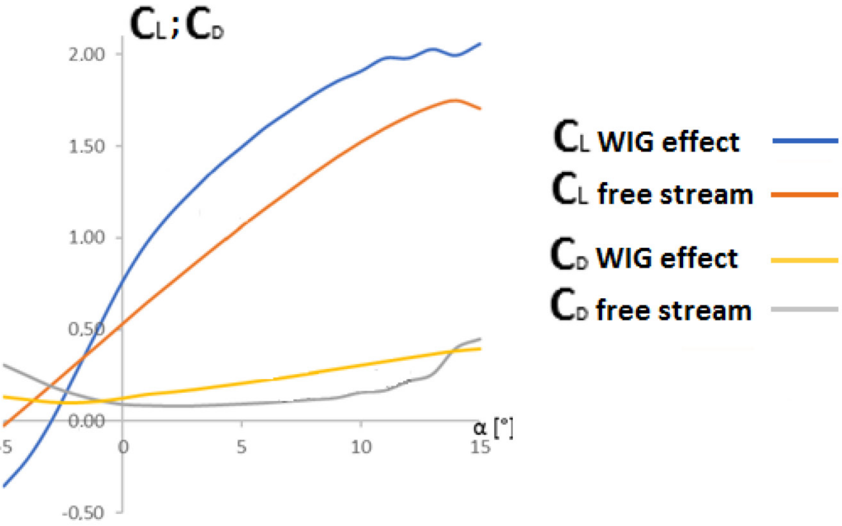

Fig. 4. Characteristics of NACA M8 profile [3]

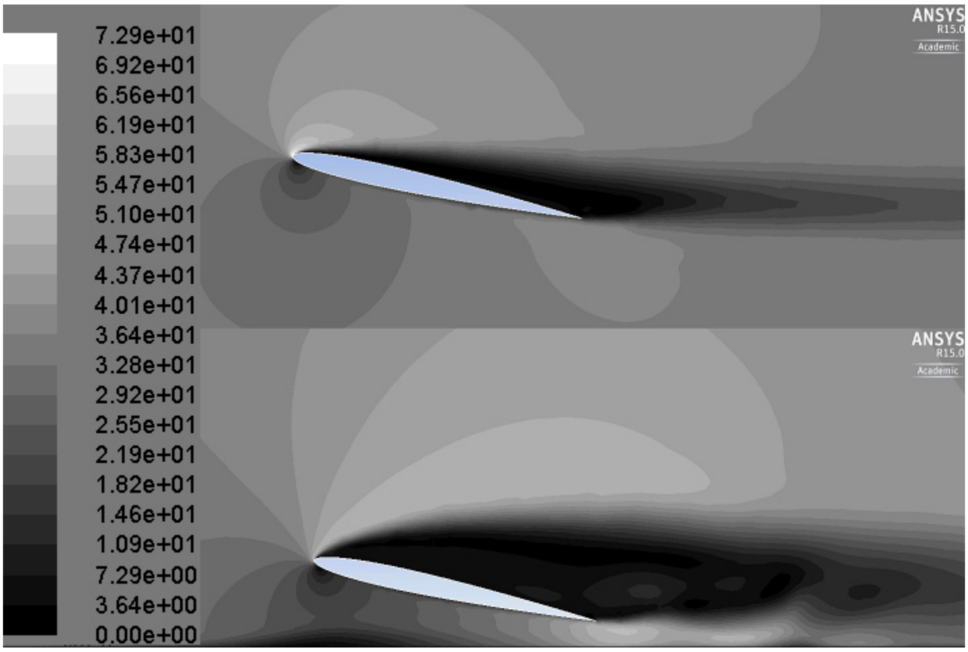

Fig. 5. Distribution of air stream velocity [m/s] for angle of attack equal to 12 [°], from the top of free air stream flight, and below for wing in ground effect [4]

it can land and start from the water. The disadvantage of WIG craft is that it cannot fly above water when waves are too high. WIG effect with a negative angle of attack produces downforce so it is important to avoid negative angle of attack in WIG effect influence because it provides to sudden lift force loss.

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