

# Effect of ground proximity on the flow over STOL CH750 multi-element airfoil

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**Abstract.** The paper presents the influence of ground distance on aerodynamic characteristics of the flow over short take-off and landing STOL CH750 aircraft multi-element airfoil at various flap angle of deflection. The angle of attack is kept constant throughout the computations. ANSYS is used for the grid generation and the computational calculation. Further investigation suggests the best range of deflection angle where the aerodynamic performance of the airfoil increases in the presence of ground. Furthermore, a cushion of high-pressure air region between the airfoil pressure side and the ground surface also emerges.

## 1. Introduction

The phenomenon of ground effect becomes apparent in the proximity of the runway, and is beneficial in the control of fixed wing aircrafts during take-off and landing. When an aircraft is flown at about the equivalent to one wing span above the runway, the interaction between the airflow around the airfoil and the ground surface modifies the fluid velocity's vertical component and changes its normal pattern which consequently affects the lift-to-drag ratio  $L/D$  [1,2,3]. In particular, the corresponding rotation of the resultant force vector gives change to the component of lift and drag forces [4]. A well trained pilot takes the phenomena into account in order to enhance the safety prior to airborne and touchdown [5].

The paper evaluates the influence of ground on the multi-element airfoil during landing. The problem is analysed with regard to the aerodynamic characteristics of the flow over NACA 4412 airfoils which form the cross sections of STOL CH750 light sport aircraft (LSA) wing with constant chord length [6,7]. The evaluation focuses on fixed angle of attack, but the distance between the airfoil and the ground varies. The main airfoil is equipped with a junkers flap with various angle of deflection (AoD), namely 0°, 10°, 25°, 40°. Such AoD is crucial in achieving touchdown point accuracy and preventing ballooning especially if the aircraft is close to the runway during flare; the recovery from such problem would require emergency procedures [8]. The junkers flap is slotted below the trailing edge of the main airfoil. The design allows the airflow to pass between the main airfoil and the flap, even when the latter is retracted. Because of the increase in airflow, a significant increase in lift is added to the airfoils, even at low speeds. The flap is employed nowadays in many modern ultralights [9]. A steady-state RANS investigation is performed using the commercial CFD code ANSYS. The relationship between AoD and the nature of ground effect at constant landing speed is observed. The effect is also considered for different distances between the airfoil and the ground.



## 2. Governing equations and modelling assumptions

A finite volume numerical method based on solving RANS equations describing the case under consideration is used for calculating the flow around the airfoil. In the case of incompressible, steady, 2-D viscous flow, the equations are given by:

$$\rho \left( u_1 \frac{\partial u_1}{\partial x_1} + u_2 \frac{\partial u_1}{\partial x_2} \right) = F_1 - \frac{\partial P}{\partial x_1} + \mu \left( \frac{\partial^2 u_1}{\partial x_1^2} + \frac{\partial^2 u_1}{\partial x_2^2} \right) - \rho \left( \frac{\partial \langle u_1' u_1' \rangle}{\partial x_1} + \frac{\partial \langle u_1' u_2' \rangle}{\partial x_2} \right), \quad (2.1)$$

and

$$\rho \left( u_1 \frac{\partial u_2}{\partial x_1} + u_2 \frac{\partial u_2}{\partial x_2} \right) = F_2 - \frac{\partial P}{\partial x_2} + \mu \left( \frac{\partial^2 u_2}{\partial x_1^2} + \frac{\partial^2 u_2}{\partial x_2^2} \right) - \rho \left( \frac{\partial \langle u_1' u_2' \rangle}{\partial x_1} + \frac{\partial \langle u_2' u_2' \rangle}{\partial x_2} \right), \quad (2.2)$$

where  $u_1, u_2$  are time-averaged velocity vectors,  $P$  is the pressure,  $\mu$  is the dynamic viscosity,  $u_1', u_2'$  are fluctuating velocity vectors, and  $F_1, F_2$  are body forces. It is necessary that the continuity equation,

$$\frac{\partial u_1}{\partial x_1} + \frac{\partial u_2}{\partial x_2} = 0, \quad (2.3)$$

is satisfied by (2.1) and (2.2).

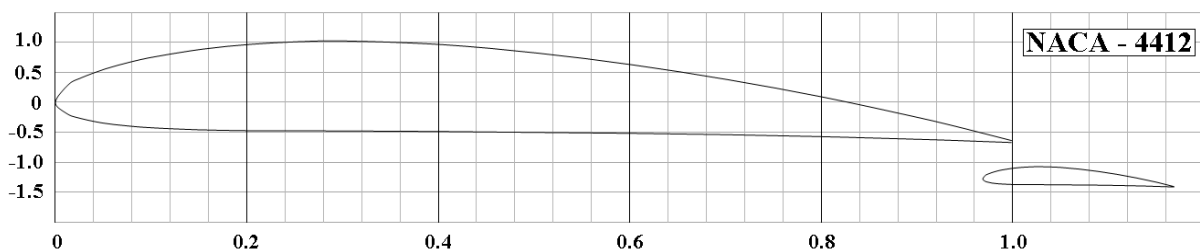
Since the Reynolds averaging is involved in the derivation of (2.1) and (2.2), then a set of new unknowns called the Reynolds stresses need to be modeled to ensure that the equations can be closed. In particular, the  $k-\varepsilon$  turbulence model which gives a general description of turbulence by means of two transport equations is applied.

The method is applied with second-order upwind discretization schemes. The algorithm called SIMPLE is employed for the velocity-pressure coupling. The airfoil velocity and the Reynolds number are 25 m/s and  $1.7 \times 10^6$ , respectively. The values are within the range of CH750 landing and take-off conditions. The Mach number of flow is equal to 0.07, so then the compressibility effects could be neglected since they should be taken into account for a Mach number greater than 0.3. The investigated AoD and heights of airfoil flights represented by the relative ratio of the height-to-airfoil chord length ( $h/c$ ) are introduced.

## 3. Geometry, grid and computational domain

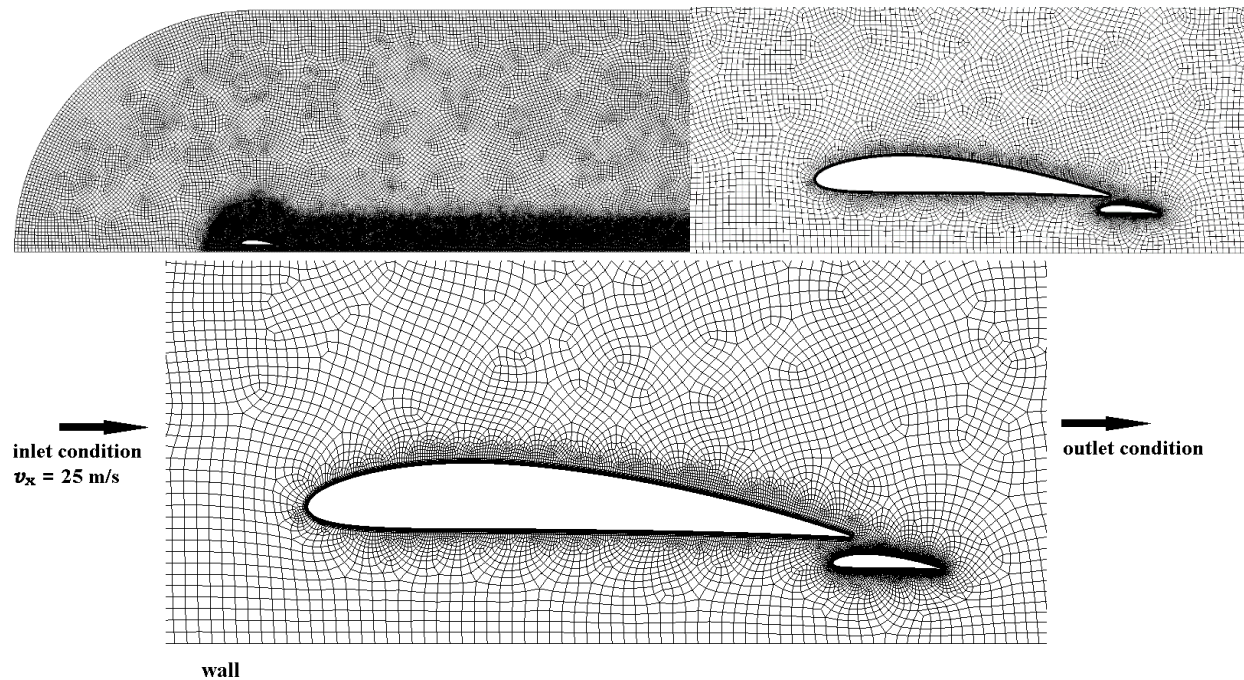
The flow is studied for the NACA 4412 for both the main airfoil and the junkers flap. The airfoil has a flat shape of the pressing (bottom) side. The geometry of the airfoil is given in Fig. 1.

For discretization of the computational domain, an unstructured type of grid with quad elements is selected. The airfoil model moving above the ground and the grid used for calculations are given in Fig. 2.



**Figure 1.** Geometry of NACA 4412 airfoils (main airfoil with junkers flap)

Inlet and outlet boundary conditions are specified on the outer sides of computational domain with necessary turbulence and flow parameters. The boundary condition on the airfoil is a no-slip condition with zero relative speed enforced. This should produce better representation of the reversing flow assumption.



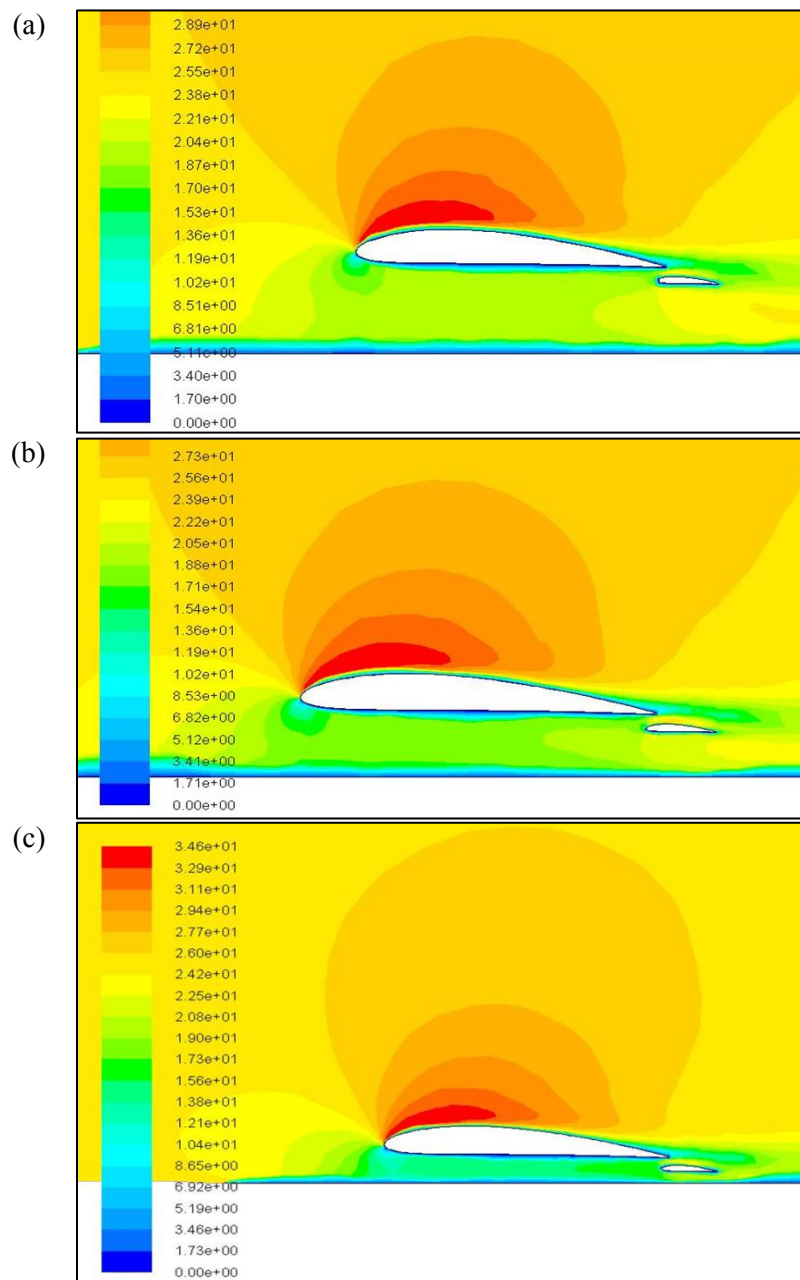
**Figure 2.** Grid applied for airfoil moving close to the ground surface

#### 4. Results of calculations

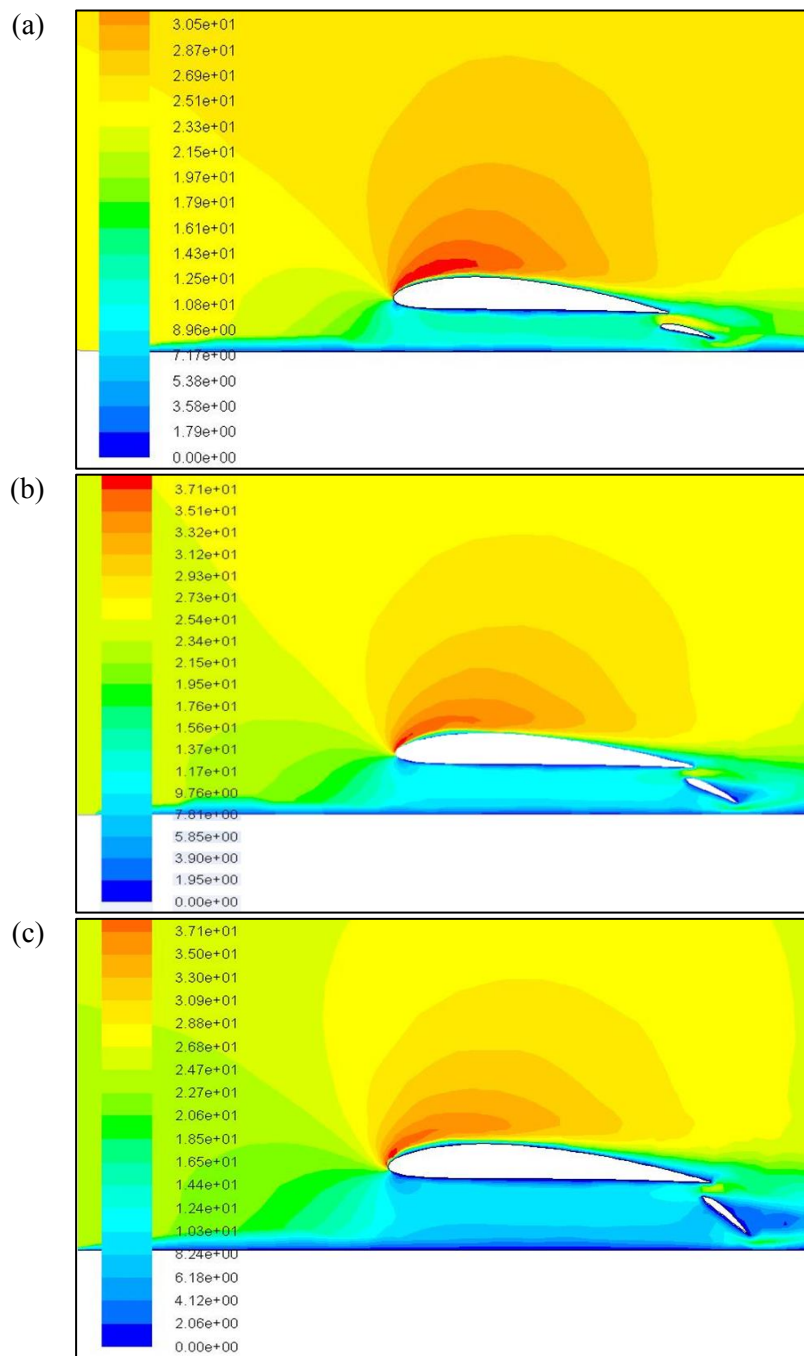
The velocity field around the NACA 4412 airfoil in clean configuration is shown in Fig. 3. Note that the airfoil is in ground proximity. It is obvious that the velocity is relatively low in particular at the pressure side when the airfoil approaches the ground, and thus gives direct influence to  $L/D$  a moment after the roundoff. This indicates that the airfoil floats on a cushion of high-pressure air region above the ground surface. Furthermore, the stagnation point shifts to the lower side of the airfoil due to the ground effect.

The ground effect on the velocity field around the airfoil in dirty configuration is shown in Fig. 4. Clearly the velocity drop is acute at the pressure side when AoD changes from  $10^\circ$  to  $25^\circ$ , and consequently  $40^\circ$ , giving therefore great influence to  $L/D$  during the final stage of the approach until touchdown. Apart from the shift of the stagnation point to the lower airfoil side, the flow separation occurs near the flap at AoD  $25^\circ$  and  $40^\circ$ .

Although the AoD increase has a positive influence on the lift, in general its impact on the drag is greater such that  $L/D$  decreases. The percentage of  $L/D$  reduction in the presence of the ground is shown in table 1. In this case the basic aerodynamic characteristics are therefore in agreement with those for unbounded airflow. The next question is whether the  $L/D$  can be much improved by the ground effect.



**Figure 3.** Velocity contour for the airfoil in clean configuration  
(a)  $h/c = 0.25$  (b)  $h/c = 0.15$  (c)  $h/c = 0.05$



**Figure 4.** Velocity contour for the airfoil in dirty configuration  
(a) AoD = 10° (b) AoD = 25° (c) AoD = 40°

**Table 1.** Influence of AoD on  $L/D$  at  $h/c = 0.15$

AoD	$C_l$	$C_d$	$L/D$	$\Delta C_l$ (%)	$\Delta C_d$ (%)	$\Delta L/D$ (%)
0°	2.891E-02	8.330E-04	34.73			
10°	3.781E-02	1.074E-03	35.20	31	29	1
25°	4.269E-02	2.081E-03	20.51	48	150	-41
40°	4.921E-02	3.114E-03	15.80	70	274	-55



The computation results based on different settings of the distance between the airfoil and the ground are tabulated in table 2. Lift and drag are the forces which act on the whole geometry consisting of main airfoil and flap. The coefficients  $C_l$  and  $C_d$  profile shows that the drag, in contrast to the lift is lower for any AoD when the airfoil approaches the ground. This unconditionally contributes to the increase of  $L/D$  in the vicinity of the ground, and keeps the aircraft to ‘float’ above the runway relatively longer before the touchdown. It is also worth to note that the airfoil best performs at AoD  $10^\circ$  where the average lift-to-drag ratio increment  $(\Delta L/D)_{av}$  with respect to  $h/c$  is approximately 44%. While at AoD  $25^\circ$  and  $40^\circ$ , the overall performance is relatively low since the flow separation compromises the flap lift (see figure 4).

**Table 2.** Influence of  $h/c$  on  $L/D$  at various AoD

AoD	$h/c$	$C_l$	$C_d$	$L/D$	$\Delta C_l$ (%)	$\Delta C_d$ (%)	$\Delta L/D$ (%)
$0^\circ$	0.25	2.697E-02	8.900E-04	30.28			
	0.20	2.797E-02	8.340E-04	33.53	3.7	-6.3	11
	0.15	2.891E-02	8.330E-04	34.73	7.2	-6.4	15
	0.10	3.024E-02	8.260E-04	36.60	12.1	-7.2	21
	0.05	3.288E-02	8.220E-04	40.00	21.9	-7.6	32
$10^\circ$	0.25	3.677E-02	1.479E-03	24.86	--	--	--
	0.20	3.679E-02	1.110E-03	33.15	0.1	-24.9	33
	0.15	3.781E-02	1.074E-03	35.20	2.8	-27.4	42
	0.10	3.841E-02	1.051E-03	36.56	4.5	-28.9	47
	0.05	3.867E-02	1.021E-03	37.89	5.2	-31.0	52
$25^\circ$	0.25	4.243E-02	2.197E-03	19.31	--	--	--
	0.20	4.262E-02	2.172E-03	19.62	0.4	-1.1	2
	0.15	4.269E-02	2.081E-03	20.51	0.6	-5.3	6
	0.10	4.403E-02	2.028E-03	21.71	3.8	-7.7	12
	0.05	4.522E-02	1.989E-03	22.73	6.6	-9.5	18
$40^\circ$	0.25	4.596E-02	3.174E-03	14.48	--	--	--
	0.20	4.818E-02	3.168E-03	15.21	4.8	-0.2	5
	0.15	4.921E-02	3.114E-03	15.80	7.1	-1.9	9
	0.10	4.930E-02	3.090E-03	15.95	7.3	-2.6	10
	0.05	4.943E-02	3.084E-03	16.03	7.6	-2.8	11

## 5. Conclusion

The study focuses on the effect of ground proximity on the flow over STOL CH750 multi-element airfoil. From the study, several conclusion can be made:

- AoD significantly influence the near ground air and cause higher pressure at the pressure side of the airfoil thus slowing down the touch down of the airplane. Higher AoD will result in increase of lift.
- However, higher AoD also contribute to the increase of drag which helps the airplane to slow down at faster rate.
- The distance between the ground and the airfoil also records similar increasing pattern of lift as the airfoil approaching the ground but records decrease of drag force.

It is important to take into consideration the AoD and  $h/c$  in the operational of an airplane during landing.

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