

Report Hess-Smith

Luca Piomboni

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Abstract

This project is based on the development of a numerical methodology employing Hess-Smith's panel method for the comprehensive analysis of two airfoils arranged in a tandem configuration. The investigation encompasses the intricate interplay between the airfoils, incorporating considerations for ground effects. The primary objective is to determine the optimal angle of attack for the rear airfoil that maximizes the lift coefficient of the front airfoil. The study focuses on NACA 3310 for the front airfoil and NACA 0012 for the rear airfoil. The numerical method is implemented using MATLAB, and subsequent validations are conducted by XFLR5.

1 Introduction

The Hess-Smith's panel method, developed in the 1960s, represents a numerical approach rooted in potential flows. This method is instrumental in analyzing aerodynamic phenomena by discretizing the geometry into a defined number of panels. Each panel incorporates distributed sources (or sinks) and vortices characterized by a constant gamma. By enforcing the non-penetration condition on each panel and incorporating the Kutta condition, the method derives the strengths of the sources and the value of gamma. Subsequently, this allows for the determination of the velocity field of the flow, accounting also for the stream flow and its angle of attack. The knowledge of the velocity field provides a comprehensive understanding of flow parameters, including the distribution of C_p and C_l .

1.1 Objectives and expectations

The objective of this project is to comprehensively analyze the behavior of airfoils across varied configurations, geometries, and scenarios, considering both the presence and absence of the ground effect. Symmetric geometries are anticipated to exhibit fluid properties symmetrically. Furthermore this method should mask information pertaining to separation effects, since the thin airfoil theory does not account for them, resulting in a linear dependence of the lift coefficient on the angle of attack. Concerning the influence of the ground, the idea is that lift coefficient will increase due to the expansion of the enclosed area in the pressure distribution diagram along the chord direction. The expectation is that this effect intensifies in proximity to the ground, relative to the airfoil's chord dimension, and gradually diminishing with increasing the distance. This report delves into these elements through graphical representations of the obtained results, followed by a rigorous post-processing phase supported by validation using XFLR5. The combination of analytical insights and empirical validation enhances the robustness and reliability of the findings.

1.2 Computational apparatus

My computational apparatus is based on: CPU = Intel(R) Core(TM) i7-10510U CPU @1.80GHz RAM = 16GB Core used = 1 The clock time depend on the script and the finesse of the mesh used for the post process, but the range is about [1,4] seconds.

2 Results

The MATLAB simulations were systematically conducted across three discrete phases, with a consistent panel count of 100 panels maintained throughout. In the initial phase, the focus centered on simulating individual airfoils in isolation. Subsequent to this, the investigation progressed to the simulation of airfoils in a tandem configuration, accounting for mutual interaction effects. The conclusive phase integrated

the ground effect into the tandem configuration simulations. In each phase, recording of pressure and lift coefficient values was executed. In the analysis of the following result it is important to remember that the procedure used for the geometry definition is based on the half-cosine distribution, such that the number of panels in the leading and trailing edge is larger than the rest of the geometry. The angle of attack instead is determined by a rotation of the airfoil around its leading edge. Initially I considered the aerodynamic performance of a tandem wing configuration with a geometry setting shown in Table 1 and featuring a NACA 3310 (Fig. 2a) wing and a NACA 0012 (Fig. 2b) tail. The chord here is assumed to be the same for both the airfoils and it is set to 1 meter. The aim was to determine the lift coefficient C_l of the wing while varying the angle of attack of the tail by a variation-step of 1° . This investigation was conducted both in the absence of ground effect (Figure 1a) and accounting for ground proximity (Figure 1b).

N_{panels}	u_∞ [m/s]	$x_{1,2}$ [m]	$y_{1,2}$ [m]	α_w [deg]	h [m]
100	1	1.2	0.11	2.5	0.25

Table 1: Data setting.

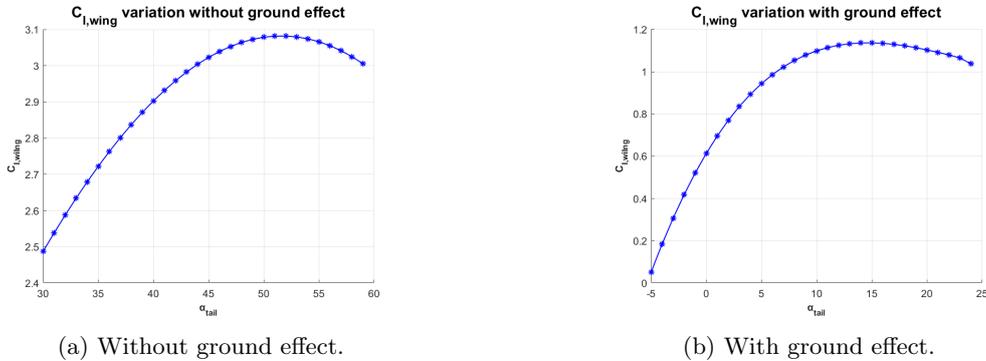


Figure 1: Effect on lift coefficient of the wing due to changing on the angle of attack of the tail without and with ground effect.

The analysis revealed that, without considering ground effects, the optimal angle of attack for the tail to maximize the lift coefficient of the front wing is $\alpha_{tail} = 52^\circ$. However, when accounting for it, this optimal angle of attack shifts back to $\alpha_{tail} = 15^\circ$. It is important to note that these values of angle of attack are not in reality the ones that actually maximise the lift of the wing. This is due to the fact that potential flow theory does not account for the effect of the separation. Notably, this theory remains valid only for small angles of attack and thin airfoils. Therefore I will explore alternative geometries and varying distances between the two previous airfoils to obtain more realistic results.

2.1 Single airfoil

The airfoils under examination are the NACA 3310 (Fig. 2a) and the symmetric NACA 0012 (Fig. 2b). I have presented the pressure coefficient values for each of them in Figure 3, along with the corresponding lift coefficient, in the Table 2 provided below. The results refer to an equal angle of attack set to be 2.5° .

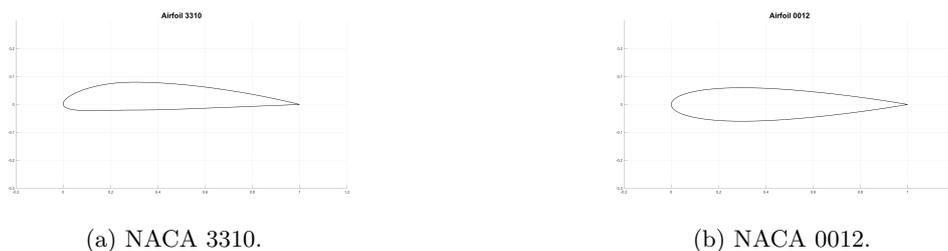
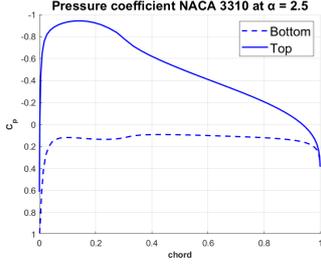
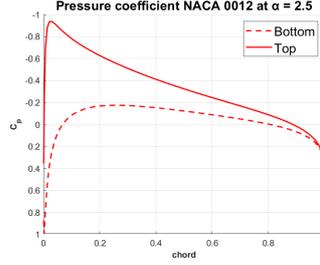


Figure 2: Comparison of NACA 3310 and NACA 0012 geometries.



(a) C_p NACA 3310 for $\alpha = 2.5^\circ$.



(b) C_p NACA 0012 for $\alpha = 2.5^\circ$.

Figure 3: Comparison C_p coefficient of NACA 3310 and NACA 0012.

NACA	C_l
3310	0.6374
0012	0.3010

Table 2: C_l for single airfoils.

2.2 Tandem configuration

I am now going to provide the values of C_l in the case of a tandem configuration for a range of $\alpha_{tail} = [-5^\circ, +5^\circ]$, changing the distances between the two airfoils, all the data-set can be seen in Table 3, and the chord of the tail is set to be 0.4 meters. It is possible to visualize the results in Figure 4 below.

Iteration	Color	α_w [deg]	$x_{1,2}$ [m]	$y_{1,2}$ [m]
1	blue	2.5	1.2	0
2	red	2.5	1.2	0.5
3	green	2.5	1.2	-0.5
4	black	2.5	1	0

Table 3: Data-set for different tandem configurations.

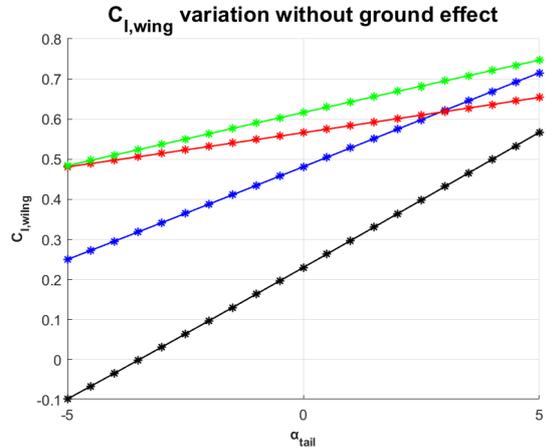


Figure 4: C_l values for a NACA 3310 and NACA 0012 in different tandem configurations, evaluated for a low range values of α_{tail} .

Examining the results reveals that the optimal configuration among those studied is the one with the tail positioned beneath the wing. Furthermore, the fourth iteration highlights that maintaining a null difference in height between the two airfoils, when their distance is short, can adversely impact the wing's lift coefficient. It is essential to note, however, that these findings are based on a limited set of configurations; variations not explored may exhibit different behaviors, so to gain a more comprehensive understanding of their interactions, a more in-depth investigation into additional configurations is needed. Nevertheless, a consistent observation across all the positions is the direct relationship between an increase in the angle of attack of the tail and a corresponding increase in the lift coefficient of the wing. Finally I want to notice that as the distances between the two airfoils increase (iterations 1 and 2), as the effect produced by the tail is not impacting the wing too much and this can be seen by the slope of the lines in the plot.

2.3 Ground effect

Wrapping up this analysis, I share the findings for the tandem configuration, taking into account the impact of ground effects. In this scenario, I will use the same configuration as previously obtained for the maximum lift coefficient of the wing (iteration 3 of Table 3), maintaining consistency in the setup for a comprehensive comparison. The height of the wing from the ground is chose to be 0.8 meters and the angles of attack are $\alpha_{wing} = 2.5^\circ$ and $\alpha_{tail} = 5^\circ$. I present the results in terms of pressure coefficient in

Figure 6, comparing the differences between the case with and without the effect of the ground.

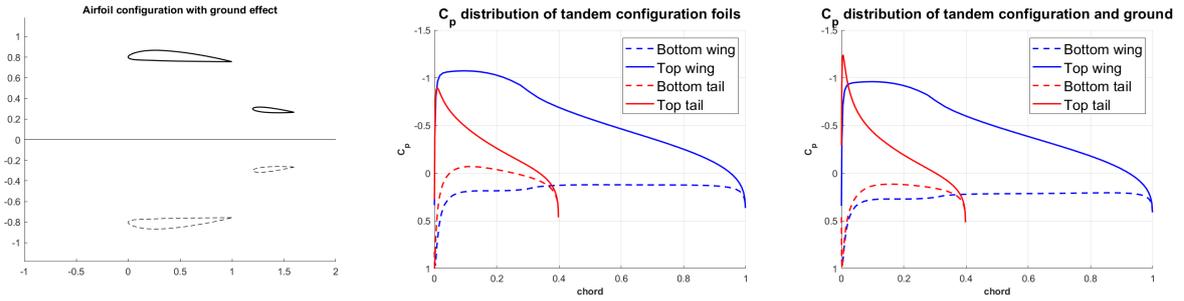


Figure 5: Geometry of the tandem configuration and its image for accounting the ground effect.

(a) Without ground effect.

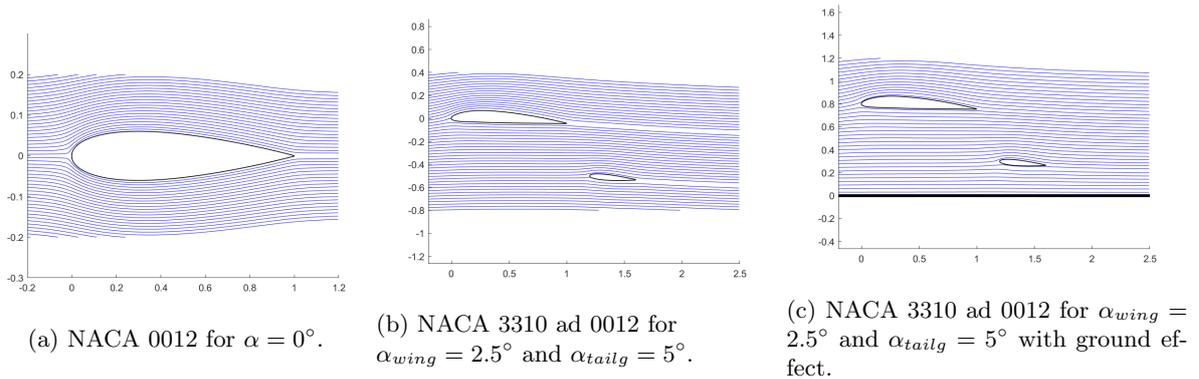
(b) With ground effect.

Figure 6: Comparison of the effects on the pressure coefficient.

In comparing the two scenarios, the influence of the ground effect becomes evident. Particularly noticeable is the impact on the airfoil closer to the ground, where the presence of the ground seemingly enlarges the area enclosed by the C_p curve. This expansion correlates with an increased lift coefficient, rising from 0.3203 in the absence of ground effect to 0.4465 when the ground is considered. Conversely, the wing positioned farther from the ground is less affected, with the C_l coefficient remaining consistent at approximately 0.74 for both scenarios.

3 Post Processing

An extensive examination of streamlines was conducted, and the outcomes are visually presented in Figure 7. This figure includes a single NACA 0012 with a zero angle of attack (Figure 7a), a tandem configuration featuring a NACA 3310 at $\alpha = 2.5^\circ$ and a NACA 0012 as tail with $\alpha = 5^\circ$ (Figure 7b), and, finally, a tandem configuration incorporating the same foils as before, accounting for ground effect with $\alpha_{wing} = 2.5^\circ$ and $\alpha_{tail} = 5^\circ$ (Figure 7c). In each of these scenarios the results look consistent, with the streamlines always tangent to the geometry, a behavior expected by theoretical predictions.



(a) NACA 0012 for $\alpha = 0^\circ$.

(b) NACA 3310 ad 0012 for $\alpha_{wing} = 2.5^\circ$ and $\alpha_{tailg} = 5^\circ$.

(c) NACA 3310 ad 0012 for $\alpha_{wing} = 2.5^\circ$ and $\alpha_{tailg} = 5^\circ$ with ground effect.

Figure 7: Streamlines for the three analysis developed.

As a final step, I present a color map illustrating the velocity field of the three cases in Figure 8, considering a NACA 0012 airfoil at a zero angle of attack, and the tandem configuration with and without ground seen previously. Checking the single foil it is possible again to see a symmetric behaviour of the fluid flow. In each case are also shown the stagnation points as the ones where the velocity has a value of zero which in the single foil coincide with the leading edge as expected.

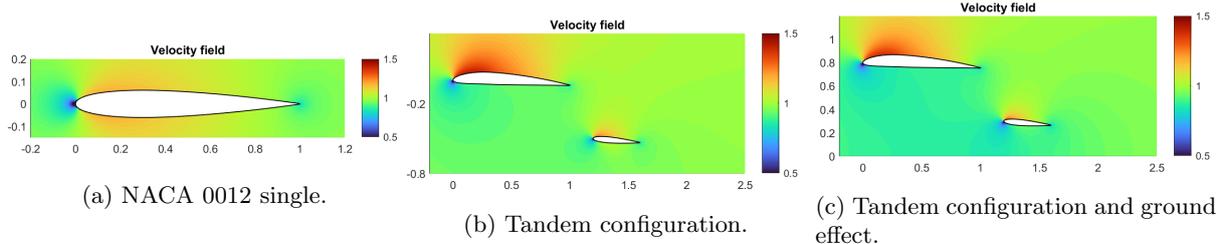


Figure 8: Color map for the three different analysis.

4 Validation

To validate the results I have used XFLR5 either for the NACA 0012 (Figure 9a and 9b) and 3310 (Figure 9c) with different angles of attack, assuming a Reynold's number equal to 50000 and a critical number set at 4. From the results provided in the figures below it is possible to see that the approximation obtained has the same curve as the one of got with the software. Furthermore the values of the lift coefficient are also matched and the comparison is provided in the Table 4 below. By investigating the value of the lift coefficient of a symmetric airfoil with a zero angle of attack it is possible to understand the correctness of the results, since with potential flow theory a symmetric body into a symmetric flow should give a value of the lift coefficient that has to be null. Accounting for a NACA 0012 in the configuration just mentioned, the pressure coefficient results are shown in Figure 9a and the behaviour is as predicted, obtaining a C_l that is -4.0766×10^{-17} . Considering computational errors, this value can effectively be treated as zero.

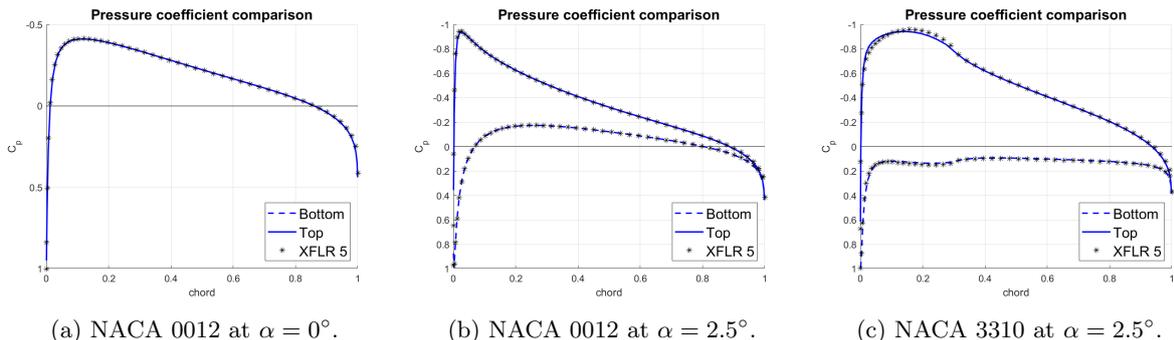


Figure 9: Comparison of the result obtained for single airfoils with XFLR5 for different angles of attack.

NACA	α	C_l	$C_{l_{XFLR5}}$
0012	0	-4.0766×10^{-17}	0.000
0012	2.5	0.3010	0.3784
3310	2.5	0.6374	0.5702

Table 4: C_l comparison with XFLR5 data.

5 Conclusion

The implemented method has demonstrated a commendable level of accuracy in predicting results, aligning closely with expectations. However, it's crucial to note that its practical applicability is confined to thin airfoils conforming to the thin airfoil theory. This limitation implies that the method excels primarily in scenarios involving small angles of attack and neglecting the effects of separation. This study has shed light on the intricate interactions between two distinct airfoils, revealing a predictable trend: increased spacing correlates with reduced interaction. Similarly, when considering the influence of the ground, the findings affirm expectations by illustrating that proximity induces a lift augmentation. The overall success of the implemented theory underscores its effectiveness.