1 Introduction

This project aims to build a model of two airfoils in a "Tandem" configuration under Matlab and to maximize the lift coefficient of each of them. The Hess-Smith method enables to build a linear system, which will be used to obtain the pressure distribution as well as the lift coefficient.
The airfoils model is a 4 digit NACA. The first part of the report will detail the Hess-Smith method for one airfoil which will then be extended to a random number N of airfoils. The last part explains the reproduction of the ground effect on a tandem configuration.

2 One airfoil

In this first part, we will see how to build the NACA model and how to apply the Hess-Smith method to it. The calculation of the lift coefficient, the distribution of pressure on the wing and the creation of the velocity field and streamline are also explained.

2.1 NACA Structure

The airfoil can be build in 2 ways, symmetrical and cambered.
For symmetric airfoils :

$$y_t = 5 * t * (0.2969 * \sqrt(x) - 0.1260 * x - 03516 * x^2 + 0.2843 * x^3 - 0.1015 * x^4)$$

$$x_u = x_l = x \quad y_u = y_t \quad y_l = -y_t$$

For cambered airfoils :

$$yc = \begin{cases} \frac{m(2px-x^2)}{p^2} & 0 <= x <= p \\ \frac{m((1-2p)+2px-x^2)}{(1-p)^2} & p <= x <= 1 \end{cases}$$

$$x_u = x - y_t * sin(\theta) \quad y_u = y_c + y_t * cos(\theta)$$
$$x_l = x + y_t * sin(\theta) \quad y_l = y_c - y_t * cos(\theta)$$

Once the NACA profile is created, a discretization is applied. We chose a distribution carried out by a cosine function to increase the number of points near the leading and the trailing edges : $x = 0.5 * (1 - cos(\beta))$. This form of distribution gives both the points of the panel and the control points of each panel.
For a NACA 2312 profile of 1 meter size with an angle of attack of 5 degrees we obtain:

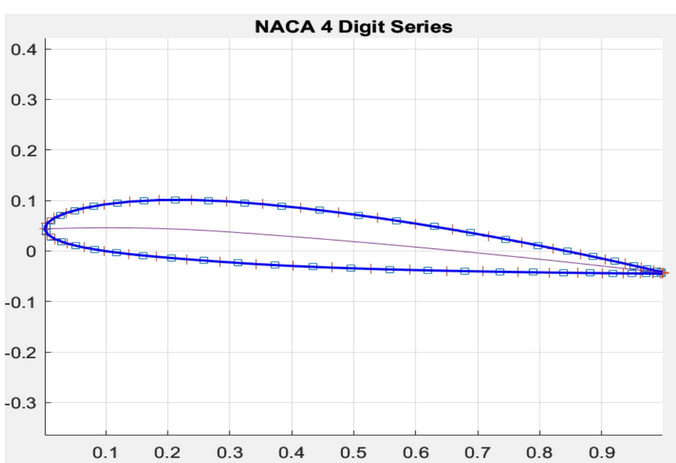

Figure 1: NACA 2312 with an AoA of 5 deg

2.2 Hess-Smith method

The Hess-Smith method is computed this way:

$U(x,y) = U_{inf} + \sum_j^N (U_{js}(x,y) * q) + \gamma \sum_j^N (U_{jv}(x,y))$

This gives a linear system of the form Ax=B. The strength of the sources and the vortex can now be computed. To check the results, we use two different methods. The first is based on the features of a symmetric airfoil ($\gamma = 0$). The second one relies on the data given by during class (NACA 2312 $AoA = 5 \rightarrow C_l = 0.8344$). In this case, we obtain $C_l = 0.8032$, which is equal to a relative deviation of $3,74\%$.

2.3 Post process

For the post process it remains to compute the streamlines, the distribution of the pressure coefficient along the airfoil as well as the velocity field around the wing. These results are compared with the data provided on Webeep as well as the study carried out on Xflr5.

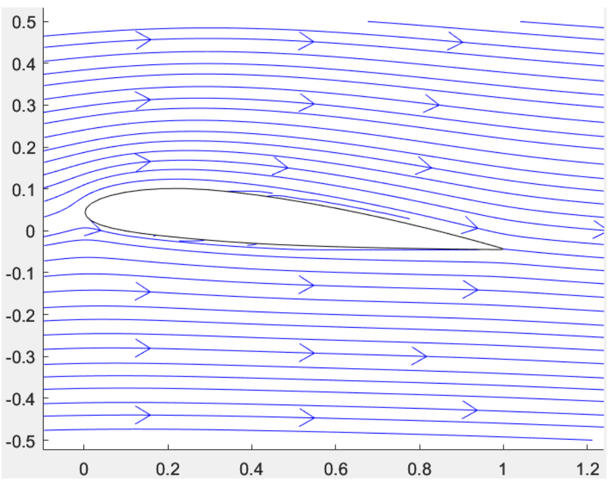

Figure 2: NACA 2312 streamlines

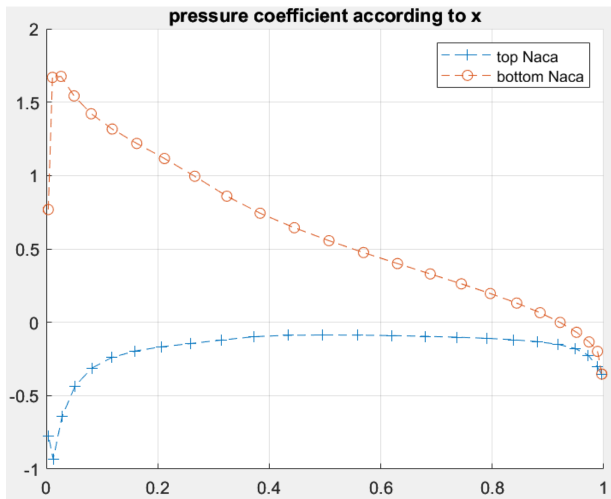

Figure 3: NACA 2312 pressure distribution

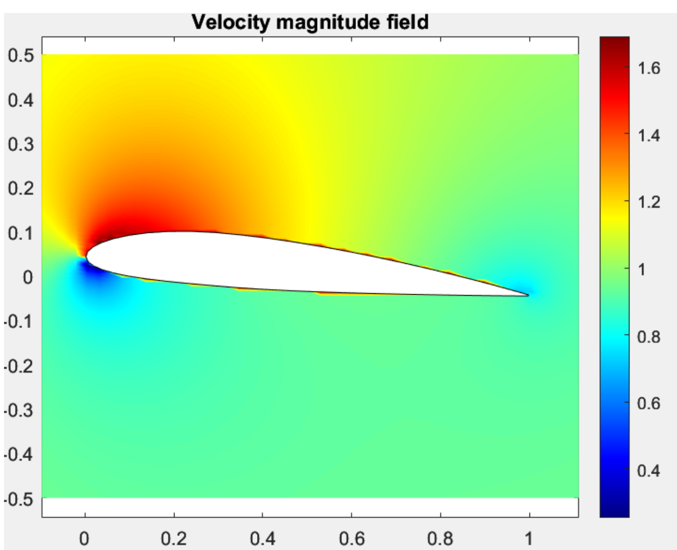

Figure 4: NACA 2312 velocity field

2.4 Xflr5 result

To compare our results we perform the same study on Xflr5. For the same configuration we obtain the following values and graph.

It can be seen that the graph of the pressure distribution in an in-viscid environment is substantially equivalent to that obtained with Matlab (dotted curve). The viscous part induces a weaker pressure distribution. This is reflected in the C_l value which is also lower (because it depends on the C_p).

3 N airfoils

In this part, we will extend the matlab code for an airfoil to N (unknown) number of airfoils

To extend the code we add a new variable (here Na) corresponding to the airfoil numbers. We thus create three-dimensional arrays for each variable and we apply a quadruple ”for” loop to compile the linear system. We obtain N*Na+2 unknowns. We then find the value of Cl for each airfoil as well as the pressure distribution Cp. We end up performing the post-process to this new code.

These graphs compare the values obtained with the ones given during class:

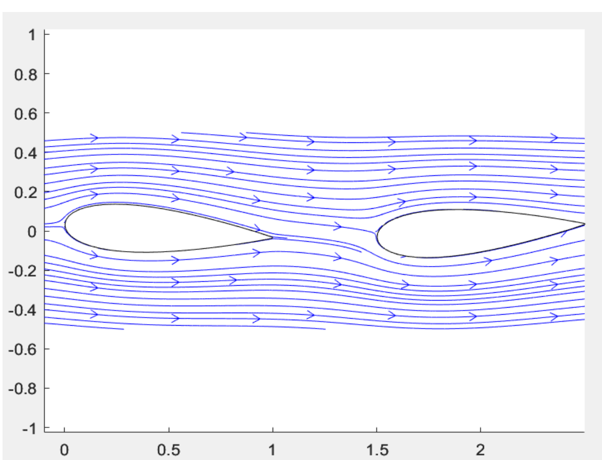

Figure 5: Streamlines for 2 airfoil 0024

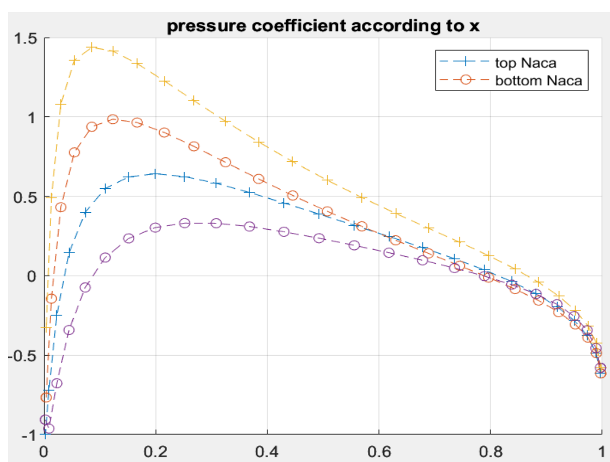

Figure 6: Pressure distribution for 2 airfoil 0024

We obtain a lift coefficient value of 0.1116 and -0.5245 for the first and the second airfoil respectively. If we compare this value to the lift coefficient of identical airfoils without tandem configuration, we obtain $C_l = 0.5158$ for $\alpha = 4$ and $C_l = -0.5087$ for $\alpha = -4$. It can therefore be concluded that the influence of a tandem configuration imposes a lower lift creation. The same observation can be made for the pressure distribution.

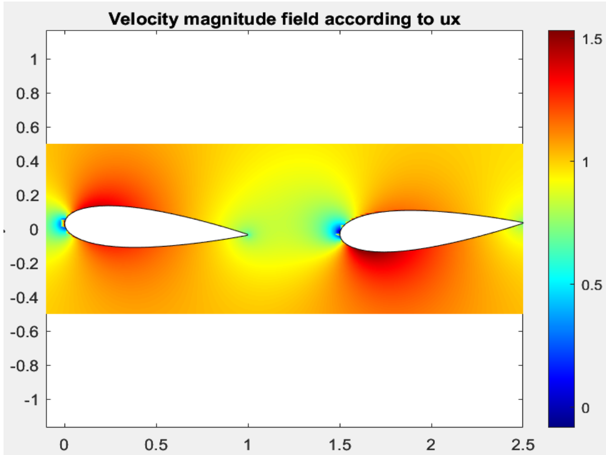

Figure 7: Velocity field along u_x for 2 airfoil 0024

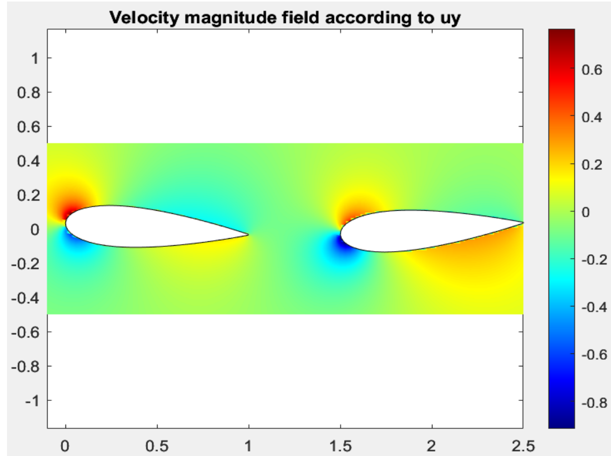

Figure 8: Velocity field along u_y for 2 airfoil 0024

4 Ground effect

In this part we will study the effect of the ground effect on the tandem configuration. We create a mirror configuration with the same characteristics, identical sources and an opposite sign vortex.

We obtain these graphs:

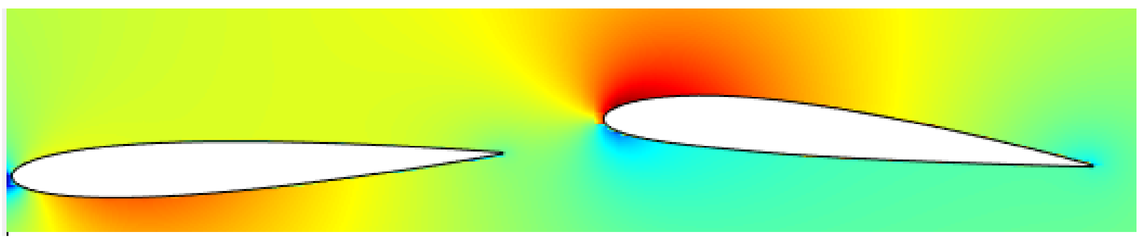

Figure 9: Velocity field for 2 airfoil (0012 2312) with ground effect

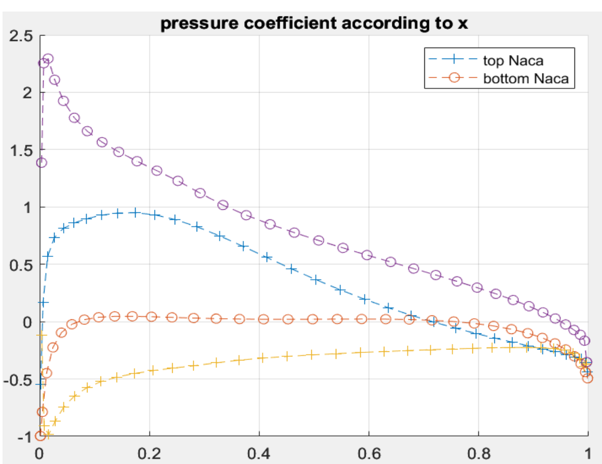

Figure 10: Pressure distribution around the 2 airfoils (0012 2312) with ground effect

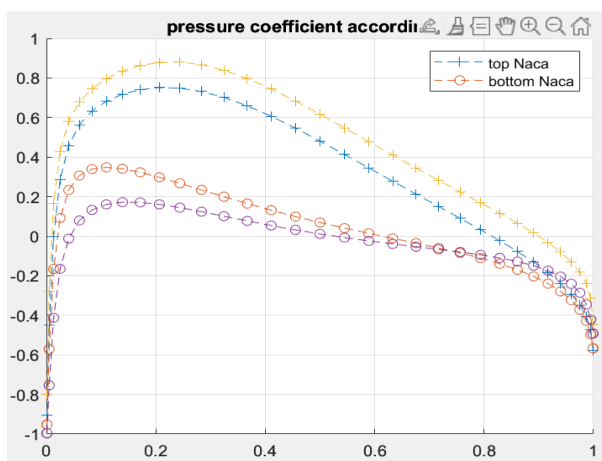

Figure 11: Pressure distribution for 2 airfoil 0012 with ground effect

In the first case the lift coefficient are -0.3870 and 1.1734. The values given in the course are different, unfortunately the lack of time prevents me from modifying the program to fix the error. We will nevertheless use these values for the rest of the study. We can see that in case of ground effect the lift coefficient is higher. That is why birds use it to save energy.

5 Study of values

Now we can vary the angle of attack of the second airfoil to optimize the lift coefficient. We get these 2 graphs:

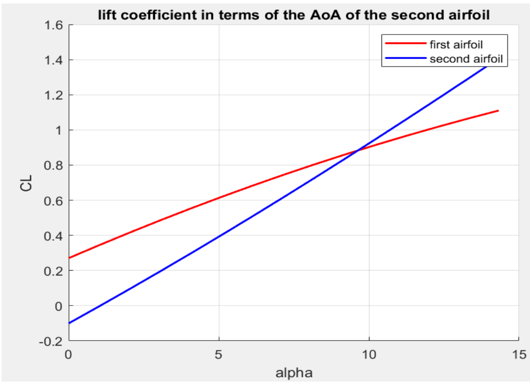

Figure 12: Lift coefficient according to alpha (AoA)

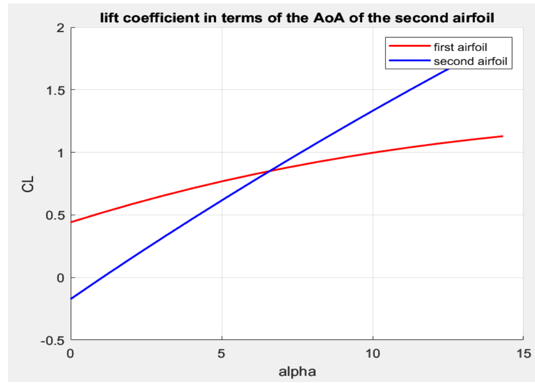

Figure 13: Lift coefficient according to alpha (AoA) with the impact of ground effect

The curves obtained on Matlab are unusable to maximize the lift coefficient as a function of alpha. Indeed, Matlab does not take into account stall conditions, this implies a linear curve without the presence of a physical maximum. To obtain a usable curve it is necessary to use Xflr5 in 3D configuration.

There are limits to this project. For starters, the Hess-Smith method has drawbacks. Indeed, its pressure distribution is imprecise close to the leading edge, and it is unable to manage thick profiles. Then, the tandem configuration has many disadvantages : a low CL max (balance of the center of pressure), a high control load and an asymmetric flight difficulty among others.

6 Ending

We can note that at the end of the project the program scrolls in about 8 seconds for the tandem configuration, which is largely respectable for the size of the post process.

This project still has points for improvement. Indeed, the values could have been checked more precisely, especially on the ground effect and the variation of alpha. As well as developing the comparative part with Xflr5. the logical continuation of this project is to apply it to Weissinger's 3D method, which includes parasite drag, aerodynamic moment and complex geometries. You can even use it in not aligned flat fix wake and more complicated flight conditions. Finally, the post-process could have been more advanced as well as the optimization of the program (the part on the alpha variation takes a long time to run).

In the end, this project was for me a good application of my knowledge in aerodynamics and allowed me to learn two new programming languages (Latex and Matlab).