WIG Project - Aero team member

SD2461

Final Report

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1 Introduction

This report will synthesize the work done on the course SD2461 under the project Wing In Ground effect (WIG).
This project aimed in building a plane, from calculations to conception through tests, in order to study ground effect on flight's performances.

To divide the work to do during this project, the group has been split into 3 sub-teams : one for the electronic field, an other one for the structure field and the last one for the aeronautical field.

In this context, the aeronautic team, constituted of Jiaqui Zhang, Jerry Osele, and myself, had tasks like defining the cruise speed, measuring the effect of ground effect, working on the dynamic stability, etc.

As a member of this team, and as I'm leaving the project before it ends, I will in this report summarize the work I did in order for future and current members of the project to know what I've been doing and achieving.

First, we will see the theoretical conception of the plane throughout the semester to put in context the work I did and see when on semester it was achieved. This will aim in structuring this presentation and in the same time building the plan for it.

Then, we will go in more detail in each part, presenting detailed explanation of the work behind the results I present.

Finally, we will make a balance sheet of the main informations and recalling what I have achieved.

2 Preliminary work

Before heading towards working on building a plane, I had to acquire knowledge on GE and plane testing. Generally speaking, I based my work on these documents [1] [2]. These documents can provide you, on my opinion, the bases on the project, and they are basically the one that helped me in the works that follow.

One of the preliminary work as a team was also to build the team and the project's identity. To do so, we first decided to work on a name and a logo for the project. This have led me to draw some logos, with team's name coming with it, that you can find here below :

Figure 1: Team's logo designs

To go quickly on those, the idea was to create a logo that represents the current project and potentially future projects to be done by the team. This implied defining a logo including the shape of a plane and the name of the team as well.

The final logo, available here below, shows that the idea of the first logo I did is the one we went towards. This logo is in fact based on symbols of water and air, and was initially suggested by *Lucas Westin* :

Figure 2: Team's official logo

3 Timeline

In this section, we will briefly see the subjects I have been working on with respect to the stages in the project. You will thereby be able to know when the tasks, that will later be detailed, did take place during the first semester.

Here below, you have a timeline presenting the informations introduced above :

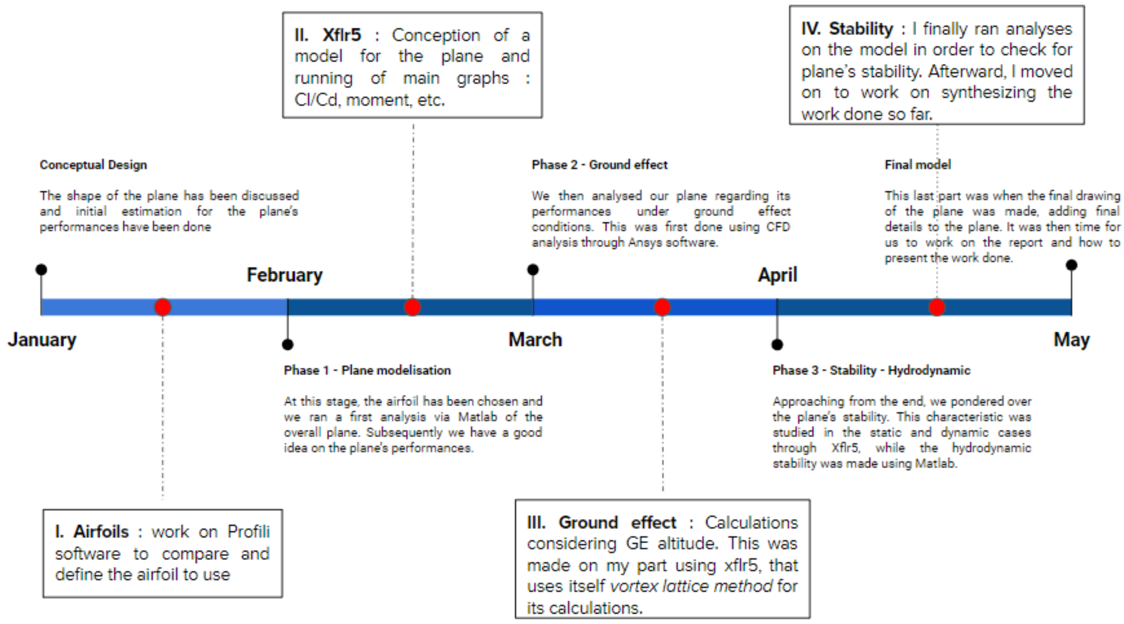

Figure 3: Timeline for aeronautical team main tasks

NOTE : each of the red points represent one of the works I've been working on and producing.

Now that the framework has been set, we will move into seeing in details what was done during each of the four above points.

4 Airfoil

4.1 Airfoil selection - *Profili*

The software used to do the airfoil selection was *Profili*. This software allows in fact to compare airfoils regarding criteria such that flight's Reynolds number and angle of attack. Moreover, it is based on calculations ran by *xfoil* software.

Thus, using *Profili*, the idea was to gather several similar airfoils to then compare them with respect to the above criteria.

Nevertheless, the software presents a set of airfoil that was to much to go through in an efficient way. It was indeed needed to run analyses for more than a hundred airfoils for the above criteria.
In order to structure the way of choosing our airfoil, I then established kind of a protocol.

Thereby, it was first decided to consider airfoils used in seaplane. As a matter of fact, I aimed in analysing foils presenting close characteristics of flight.

At this point, I had a list of potential airfoil showing consistency regarding ground-effect flight.

Subsequently, a feature on *Profili* provided me a list of airfoil. In fact, once I had the initial airfoils, this feature gave me a list of similar airfoils, based on criteria such as overall thickness (resemblance), lift performance, etc.

To conclude, I thereby reduced a process that was meant to last a long time to a more relevant way of defining the optimal airfoil. You can have a glance to some data obtained at this stage by looking to [6] [7] [8].

4.2 Airfoil optimization - *Xflr5*

Once I did the comparison between the airfoils, it has been decided by the aeronautical team that the airfoil K3311 was the optimal one.

However, at that time I began working on Xflr5 software (around February) and I learned that it was possible to reshape airfoils such that we optimize some aspect of the airfoil performances. I therefore decided to ponder over it and I deduced that a point that needed to be optimized was the airfoil's moment.

Indeed, the moment that appears in the graph [8] is in fact the pitching moment.

I rapidly saw that to get zero moment with the airfoil wasn't possible for the considered airfoil. I then decided to smooth the moment curve and thereby to have a pitching moment as constant as possible.

The idea here was to have a moment stable for a large range of AOA. In the end, this would allow us to work at angles of attack maximizing the lift over drag ratio, without looking to the moment.

To conclude, I made a reshape of the airfoil in order to simplify the choice of AOA, be reducing to the maximum the influence of pitching moment.

You can have a look to this part of my work regarding the figures [9] [10] [11].

5 3D model

In this section, we will take a look to the model of the plane that I did with the software *Xflr5*. You have already seen on the above graph for the airfoil optimization how graphs through this software look like, but we will now take a look to a 3D model.

On the graph here below, you have an isometric view of my numerical model :

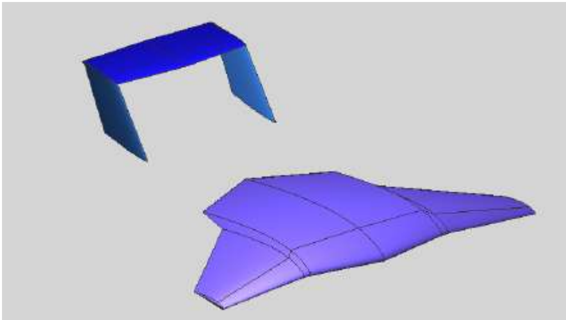

Figure 4: Model of the plane within Xflr5

To have done this model was a way for us to study the plane's performances like induced and viscous drag, lift force, pitching moment, etc, with respect to the angle of attack.

To summarize, it's a simplification of the plane made to run calculations as well on the basic performances such as lift over drag ratio, and performances like plane's stability.

6 Ground effect

Before looking at the stability aspect depicted above, we will go through the process of studying ground effect.

Indeed, an other aspect of Xflr5 software is its possibility to run calculations considering ground effect. This simply implies that we can work on our model by considering different altitude of flight. Nevertheless, the challenge was to afterwards demonstrate the relevance of this software when considering GE.

On the graph below I plotted some of the flight's characteristic depending on the altitude to show this effect of ground effect on the plane :

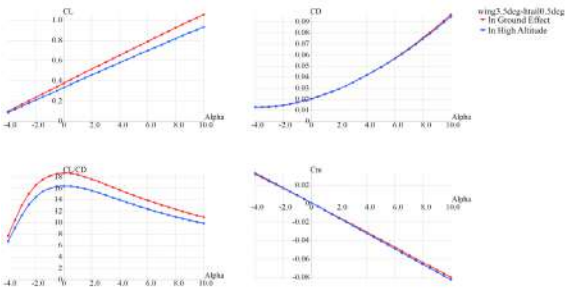

Figure 5: Study of ground effect on the plane's performances

NOTE : these results have been studied and obtained in collaboration with Ji-acqui Zhang.

It appears clear that the ground effect does improve the ratio lift over drag forces as expected.

Moreover, as mentioned, the idea was then to compare these results with the one of Jiacqui Zhang obtained with CFD using Ansys fluent. Indeed, CFD is a relevant and reliable way of studying the plane in flight conditions and to obtain a large set of characteristics out of it but it takes a lot of time.

On the contrary, with xflr5, the same calculations are made in a few seconds, providing equivalent and as reliable results (Xflr5 uses Vortex lattice method for numerical calculations). To finally decide if we were gonna use this software, I have been comparing the two models (from Xflr5 and CFD), and the results provided by each of them. The result, as you might know now is that Xflr5 software gave very close results from Ansys's results, and was within 5 % from CFD results.

To summarize, I have been creating a model close to the detailed one, simplifying the calculations regarding the plane. You can see plots associated to this section at [14] [15] [16].

We will now see how this model has provided informations regarding the plane stability.

7 Stability

To finish with the tasks we had, regarding either the aero group or me, we had to study stability. Regarding how efficient Xflr5 was at this stage, I decided that running the stability analysis with it was meaningful and in accordance with the work done that far. Thereby, using the same model, I have been working on way of optimizing again the plane natural stability and ways of studying it.

For the first point, the idea was to work more precisely on the horizontal tail at the back of the plane. The point here was to define the optimal angle for the horizontal tail such that we optimize the static margin. Through the optimization of the static margin, we have in fact the optimization of the longitudinal static stability.

This means that greater the static margin, better the stability. Nevertheless, it was necessary to also deal with other components such as speed. In the graphs [12] [13] we have an illustration of how are bounded speed, static margin and angle of the horizontal tail.

What we have to see here is that if we want to increase the static margin, we have to reduce the horizontal tail angle but thereby we increase the plane's speed. Yet, we have a speed limit around 17 $m.s^{-1}$ and so we have had to make compromises here. In the end, what is circled in orange is the angle for the horizontal tail that was deduced as optimal from graphs, and the associated cruise speed and static margin.

For what is up to studying the plane stability, there was also visual ways of doing it. Thus, there is a feature I've been studying and using and that consists into modeling different perturbation and then see the repercussions on the plane.

As mentioned, I mainly took a look to the longitudinal stability as the pitching moment was here the one potentially source of instabilities (as we ensured a symmetry for the two others axes).

8 Conclusion

To conclude on this report, it allowed me put my knowledge to contribution, while acquiring even more.

I have then been learning on a theoretical aspect as well as on a more analytical way. Moreover, to have been working with other people and keeping contact with the other sub-teams allowed me to have more hindsight on the work achieved and to learn from each field.

As a bachelor student, I already did a few project but it was still a very good way for me to put a big feet on the aeronautical field, and more specifically on plane analysis.

9 Graphs, table and figures

9.1 Airfoil selection - *Profili*

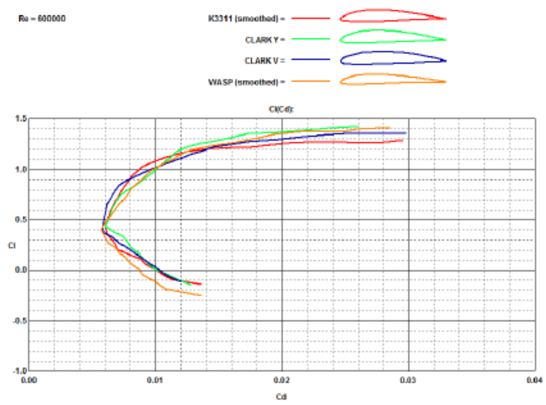

Figure 6: Lift over drag ratio comparison

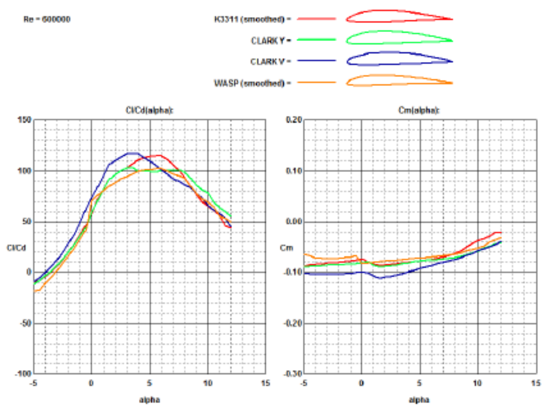

Figure 7: Airfoil's efficiency regarding C_l over C_d ratio and momentum with respect to the angle of attack α

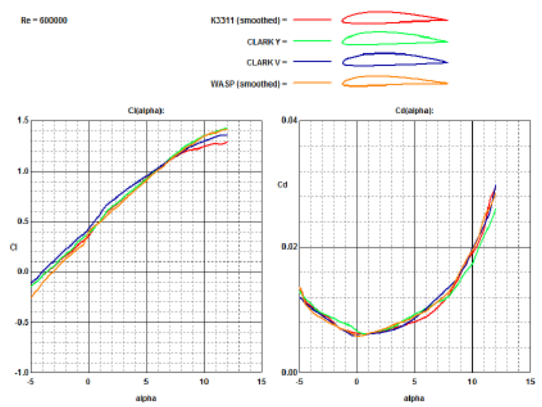

Figure 8: C_L and C_d with respect to the angle of attack α

9.2 *Airfoil optimization*

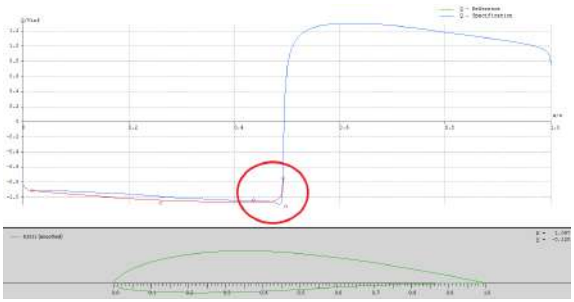

Figure 9: Speed over surface on the airfoil, before reshaping

What is circled in red in this graph is a discontinuity that presents the initial airfoil. As you will see on figure 11, this discontinuity appears as a jump in the moment.

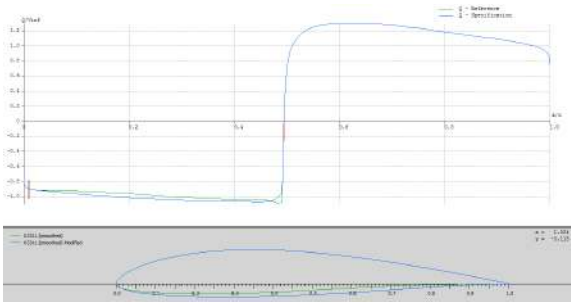

Figure 10: Speed over surface on the airfoil, after reshaping

We can see on this figure that to have reshaped the airfoil mainly added thickness to it.

Moreover, there is no discontinuity anymore.

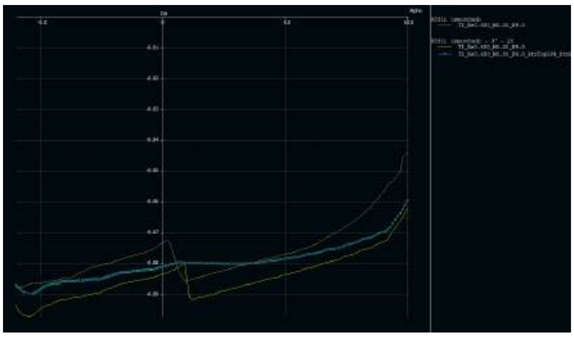

Figure 11: Graph of pitch moment for the airfoil before reshape, after reshape and when considering a flap at the nose

9.3 Stability

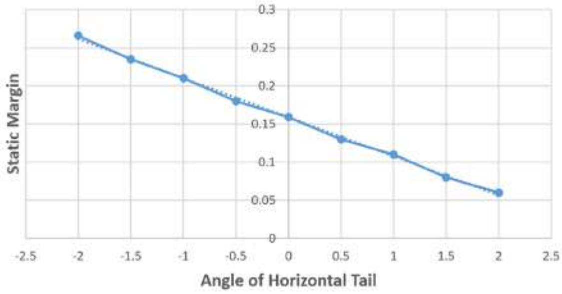

Figure 12: Static margin in the case of a study of horizontal tail

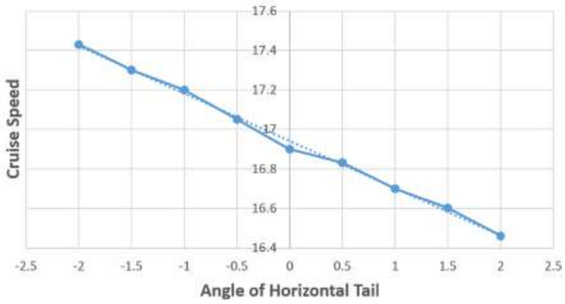

Figure 13: Cruise speed as a function of the horizontal tail angle

9.4 Xflr5 features

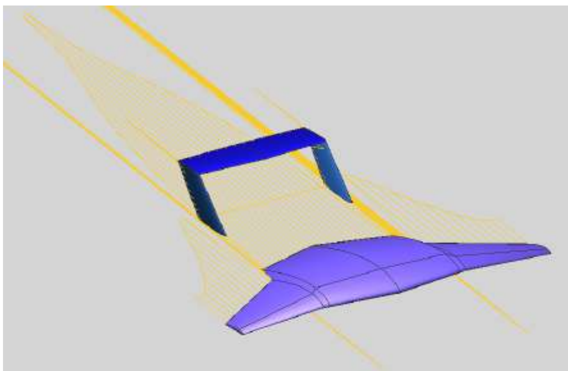

Figure 14: Drag force at $\alpha = 5°$

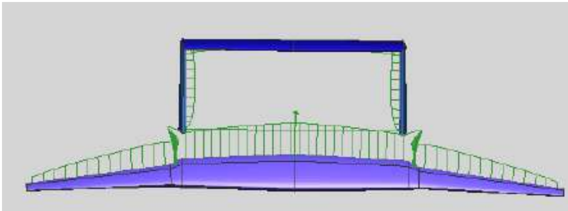

Figure 15: Lift force at $\alpha = 5°$

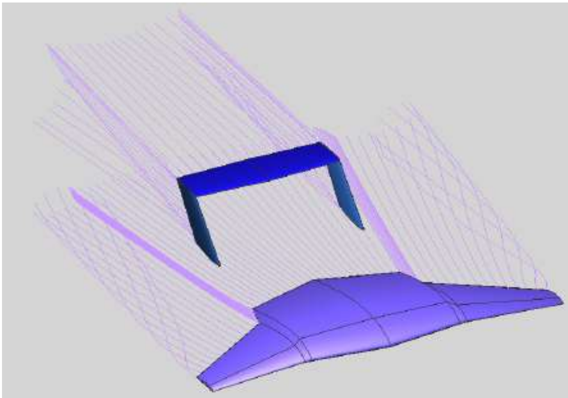

Figure 16: Streamlines at $\alpha = 5°$

NOTE : these figures give a visual idea of the forces acting on the plane during the flight. These plots also show that the model can present discontinuities at the cross sections.

References

[1] Martin Hepperle. Wing in ground proximity (*WIG*). Available : https://www.mh-aerotools.de/airfoils/jf_wig.htm, May-21-2018. [Accessed : Feb-15-2020].

[2] Tomasz Abramowski. Numerical investigation of airfoil in ground proximity. *JOURNAL OF THEORETICAL AND APPLIED MECHANICS*, 45:425–436, 2007. [Accessed : 20-March-2020].