SUBSTANCE

Research article
AEROSPACE

# Original Methods for Finding a Wing Shape Airfoil

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SUMMARY

> Abstract: In view of the future application of a morphing wing technology on the horizontal tail of the Cessna Citation X, the LARCASE team had to develop an accurate aerodynamic model of the horizontal tail. To this end, a geometry of the wing was required, especially its airfoil shape, which is strictly confidential. Using a reverse engineering method, the team managed to find an airfoil that delivered a performance close to the original one. Keywords: Airfoil, Morphing, Horizontal Tail, Optimization, Performance, Parameterization, Bezier-Parsec, Particle Swarm Algorithm, Aerodynamic, Cessna Citation X

# Introduction

Due to the increase in airplane traffic, the rate of atmospheric carbon dioxide and other pollutants is steadily rising. Added to this, airline companies wish to operate their aircraft in the most efficient way possible. With these two objectives in mind, the aeronautical industry is working on different methods and techniques to transform actual airplanes into aircraft that are more efficient in terms of fuel consumption, noise, range and pollution. This improvement encompasses different fields: aircraft structure, instrumentation and aerodynamic characteristics. Since our intention was to use a morphing wing technology to improve general performance [1-3], it is the last field that was of interest to us. The “Morphing Wing” technology consists in adapting the airfoil geometry in order to change and optimize aerodynamic features of the entire airplane for several flight conditions.

Figure 1- Cessna Citation X future morphing wing location

This study focused on applying the Morphing Wing technology on the horizontal tail of the Cessna Citation X. The purpose of the study consisted in equipping an aircraft with a morphing system for the horizontal tail, and comparing performance variations (speed, consumption and range) between the original aircraft and the modified aircraft.

However, this study would have been too expensive to be performed on an actual aircraft, so a model able to reproduce the Cessna Citation X behavior during flight was required. From a level D flight simulator (RAFS), which provides which provides a 5% deviation in accuracy compared to the actual aircraft, an accurate model was designed and validated in previous studies [4-9]. Consequently, this model could simulate the behavior of the future morphed aircraft. For that, original data would be changed by aerodynamic data that correspond to the new aircraft designed. Because the morphing imagined is focused on the horizontal tail, it could be interesting to design an aerodynamic model of the horizontal tail in such a way that for a given geometry, the model could compute corresponding aerodynamic coefficients [10].

# Methodology

To design this model, some data was available, such as horizontal tail aerodynamic coefficients ($C_{L\,\text{ref}}$ and $C_{D\,\text{ref}}$), according to a combination of several flight conditions (Mach and Angle of Attack AoA), and the 2D geometry of the horizontal tail (span, root and tip chord). But the airfoil shape remained unknown. For this reason, the first step was to find the airfoil shape of the horizontal tail (Fig. 2).

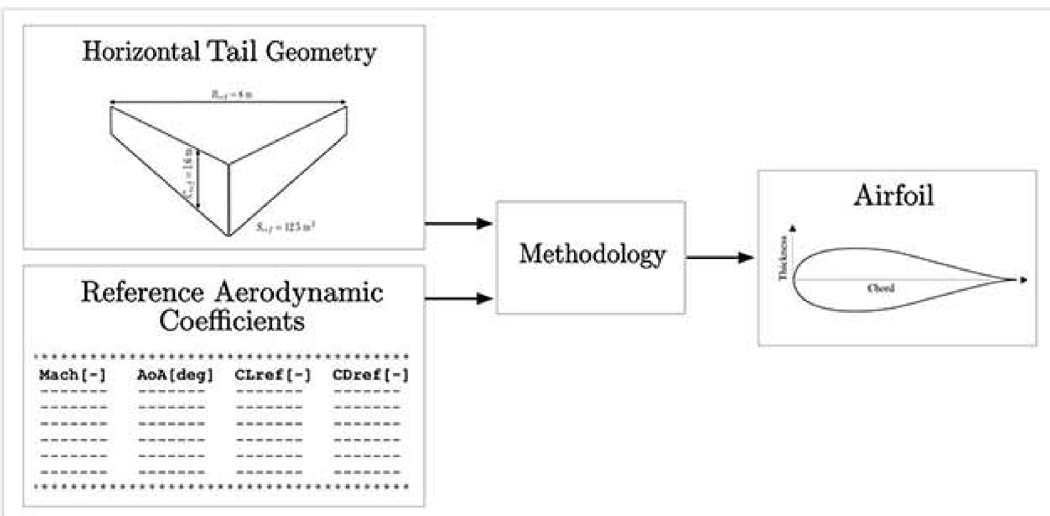



Fig. 2 Inputs and outputs in relation of our methodology

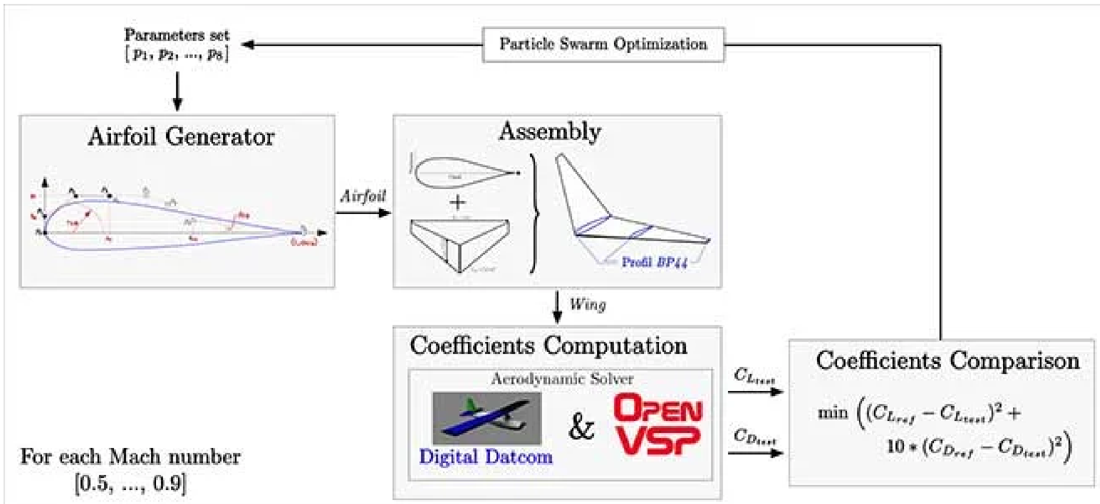



Figure 3- Reverse methodology used to find the airfoil shape from its 3D aerodynamic coefficients

To find the airfoil shape, the methodology used is summed up in Fig. 3. First, an airfoil generator allowed to create an infinity of airfoils using parameterized curves. This airfoil generator was based on Bezier-Parsec methods that allow to create an airfoil shape using several control points, as shown in figure 4 [11]. Then, a combination of a wing with the same dimensions as the horizontal tail, and an airfoil was designed. Finally, lift and drag coefficients of this new wing were estimated ($C_{L\,\text{test}}$ and $C_{D\text{test}}$) using an aerodynamic solver (Digital Datcom and OpenVSP). The last step consisted in comparing reference and testing aerodynamic coefficients.

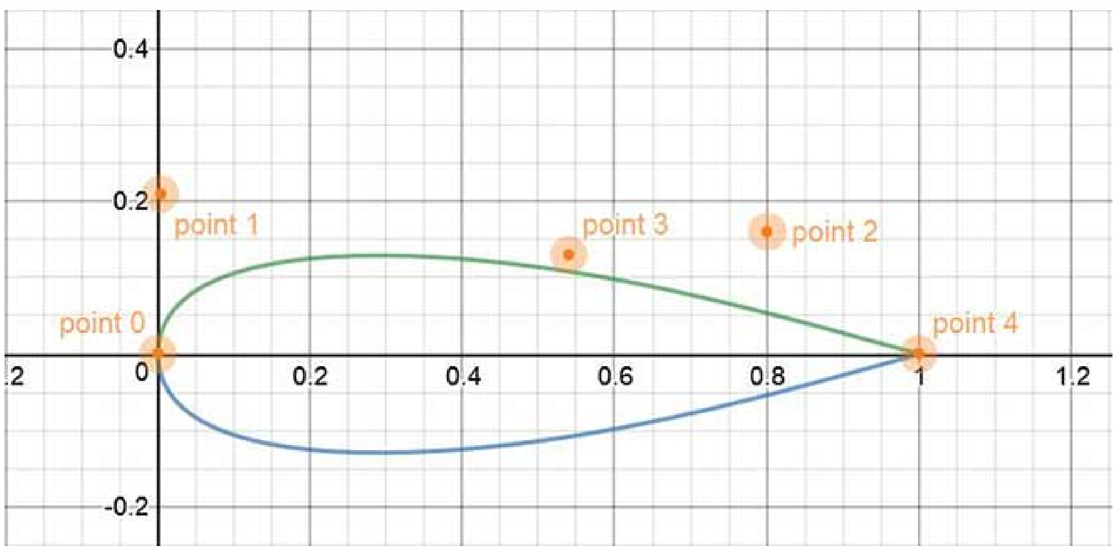



Figure 4- Airfoil designed with 5 points of the Bezier-Parsec method

The key of the comparison resided in minimizing an error that represents the gap between aerodynamic coefficients of the designed horizontal tail and those of the flight simulator, our reference, for each Mach number. This minimization was achieved through an optimization algorithm called Particle Swarm Optimization (PSO), which is in charge of managing a set of parameters to design a new airfoil. This process was done at each loop (Fig. 3) until PSO found a set of parameters that corresponded to the airfoil that had the characteristics closest to the target airfoil ($C_{L\,\text{ref}}$ close to $C_{L\,\text{test}}$ and $C_{D\text{ref}}$ close to $C_{D\text{test}}$).

# Results

Concerning the identification of the horizontal tail, the study was conducted for several Mach numbers, from 0.5 to 0.9. Figure 5 represents the average shape of airfoils found for each Mach number. Figure 6 shows the final comparison between reference and test coefficients. It is possible to see that, for a Mach number equal to 0.5, 0.6 and 0.7, results are very satisfying. In fact, the aerodynamic polar of the flight simulator and the polar of the model are almost similar. However, Mach 0.8 and 0.9 present more deviations, mainly for Mach 0.9, but these results are still acceptable.

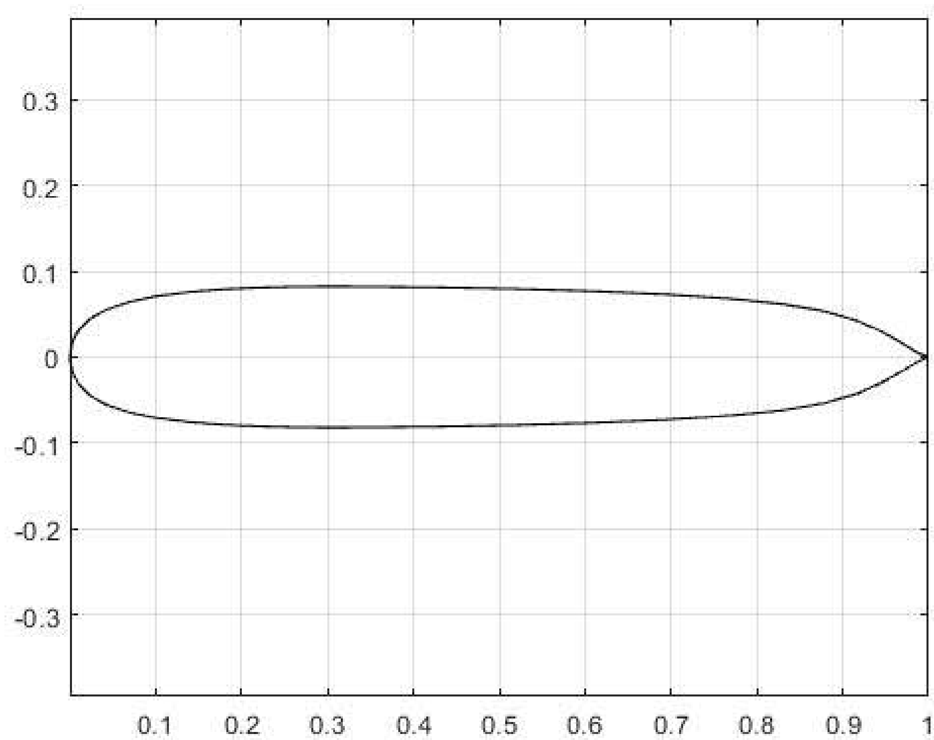
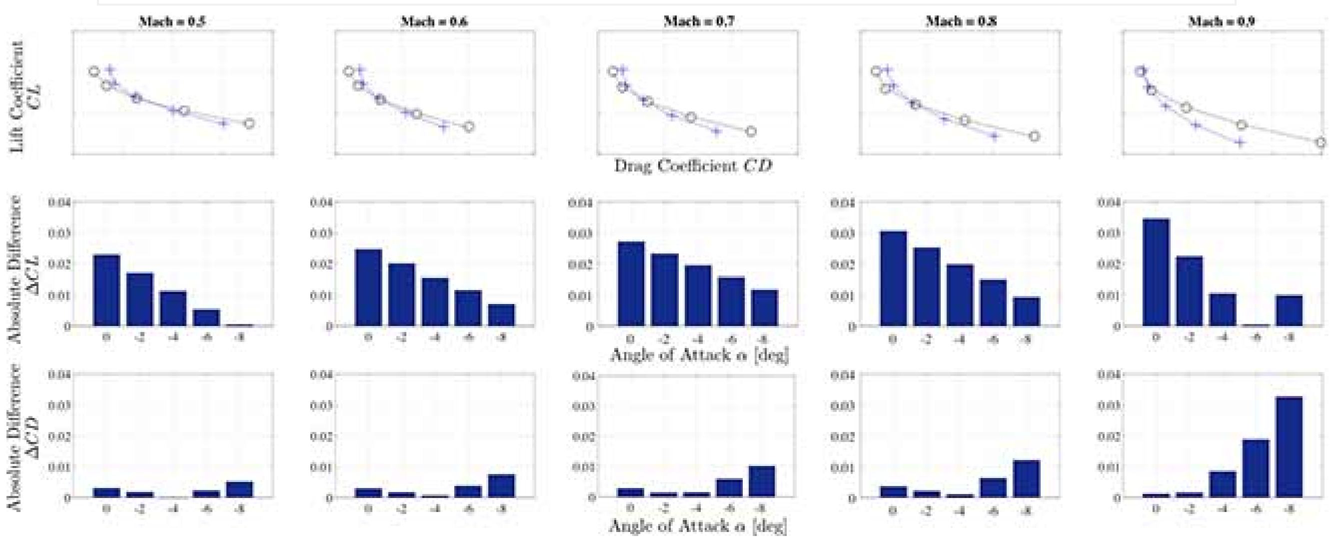



Figure 5-Identified airfoil of the original Cessna Citation X



# For more information

This work was presented in "*Design and Validation of an Aerodynamic Model of the Cessna Citation X Horizontal Stabilizer using both OpenVSP and Digital Datcom*", at the International Conference on Engineering Education and Research, 2018.

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