

A Strategy for Airfoils Selection in the Design of Customized Aircraft Models for Flight Simulation Testing

Fernando Duarte López.
UMI-LAFMIA
CINVESTAV
Mexico City, Mexico
fernando.duarte@cinvestav.mx

Juan M. Bustamante
UMI-LAFMIA
CINVESTAV
Mexico City, Mexico
juan.bustamantea@cinvestav.mx

José L. Sánchez
UMI-LAFMIA
CINVESTAV
Mexico City, Mexico
jose.sanchezm@cinvestav.mx

Luis H. Manjarrez
UMI-LAFMIA
CINVESTAV-UTC
Mexico City, Mexico
luis.manjarrez@cinvestav.mx

Filiberto Muñoz Palacios
UMI-LAFMIA
CONACYT-CINVESTAV
Mexico City, Mexico
filiberto.munoz@cinvestav.mx

Eduardo S. Espinoza
UMI-LAFMIA
CONACYT-CINVESTAV
Mexico City, Mexico
eduardo.espinoza@cinvestav.mx

Abstract—One of the pivotal aspects in aircraft design and manufacturing is the definition of airfoils. This activity can be addressed with software such as Plane Maker and Airfoil Maker, two applications bundled with the X-Plane flight simulator, which allows the design of airfoils or use of predefined ones to build aircraft lifting elements. However, such airfoils can only be selected from a folder included with X-Plane, where, as stated, either default or custom airfoils designed with Airfoil Maker can be found. The design of airfoils using this program is done based on their desired aerodynamic characteristics, which is a tedious and time consuming task if they are meant to be designed for the whole range of angles of attack. For this reason, designers prefer using the provided default airfoils in a preliminary design, but choosing them arbitrary is far from a correct decision due to the variation in the aerodynamic performance. In this article we present a strategy for selecting suitable default airfoils to build the aircraft lifting elements in Plane Maker such that their aerodynamic performance is not considerably affected. The proposed strategy consist on conducting a geometric comparison between software-provided default airfoils and user-defined airfoils in order to select the ones with the best aerodynamic performance for a specific aircraft. To validate the effectiveness of the proposed strategy, we used the XFLR5 software to compare the aerodynamic behavior of same-shape wings generated by similar airfoils in a fixed wing Unmanned Aerial Vehicle.

Index Terms—Airfoil, X-Plane, Plane Maker, Mean Square Error (MSE), Computational Fluid Dynamics (CFD), XFLR5.

I. INTRODUCTION

The design and validation of aerial vehicles have been an object of study of great interest during the last decades given their multiple applications [1], [2]. Two of the most important areas of study are the design and selection of airfoils. The process of airfoil design has already been addressed with

methodologies like those presented in [3], [4]. Similarly, the process of airfoil selection has been studied for various applications [5], [6], [7] and more recently, for the case of UAVs, a similar technique has been developed [8].

On the other hand, X-Plane is a state-of-the-art flight simulator [9] that allows, among other actions, to simulate the flight of an own-designed aircraft. The simulations can be run in manual or autonomous mode and the designs are geometrically built in Plane Maker. Plane Maker is a program bundled with X-Plane that lets users design their own aircraft [10], where, among other things, airfoils can be selected for its usage in the generation of lifting elements such as wings, stabilizers, and even propeller blades.

The design of the aircraft lifting elements can be divided in two cases, in the first case the lifting elements of aerial vehicles are designed based on existing airfoils whose aerodynamic characteristics have already been previously defined for almost the entire range of angles of attack; conversely, in the second case, the lifting elements are designed with custom airfoils and therefore, the aerodynamic characteristics of such have not yet been fully defined.

In the first case, in order to model an aircraft in Plane Maker, one can choose airfoils files predefined in the “X-Plane/Airfoils” folder included in the X-Plane flight simulator installation package to define the root and tip of the lifting elements. However, the available airfoils in this folder are limited to only 28 different airfoils, and the possibility to do not find the desired ones is huge. In the second case, the custom airfoils to be used must be generated in a file format compatible with the program, such as those found in the folder.

Thus, airfoils can be generated in Airfoil Maker, another program bundled with the X-Plane flight simulator. The problem with this is that this program does not allow defining airfoils with coordinates based on their geometry, but only allows it through an inverse methodology; i.e. taking into account its aerodynamic characteristics, similar as in [11]. Now, the airfoils available in the folder bundled with X-Plane have the extension AFL [12] where, in addition to other aerodynamic parameters, their lift, drag and moment coefficients are read for each angle of attack with steps of 1 degree for angles from -180 to -21 and 21 to 180 degrees and steps of 0.1 degrees for angles from -20 to 20. Not only that, but that format loops in the same file for up to four instances of Reynolds numbers for some airfoils; Fig. 1 shows this description. Therefore, the airfoils desired to be generated must share this same structure.

	alpha	cl	cd	cm	
Data for a certain Reynolds number	-180.0	0.14000	0.05640	0.03500	
	-179.0	0.19712	0.07873	0.04962	
	-178.0	0.25424	0.10104	0.06440	
		...			
	-21.0	0.02189	0.20636	0.05814	
	-20.0	0.10000	0.17721	0.05000	
	-19.9	0.07769	0.17439	0.04900	
	-19.8	0.05556	0.17158	0.04800	
		...			
		19.8	0.44444	0.18417	-0.07250
Data for another Reynolds number	19.9	0.42231	0.18705	-0.07375	
	20.0	0.40000	0.18996	-0.07500	
	21.0	0.44672	0.21985	-0.08896	
		...			
	178.0	0.02576	0.10104	0.00555	
	179.0	0.08288	0.07873	0.02037	
	180.0	0.14000	0.05640	0.03500	
		...			
		Another -180° to 180° loop of the aerodynamic coefficients			

Fig. 1: Partial visual description of the the airfoil AFL file.

However, collecting this information is not easy, because free CFD software does not always specify the airfoil aerodynamic coefficients for all angles of attack established by the user. This occurs due to the divergence that can occur during numerical solution processes for any given value due to multiple factors, such as poor meshing, among others [13], [14]. Ensuring convergence in a CFD software entails carefully reviewing and configuring many other aspects of it that may not be worth it for purposes of carrying out flight simulations. So, for both occasions mentioned, the question arises as to whether it is possible to select airfoils from the airfoils folder bundled with X-Plane to be used in the building of lifting elements in Plane Maker such that, after selecting their root and tip airfoils, their aerodynamic performance not differ much from the performance of the actual lift elements generated by the originally desired root and tip airfoils. Therefore, in this article a solution for this question will be proposed under a scheme of synergistic comparison between airfoils based on their geometry and aerodynamic performance.

The main contributions of this work are summarized as follows:

- The development of a methodology to select the airfoils to be used in the building of aircraft in Plane Maker

TABLE I: Default airfoils files bundled with X-Plane 11.

1	Boeing Mid (high subsonic)	15	NACA 64-208 (supersonic)
2	Boeing Root (high subsonic)	16	NACA 65(216)-415 (lam flow)
3	Boeing Tip (high subsonic)	17	NACA 65-006 (supersonic)
4	Clark-Y (good propeller)	18	NACA 2412 (popular) cuffed
5	e63	19	NACA 2412 (popular) invert
6	Flat Plate (very thin)	20	NACA 2412 (popular)
7	NACA 0006 (symmetrical)	21	NACA 23010
8	NACA 0009 (symmetrical)	22	NACA 23012 (low-moment)
9	NACA 0012 (symmetrical)	23	NACA 23016
10	NACA 16 (good propeller)	24	NASA LS(1)-0417 (hi-lift)
11	NACA 0024 (symmetrical)	25	NASA LS(1)-0417 inverted
12	NACA 0030 (symmetrical)	26	NASA LS(1)-0421 (hi-lift)
13	NACA 63-015 (Helo Rotor)	27	NLF(1)-0215F (laminar flow)
14	NACA 63-209 (supersonic)	28	round strut

without affecting their aerodynamic performance during a flight simulation in X-Plane.

- This methodology avoids to the designers the generation of new custom airfoils files in the Airfoil Maker program, while gives a quick solution for the selection of the default airfoils from the airfoils folder bundled with X-Plane by choosing those closest in functionality to the originally desired airfoils.
- We established a way in which a geometric and aerodynamic comparison between airfoils can be made. This is useful for reverse engineering purposes, such as knowing the probable airfoils with which an aircraft was designed.

The remaining of this paper is organized as follows. Section II describes an algorithm to establish a geometric comparison between airfoils. Section III presents the results for the geometric comparison between two sample custom airfoils with those within the airfoils folder. Section IV indicates what it is necessary for the aerodynamic analysis. Section V presents the verification comparison of the aerodynamic performance of a wing generated by the custom and selected airfoils. Finally, in Section VI we present a discussion of our research work.

II. PREPARATIONS FOR GEOMETRIC COMPARISON

Plane Maker only allows the selection of the root and tip airfoils for the building of the lifting elements. Assuming that the root and tip airfoils chosen for the design of the wings of a certain aerial vehicle are not present in the airfoils folder bundled with X-Plane, whose content is shown in Table I, it is proposed to compare these airfoils with those from the folder in order to select from the latter the ones that have greater geometric similarity. We followed the next methodology:

- 1) To speed up the process, we discarded the airfoils that are not related to the aircraft purpose; e. g. our vehicle's flight mission is not set to supersonic flight, then we remove those with the (supersonic) tag in their filename.
- 2) We collected the .txt files that describe the coordinates of the non-discarded airfoils. Most of them founded at <http://airfoiltools.com>.
- 3) We applied the airfoil's geometric comparison algorithm between the root and tip airfoils of the real vehicle and the airfoils within the airfoils folder. This algorithm will be briefly explained below in this section.

4) Finally, we selected the airfoils from the folder with the least geometric error compared to actual root and tip airfoils; for this, we took into account the Mean Squared Error measurement.

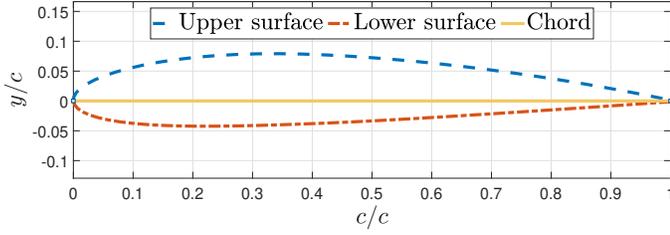


Fig. 2: Visual description of the upper- and lower surface curves and chord of a normalized airfoil. The axes are dimensionless, hence the ratios c/c and y/c , where c is the length of the chord and y the images. In the rest of the graphs these axes labels will not be presented in order to save space.

A. Mean Square Error (MSE) & airfoil coordinate files

The MSE is a simple mathematical technique for numerical comparison between two vectors of the same dimension, whose popularity lies in the large number of applications for which it serves, such as statistical estimation and prediction [15], signal comparison [16], etc.

This technique is verified by the following structure:

$$\text{MSE}(X, Y) = \frac{1}{n} \sum_{i=1}^n (X_i - Y_i)^2; \quad \text{with } i \in \{1, 2, \dots, n\}$$

where n is the dimension of the vectors X or Y .

On the other hand, the .txt files of coordinates that geometrically describe the airfoils present, in general, the following characteristics: (1) They are normalized versions, this means that the coordinates are scaled so that the chord is defined between 0 and 1, see Fig. 2. (2) They are made up of two columns, where the first stands for the values of the x -axis and the second for their images in the y -axis; therefore, the first corresponds to the chord and the second to the upper and lower surface curves. (3) The x -axis values start from 1 and move backwards with non-homogenized jumps to 0 (or nearly 0), to then reverse their direction and go again with non-homogenized jumps to 1; where the first cycle forms the vector whose images in y generate the upper surface and the second the vector that generates the lower surface, these two vectors are not necessarily of the same dimension. See Fig. 3.

B. Airfoil's geometric comparison technique

The following technique is proposed to carry out the geometric comparison between two airfoils, which consists of obtaining the MSE between the upper surface curves of both airfoils, then for the lower surface curves. Finally, the MSE of the airfoils is obtained by the mean value of both previous results. This is,

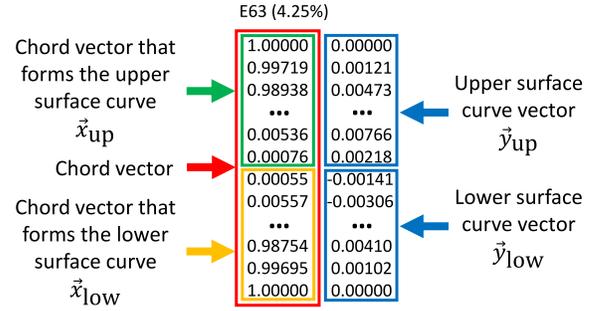


Fig. 3: Example of an airfoil coordinates .txt file.

$$\text{MSE}_{\text{airfoils}} = \frac{\text{MSE}_{\text{upper surface}} + \text{MSE}_{\text{lower surface}}}{2}$$

To obtain the MSE, the vectors of the upper surface curves of both airfoils must coincide in dimension and in their position with respect to the x -axis; the same for the vectors of the lower surface curves.

In the following, only the case of the upper surface will be taken to exemplify this in more detail, since the process is analogous for the lower surface.

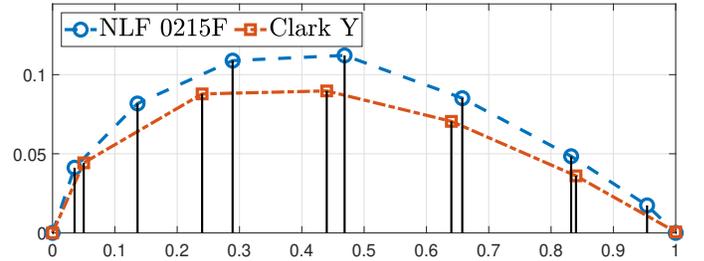


Fig. 4: Example of two upper surface curves from two distinct normalized airfoils. Not all the airfoils coordinates are considered for visualization purposes.

If we have two upper surface curves from two different airfoils formed by the images of two normalized chord vectors of different dimensions and we superimpose them in the XY plane, they would look like in Fig. 4. Where it can be seen that both upper surface curve vectors do have different dimensions, the one for the NLF 0215F airfoil having dimension 9 and the one for Clark Y having dimension 7; it is also evident from the vertical black lines that the projected positions of the coordinates of both curves on the x -axis are not coincident. Remembering that they must be so that the MSE technique between them can be applied.

To solve the problems of the non-coincidence between the dimensions and the non-coincidence in the positions of the coordinates of both curves with respect to the x -axis, a vertical projection of the coordinates of the curve with the largest dimension S_M is made on the curve with the smallest dimension S_m , as seen in Fig. 5 (where S_M would correspond to the NLF 0215F upper surface and S_m to the one of Clark Y). This is

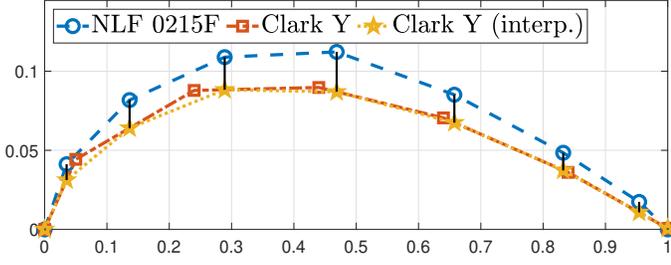


Fig. 5: The same upper surface curves of the Fig. 4 but coincident with respect to their dimension and position projected on the x -axis by interpolation.

done iteratively for each of the coordinates $(x_i, y_i) \in S_M$ when taking the value x_i and obtain its corresponding new image \tilde{y}_i over the line whose domain contains x_i generated by the coordinates $(x_j, y_j), (x_{j+1}, y_{j+1}) \in S_m$.

This can also be simply understood as the execution of linear interpolations between the coordinates of the curve S_m taking the values $x_i \in S_M$ as reference.

Note: If both curves dimension is equal, this interpolation process must also be carried out in order to make the coordinates of both curves coincide with respect to the x -axis; the process is the same, with the difference that either of the two curves can be taken as the S_M .

\vec{x}_{up}	\vec{y}_{up}	\vec{x}_{low}	\vec{y}_{low}
0	0	0	0
0.00055	-0.00141	0.00557	-0.00306
0.00076	0.00218	0.01651	-0.00330
0.00536	0.00766	0.03316	-0.00227
...			
0.97751	0.00986	0.99695	0.00102
0.98938	0.00473	1	0
0.99719	0.00121		
1	0		

Fig. 6: Example of the structure of the comma-separated file required by the Algorithm 1 for the execution of the airfoil's geometric comparison technique. The up and low suffixes refer to the upper surface and lower surface, respectively.

The Algorithm 1 shows the technique described above that can be applied between two airfoils to compare them geometrically using the MSE criterion. The present algorithm can be executed as long as the vectors of a) the chord that forms the upper surface, b) the upper surface, c) the chord that forms the lower surface, and d) the lower surface are organized in that order in four columns in a file separated by commas; this structure is shown in Fig. 6. The rows' number that defines the upper surface coordinates does not necessarily have to match that which define the coordinates of the lower surface.

III. GEOMETRIC COMPARISON RESULTS

A pair of custom airfoils intended to serve as the root and tip airfoils of a wing, shown both with blue striped lines in Fig. 7,

Algorithm 1 Airfoil geometric comparison technique

- 1: Read from the file separated by commas with the structure of Fig. 6 the vectors $\vec{x}_{up}, \vec{y}_{up}, \vec{x}_{low}, \vec{y}_{low}$ of the 1st airfoil.
- 2: Repeat step 1 but for the 2nd airfoil.
- 3: **if** $\dim(\vec{x}_{up_{2nd}}) > \dim(\vec{x}_{up_{1st}})$ **then**
- 4: Linearly interpolate on $S_{m_{up}}$ with the $\vec{x}_{up_{2nd}}$ values.
- 5: Replace the vector $\vec{y}_{up_{1st}}$ for the new one interpolated.
- 6: **else**
- 7: Linearly interpolate on $S_{m_{up}}$ with the $\vec{x}_{up_{1st}}$ values.
- 8: Replace the vector $\vec{y}_{up_{2nd}}$ for the new one interpolated.
- 9: **end if**
- 10: Compute the MSE with the $\vec{y}_{up_{1st}}$ and $\vec{y}_{up_{2nd}}$ vectors.
- 11: Save the result as MSE_{up} .
- 12: Repeat steps 3 to 11 but for the lower surface of both airfoils. ▷ Now use the vectors with the low suffix.
- 13: Compute $MSE_{airfoils} = (MSE_{up} + MSE_{low})/2$

were compared geometrically using the previous explained technique. Table II lists in descendent order the mean square errors between the airfoils in question and a selection of 8 airfoils from the airfoils folder bundled with X-Plane. The comparison goal is to find the folder airfoil that results in the minimum MSE for both the root and tip custom airfoils.

TABLE II: Results of MSE geometric comparison between root and tip custom airfoils and the 8 airfoils selection.

	Airfoil	MSE
Vs. Root custom airfoil	e63	133×10^{-5}
	NACA 63-015 (Helo Rotor)	55×10^{-5}
	NASA LS(1)-0421 (hi-lift)	50×10^{-5}
	NACA 23012 (low-moment)	25×10^{-5}
	NACA 2412 (popular)	17×10^{-5}
	NASA LS(1)-0417 (hi-lift)	16×10^{-5}
	NLF(1)-0215F (laminar flow)	12×10^{-5}
	Clark-Y (good propeller)	11×10^{-5}
Vs. Tip custom airfoil	NASA LS(1)-0421 (hi-lift)	119×10^{-5}
	e63	78×10^{-5}
	NACA 63-015 (Helo Rotor)	51×10^{-5}
	NASA LS(1)-0417 (hi-lift)	50×10^{-5}
	NLF(1)-0215F (laminar flow)	35×10^{-5}
	NACA 23012 (low-moment)	11×10^{-5}
	Clark-Y (good propeller)	8×10^{-5}
	NACA 2412 (popular)	5×10^{-5}

As can be seen in red color in Table II, the closest geometrically speaking airfoils to the custom root and tip airfoils are the Clark Y and the NACA 2412, respectively. These airfoils can also be seen in red in Fig. 7, being the most opaque those mentioned.

In Section IV it is verified that the wing aerodynamic behavior formed by the original airfoils is similar to that formed by the two selected airfoils by the airfoil's geometric comparison technique and, thus, determine that such airfoils can be used in the building of the wing in Plane Maker with the certainty that the aerodynamic performance of the aircraft in flight within the X-Plane flight simulator will not differ much from the performance it would have in reality, where it would be built with the real airfoils.

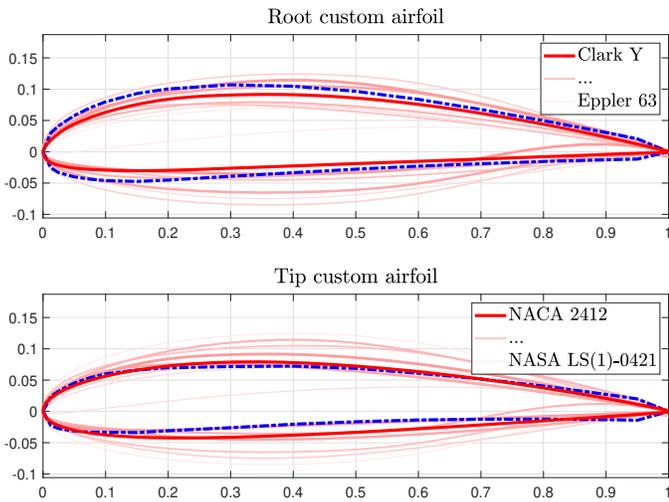


Fig. 7: Geometric comparison of the root and tip custom airfoils (blue striped lines) with the folder airfoils showed in Table II. The level of opacity is the level of similarity. See in color for a better appreciation.

IV. PREPARATIONS FOR THE AERODYNAMIC ANALYSIS

XFLR5 is a computational fluid dynamics software that allows the execution of two-dimensional and three-dimensional aerodynamic analyzes of wings; being able to be carried out in an isolated manner, that is, without considering the aerodynamic interferences with other elements of the aircraft [17]. For our particular case, we will employ it to contrast the aerodynamic performance of a wing generated by the root and tip custom airfoils of Fig. 7 against the aerodynamic performance of a wing generated by the selected airfoils with less geometric error respect to the first ones.

To carry out this contrast we do the listed below:

- 1) First of all, we calculate the Reynolds number for which our hypothetical aircraft operates. This value was taken as the mean of a Reynolds number operating range. For the length reference needed in the calculation, we choose the chord of the airfoil midway between the root and tip custom airfoils. This can be observed in Table IV.
- 2) In this range and for the same interval of angles of attack, α , we carried out a 2D CDF analysis for each one of the airfoils.
- 3) We define an aircraft with a wing as its only element using the custom root and tip airfoils to generate it. Then we do the same, but with the airfoils with the lowest geometric error found. As depicted in Fig. 8.
- 4) We defined an analysis, establishing the free stream speed with the average velocity at which the vehicle is intended to travel during cruise. Assuming a flying speed of 22 m/s.
- 5) Finally, we run the 3D analysis for the same range of angles of attack defined in the 2D analysis for each wing and observed the graphical comparison of the both wings' aerodynamic performances.

TABLE III: Reynolds number calculation to be used for the 2D CFD analysis of all airfoils. Value seen in red.

Magnitude	Variable	Value	Unit
Cruise speed	v	22	m/s
Root custom airfoil chord	c_1	0.3	m
Tip custom airfoil chord	c_2	0.25	m
Interpolated medium airfoil chord	$c = \frac{c_1 + c_2}{2}$	0.275	m
Kinematic viscosity	ν	1.5×10^{-5}	m^2/s
Reynolds number	$\text{Re} = \frac{vc}{\nu}$	4.03×10^5	-

V. AERODYNAMIC COMPARISON RESULTS

In this section, the results of the aerodynamic contrast that we got between the two hypothetical wings with the same shape but slightly different aerodynamic twist given by the usage of two distinct pairs of root and tip airfoils will be presented.

Fig. 9 shows the performance of the wings for the main aerodynamic coefficients, shown in Fig. 1. The error between the curves is defined by:

$$\text{Error} = \frac{1}{n} \sum_{i=1}^n \frac{|X_i - Y_i|}{|\max(X) - \min(X)|}$$

where X corresponds to the aerodynamic curves of the wing formed by the custom airfoils and Y to those of that formed by the selected airfoils from the folder. The min. and max. values are considered as a range from 0 to 100%. Then, a 0 error occurs when the two curves coincide and a 100% error occurs when they are separated by told range.

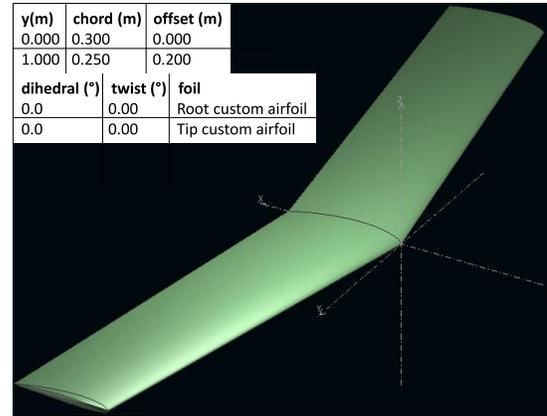


Fig. 8: Wing formed in XFLR5 for 3D CFD analysis with the custom root and tip airfoils, whose formation specifications are clarified in the software format. With that same shape, another wing is generated with the root and tip airfoils selected from the folder: Clark Y for root and NACA 2412 for tip.

TABLE IV: Summary of the wings comparison of Fig. 9.

Aerodynamic graph	Percentage error
Wing lift coefficient vs angle of attack	4.4%
Wing lift coefficient vs angle of attack	8.4%
Wing moment coefficient vs angle of attack	6.5%

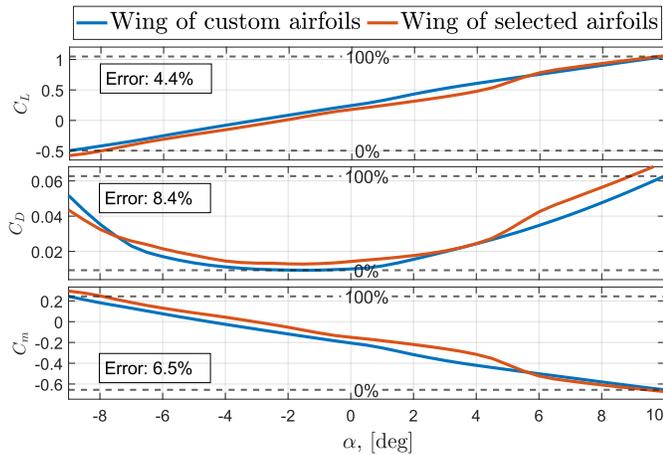


Fig. 9: Wing lift-drag-moment coefficient vs angle of attack.

VI. DISCUSSION

As we can see from the CFD analysis results, the aerodynamic performance of two same-shaped wings with similar aerodynamic twist, given the geometric similarity between their root and tip airfoils, turned out to be quite similar. Such asseveration is verified from the aerodynamic coefficients graphs where it is possible to see that a maximum error smaller than 8.4% was obtained. In this sense, we can summarize the obtained results as follows: in i) the wing lift coefficient vs angle of attack graph, it is observed for the curves of both wings that their slope is practically the same and their y-intercept is very close to each other, which give us a 4.4% error between each graph; ii) the curves of the wing drag coefficient vs angle of attack present the greatest difference between them but not very significant, an 8.4% error, with most of this error occurring in the region starting from an angle of attack of 5 degrees, this is compensated with the decrease of the error of the other coefficients in that same region; iii) for the wing moment coefficient vs angle of attack graph, we observed the same similarities as in i) with just an additional error of 2.1%.

Therefore, we can see that when using Plane Maker to build aircraft wings, selection of airfoils from the provided airfoils folder for the root and tip airfoils in replacement of the designer-defined root and tip airfoils is suitable after the implementation of the proposed geometric comparison technique, since the aerodynamic performance of the aircraft under this change within the flight simulator will not be far from a real flight performance.

REFERENCES

- [1] P. Radoglou-Grammatikis et al. “A Compilation of UAV Applications for Precision Agriculture”. In: *Computer Networks* (2020). DOI: [10.1016/j.comnet.2020.107148](https://doi.org/10.1016/j.comnet.2020.107148).
- [2] A. Birk et al. “Safety, Security, and Rescue Missions with an Unmanned Aerial Vehicle (UAV)”. In: *Journal of Intelligent & Robotic Systems* 64.1 (2011), pp. 57–76. DOI: [10.1007/s10846-011-9546-8](https://doi.org/10.1007/s10846-011-9546-8).

- [3] M. Drela. “Elements of Airfoil Design Methodology”. In: American Institute of Aeronautics and Astronautics, 1990. Chap. 6, pp. 167–189. ISBN: 978-0-930403-69-0. DOI: [10.2514/5.9781600865985.0167.0189](https://doi.org/10.2514/5.9781600865985.0167.0189).
- [4] M. S. Selig and J. J. Guglielmo. “High-Lift Low Reynolds Number Airfoil Design”. In: *Journal of Aircraft* 34.1 (1997), pp. 72–79. DOI: [10.2514/2.2137](https://doi.org/10.2514/2.2137).
- [5] H. Z. Graham et al. “Airfoil Selection for a Straight Bladed Circulation Controlled Vertical Axis Wind Turbine”. In: *ASME 2009 3rd International Conference on Energy Sustainability* 1 (2009). DOI: [10.1115/es2009-90343](https://doi.org/10.1115/es2009-90343).
- [6] Y. Ma et al. “New insights into airfoil sail selection for sail-assisted vessel with computational fluid dynamics simulation”. In: *Advances in Mechanical Engineering* 10.4 (2018), pp. 1–12. DOI: [10.1177/1687814018771254](https://doi.org/10.1177/1687814018771254).
- [7] B. M. Kanya and K. D. Visser. “The Impact of Airfoil Selection on the Design of Small Horizontal Axis Wind Turbines”. In: *48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition* (2010). DOI: [10.2514/6.2010-1583](https://doi.org/10.2514/6.2010-1583).
- [8] N. K. Hieu and H. T. Loc. “Selection for Fixed Wing of Small Unmanned Aerial Vehicles”. In: *Lecture Notes in Electrical Engineering* (2016), pp. 881–890. DOI: [10.1007/978-3-319-27247-4_73](https://doi.org/10.1007/978-3-319-27247-4_73).
- [9] PC Gamer. “Most realistic flight simulator”. URL: <https://www.x-plane.com/>. (accessed: 30.06.2022).
- [10] *Plane Maker Manual*. URL: <https://developer.x-plane.com/manuals/planemaker/#introductiontoplanemaker>. (last updated: 16.08.2021).
- [11] A. Robles. “Diseño de perfiles aerodinámicos mediante metodología inversa”. In: Dep. Ingeniería Aeroespacial y Mecánica de Fluidos Escuela Técnica Superior de Ingeniería Universidad de Sevilla, 2015.
- [12] IPat2007. *Airfoil Files*. URL: https://xplane.fandom.com/wiki/Airfoil_Files. (posted: 23.12.2007).
- [13] *Investigating the reasons why your CFD analysis is not converging*. URL: <https://conself.com/blog/investigating-the-reasons-why-your-cfd-analysis-is-not-converging/>. (accessed: 30.06.2022).
- [14] AUTODESK Support. *Simulation is diverging in Autodesk CFD*. (posted: 12.04.2021).
- [15] D. A. Harville and D. R. Jeske. “Mean Squared Error of Estimation or Prediction Under a General Linear Model”. In: *Journal of the American Statistical Association* 87.419 (1992), pp. 724–731. DOI: [10.2307/2290210](https://doi.org/10.2307/2290210).
- [16] Z. Wang and A. C. Bovik. “Mean squared error: Love it or leave it? A new look at Signal Fidelity Measures”. In: *IEEE Signal Processing Magazine* 26.1 (2009), pp. 98–117. DOI: [10.1109/msp.2008.930649](https://doi.org/10.1109/msp.2008.930649).
- [17] V. Prisacariu and L. Siminonescu. “Flight Performances Analysis of UAV MFD Nimbus”. In: *Scientific Research and Education in the Air Force – AFASES2018* (2018), pp. 225–232. DOI: [10.19062/2247-3173.2018.20.30](https://doi.org/10.19062/2247-3173.2018.20.30).