DOI: 10.13009/EUCASS2019-494

Cessna Citation X Static Cruise Improvement using Morphing Wing Application on its Horizontal Tail

Marine Segui, Vittorio Rogoli and Ruxandra Mihaela Botez
ETS, Laboratory of Active Controls, Avionics and AeroServoElasticity
1100 Notre Dame West, Montreal, Quebec, Canada, H3C-1K3
ruxandra.botez@etsmtl.ca

Alessandro Ceruti
University of Bologna, Department of Industrial Engineering, Italy

Abstract

This research consists in reducing Cessna Citation X fuel consumption using a morphing technique applied on its horizontal tail. The airfoil of the horizontal tail is morphed according to known airfoils series as NACA 4 digits and NACA 6 digits. Airfoils of each series have been selected by their capacity to act on the trim manoeuver without using the stabilizer position, while reducing the fuel consumption of the Cessna Citation X. Up to 2.92% of the fuel consumption has been saved for more than 160 static cruise conditions tested.

1. Introduction

This paper presents a study conducted at the Research Laboratory in Active Control, Avionics and Aeroservoelasticity (LARCASE), needed to improve the fuel efficiency of the Cessna Citation X business jet. Several methods could be used to reduce the fuel consumption of an aircraft. For instance, airlines could optimize their aircraft trajectories according to the forecasted weather at the time of each flight [1-9]. From a design point of view, it is feasible to improve aircraft performances with new optimized components (surfaces), for example, with more ecological engines [10]-[11]. All these techniques will provide some benefits for both airline companies, and for the environment thanks to the fuel saving [12-14]. Another technique, called “morphing wing” has for goal to improve the wing geometry of an aircraft throughout the flight. By changing it shape during the flight, the wing is aerodynamically optimized at each time of the flight, that conducts to a drag reduction, and thus to a fuel saving [15-21].

Morphing wing techniques could be applied on different components of an aircraft. Several studies have shown that a distortion of the wing according to its airfoil could lead to 14% of drag reduction [20]-[22-25]. Similarly, it has been shown that wing flaps could be replaced by a morphing trailing edge [26]-[27]. Consequently, the discontinuity between the wing and the flap was removed, which reduced greatly the drag generated. As another example, a study aiming to improve the winglets position throughout the flight allowed to increase the rate of climb by 26 feet/min [28]. Finally, the LARCASE team has shown that up to 45 kg of fuel per hour could be saved by applying a morphing technique on the horizontal tail of the Cessna Citation X [31]. This morphing technique has for goal to trim the Cessna Citation X by changing the horizontal tail airfoil only (i.e. without using the stabilizer motion). Indeed, in order to pay attention to the weight that the morphing system would add to the horizontal tail, it was supposed that the morphing motion will replace the stabilizer motion to trim the airplane. Consequently, this research consisted in finding airfoils shapes that could act on the pitching moment of the aircraft without inducing more drag than the original configuration. For this reason, an airfoil generator based on *BP3434* parametrized curve [29], combined to an optimization algorithm (Particle Swarm) was used. This methodology has allowed to find convenient airfoils shapes, however, there was no continuity between them (i.e. airfoils have not a common shape). Therefore, it was difficult to implement a morphing mechanism.

With the idea of implementing a morphing mechanism on the Cessna Citation X horizontal tail, it was required to constrain the airfoil shapes, for instance using NACA series. Consequently, the study presented in this paper aims to verify that airfoils coming from a NACA series could improve Cessna Citation X performances (i.e. reduce the fuel consumption), as airfoils found using *BP3434* parameterized curves.

DOI: 10.13009/EUCASS2019-494

Because the LARCASE has a level D Research Aircraft Flight Simulator (RAFS) of the Cessna Citation X, the study was performed for this aircraft. The level D is the highest qualification level issued by the Federal Aviation Administration (FAA), meaning that flight simulator data are extremely close to those provided by the real Citation X aircraft [30].

The Cessna Citation X is a business jet able to perform more than 6 300 km as range distance. It took its first flight on December 1993, and is the fastest civil aircraft behind the Concorde. It has a T-tail configuration and it is powered by two engines located at the rear of the fuselage. The Cessna Citation X main performances characteristics are shown in Table 1.

Table 1: Cessna Citation X characteristics

Designation	Cessna Citation X
Lengths	
Wing span	19.4 m
Heigh	5.9 m
Length	22.0 m
Areas	
Wing area	48.96 m^2
Horizontal tail (stabilizer) area	11.14 m^2
Performances	
Max certified speed	Mach 0.92
Max certified altitude (*51 000 ft*)	15 544 m
Altitude recommended (*FL370 à 450*)	11 277 to 13 716 m
Max number of passengers	13
Maximum takeoff weight (MTOW)	16 193 kg
Engines	
Number of engines	2
Type	AE3007C-1
Thrust per engines	28.65 kN

2. Aerodynamic and Performances Modeling

The objective of this section is to detail the mathematical models and tools considered in this study to evaluate the aerodynamic and the performances of the Cessna Citation X. For this purpose, the section begins with the description of the model used to compute the aerodynamic characteristics of the horizontal tail of the aircraft. The section then presents the model used to calculate the performance of the Cessna Citation X in cruise.

2.1 Aerodynamic Modeling of the Cessna Citation X Horizontal Tail

The model used in this study to compute the aerodynamic characteristics of the horizontal tail of the Cessna Citation X was developed by the authors in a previous study [31]-[32]. This model is schematically illustrated in Fig. 1.

As inputs, the model requires knowledge of geometry characteristics of the horizontal tail (i.e. the planar horizontal tail dimension plus an airfoil shape), and the flow characteristics (speed, direction and the density). As outputs, the model gives the aerodynamic coefficients C_L, C_D, C_m of the corresponding airfoil that is equipped the horizontal tail. For practical and time reasons (because the study requires to use an optimization algorithm), a low fidelity aerodynamic method such as the 3D-Panel implemented in OpenVSP software has been selected [33].

OpenVSP is a National Aeronautics and Space Administration (NASA) open source parametric geometrical software. The 3D-Panel method is a numerical solver for linear, inviscid and irrotational flows. To perform the computation, the geometry of the object (i.e. an aircraft or a wing) needs to be discretized in panels [34]. Due to the fact that the method considers non-viscous potential flow (i.e. irrotational) regardless of non-linear terms, it cannot predict some flow behaviours like flow separation, skin-friction drag and transonic shocks.

DOI: 10.13009/EUCASS2019-494

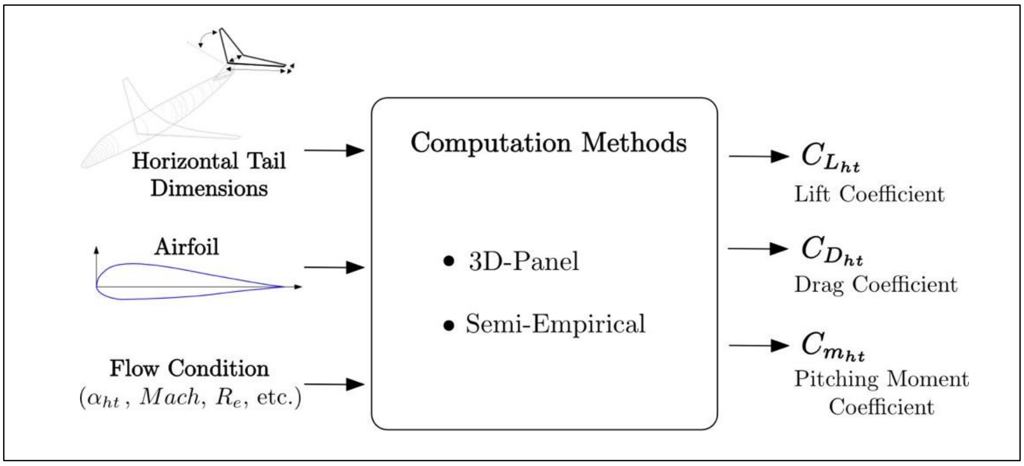


Figure 1: Illustration of the aerodynamic model of the Cessna Citation X horizontal tail

However, to keep as much accuracy as possible in our results, it has been chosen to use another type of computation, such as semi-empirical methods. For this purpose, Digital Datcom was used [35].

The second software, Digital Datcom, is provided by the United States Air Force (USAF). Based on the USAF Stability and Control Datcom documents, it is generally dedicated to perform preliminary aerodynamic stability and control design of aircrafts. Digital Datcom analysed the pressure distribution of the wing by Weber's method for inviscid aerodynamic characteristics calculations, and then corrected data issued from interpolations to take into account effects due to the Mach number [35].

Both methods were used to perform aerodynamic computations. The 3D-Panel method is used to compute the lift coefficient C_L, the drag induced coefficient C_{Di} and the pitching moment coefficient C_m. Digital Datcom is used to compute the parasite drag C_{D0} of the wing. Finally, the complete drag coefficient C_D is computed by summing the parasite drag C_{D0} and the induced drag C_{Di}.

The aerodynamic model of the horizontal tail of the Cessna Citation X was developed by modelling a wing that has the geometrical characteristics of the horizontal tail as described in Table 2 [31]-[32]. This information is provided partially by the Flight Crew Operating Manual (FCOM) of the Cessna Citation X. Airfoils given for the horizontal tail, respectively called WD140 for the root, and DGMA90 for the tip, are confidential airfoils, and for this reason, they are not available. As a consequence, in our model, an unique airfoil was supposed from the root to the tip of the horizontal tail, the NACA0009. This airfoil was selected after a study aiming to find the airfoil that leads to aerodynamic coefficients as close as those obtained from the Research Aircraft Flight Simulator (RAFS) [30].

Table 2: Geometrical characteristics of the horizontal stabilizer of the Cessna Citation X

Designation	**Cessna Citation X**
Wing span	7.95 m
Mean Aerodynamic Chord	1.62 m
Root chord	2.35 m
Tip chord	0.90 m
Sweep angle (at 25% of chord)	42.0 deg
Dihedral angle	0.0 deg
Twist angle	0.0 deg
Airfoil (from the root to the tip)	NACA0009

2.2 Cessna Citation X Cruise Performances Modeling

In order to evaluate the Cessna Citation X performances (i.e. stabilizer position, and fuel flow consumed), another tool was required. This model is called "performance model" or "mathematical model". It was developed and accurately validated in a previous study led by the LARCASE team at Montreal (see Fig. 2).

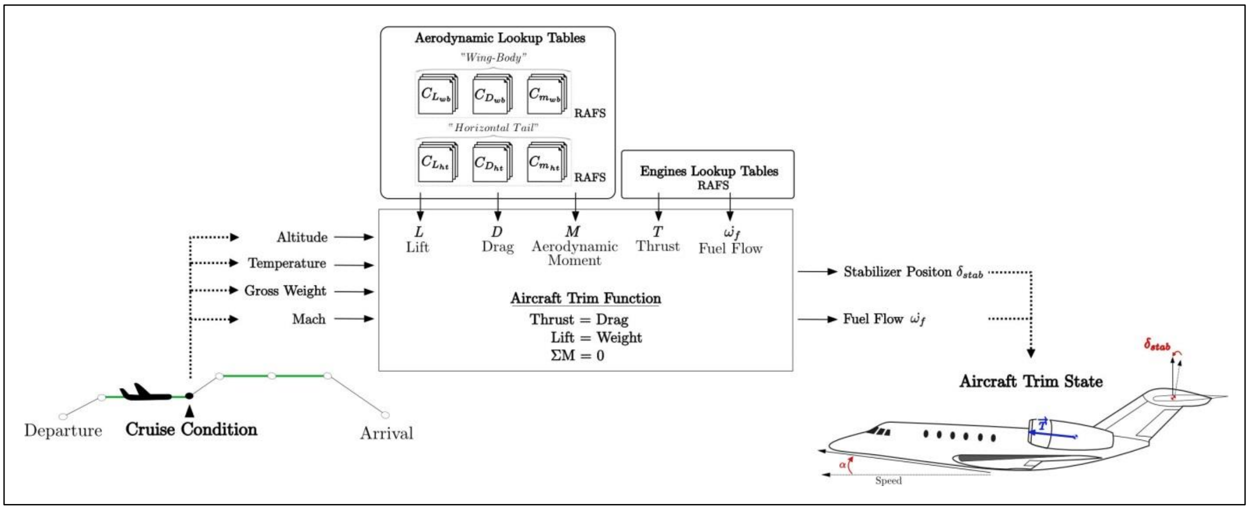


Figure 2: Reference Performance Model of the Cessna Citation X

For a cruise condition (altitude, gross weight, temperature, center of gravity, Mach number, etc.) given as input, this performance model is able to output information related to the Cessna Citation X cruise trim manoeuver. For this study, the most interesting outputs are the fuel consumption ω_f, and the stabilizer angle δ_{stab} [32].

To compute the aircraft trim state during the cruise phase, the performance model needs two kinds of data specific to the airplane, such as aerodynamic and engines data. This information is specified to the program using lookup table tools. With these tables, it is then possible to compute all forces and moments influencing the aircraft motion (i.e. lift, drag, thrust, etc.).

As shown in Fig. 2, six lookup tables are required to define the aerodynamic coefficients of the aircraft (i.e. lift coefficient C_L, drag coefficient C_D and pitching moment coefficient C_m). The first three lookup tables represents the aerodynamic coefficients of the wing body *wb* (i.e. associated with the wing, the fuselage and the vertical tail) while the remaining three lookup tables corresponds to the horizontal tail *ht*. All these aerodynamic coefficients are provided by the Cessna Citation X flight simulator (RAFS). Each aerodynamic coefficient is expressed as function of the angle of attack α_{wb} or α_{ht} and the Mach number *Mach*. The relationship between α_{wb} and α_{ht} is given in Eq. (1) where ε is the downwash induced by the wing, and δ_{stab} is the angle of the stabilizer measured from its initial position.

$$\alpha_{ht} = \alpha_{wb} - \varepsilon + \delta_{Stab} \tag{1}$$

Concerning engines lookup tables, original information of the Cessna Citation X engines, such as the fan-speed, the thrust, or the fuel burn rate are saved according to the Mach number, the altitude, the temperature deviation, and the Throttle Lever Angle. Engines lookup tables have been kept as originally (i.e. coming from the RAFS) for the whole study.

The "Aircraft Trim function" corrects angles (angle of attack α_{wb}, and the stabilizer position δ_{stab}), and adjusts the thrust in order to balance forces and moments applied on this aircraft in a cruise regime according to the second law of Newton given by Eq. (2).

$$\begin{gathered} Lift = Weight \\ Drag = Trust \\ \sum Moment = 0 \end{gathered} \tag{2}$$

Data obtained by this performance model were compared with experimental data obtained by the RAFS for a large range of static cruise conditions, and a maximum relative error of 5% was noticeable between these data [32]. Consequently, this performance model was validated, and thus represents an accurate tool for the following study.

DOI: 10.13009/EUCASS2019-494

3. Aircraft Model Optimization

The optimization of the aircraft is based on the replacement of its original horizontal tail with a new horizontal tail equipped with the morphing wing system. To be able to measure performances of this new wing (i.e. be sure that the airfoil tested is able to trim the Citation X), the mathematical model presented in section 2.2, has been modified. Indeed, aerodynamic lookup tables dedicated to horizontal tail contributions (*ht*) have been substituted by aerodynamic coefficients computed using the aerodynamic model presented in section 2.1. Figure 3 shows the "modified" performance model used for the optimization study.

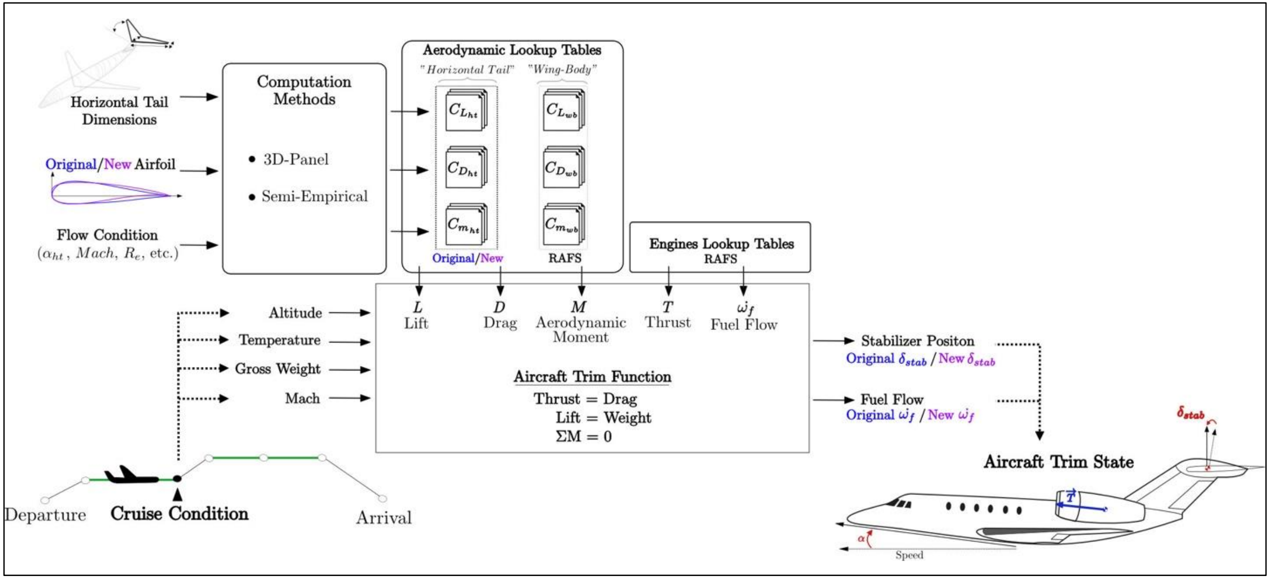


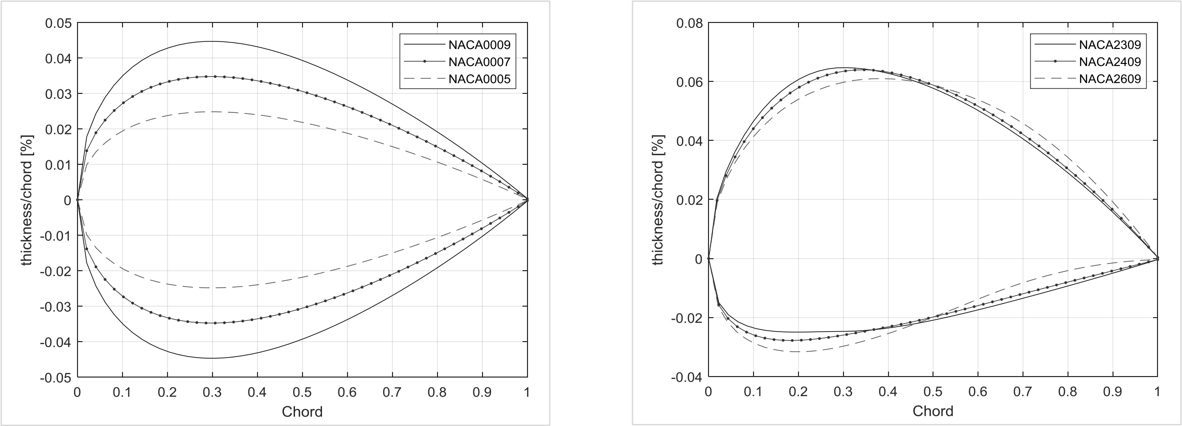
Figure 3: Modified performance model adapted to the optimization study

In order to find *ht* airfoils that can be able to trim the Citation X without requiring a stabilizer motion, different NACA airfoils series, such as NACA 4, and NACA 6 digits were used [36]-[37]. The NACA family choice was made according to the fact that these airfoils can be "parameterized" using (for the lowest series NACA 4 digits) position and amplitude parameters, and these parameters were directly linked to actuators settings.

The series NACA 4 digits is characterized by three different variables: the maximum thickness *t*, the maximum camber level *m*, and the position of the maximum camber along the chord *p* [36]. For example, the airfoil NACA1307 will have a maximum thickness of 7% related to the chord, with 1% of camber level located at a distance of 30% of the chord starting from its leading edge. An influence of each NACA 4 series design parameters is shown in Fig. 4.

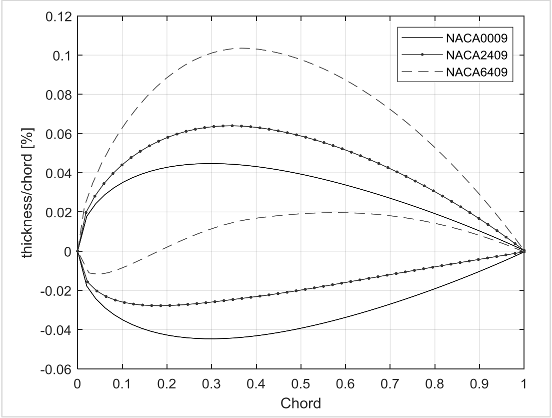
To evaluate the capabilities of the NACA 4 series, a database of aerodynamic coefficients C_L, C_D and C_m of the horizontal tail (*ht*) equipped with a wide range of NACA 4 series airfoils was developed. To be wide enough, the database was elaborated with different NACA 4 series parameters. The complete range of camber level available using NACA 4 series equations was used (i.e. from 0 to 6%). The thickness parameter has been set from 5 to 10% of the chord. Finally, the range of maximum camber position has been reduced from 0 to 60% to save computational time, and also because the most important region of the airfoil for the lift generation was located at the leading edge.

DOI: 10.13009/EUCASS2019-494



a) Thickness comparison

b) Max camber position



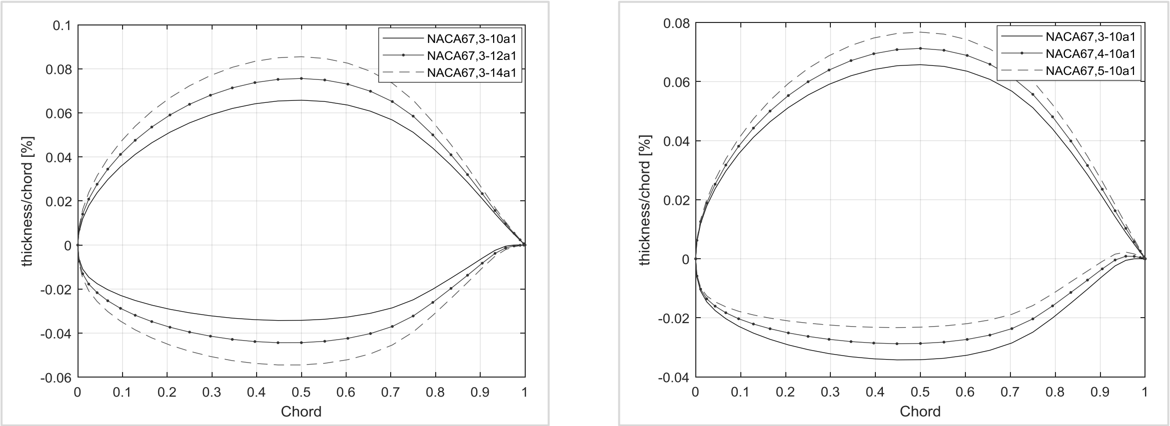
c) Camber level

Figure 4 : NACA 4 digits series wide shapes

The NACA 6 series generates appropriate airfoils for speeds involved for Cessna Citation X cruise condition (i.e. transonic regime). NACA 6 series are designed using 6 digits [36]. For instance, for the airfoil named “NACA65,3-218, a=0.5”, the first digit, the “6” is the series designation, the “5” is the chord wise position of the minimum pressure, the “3” following the comma gives the range of lift coefficient in tenths. Following the dash, the “2” corresponds to the design lift coefficient in tenths and the last number “18” indicates the thickness in percentage of the chord. Finally, the parameter “a” is given between 0 and 1, and indicates the type of mean line used, when it is not precised, a = 1. An overview of the influence of each NACA 6 digits is shown in Fig. 5.

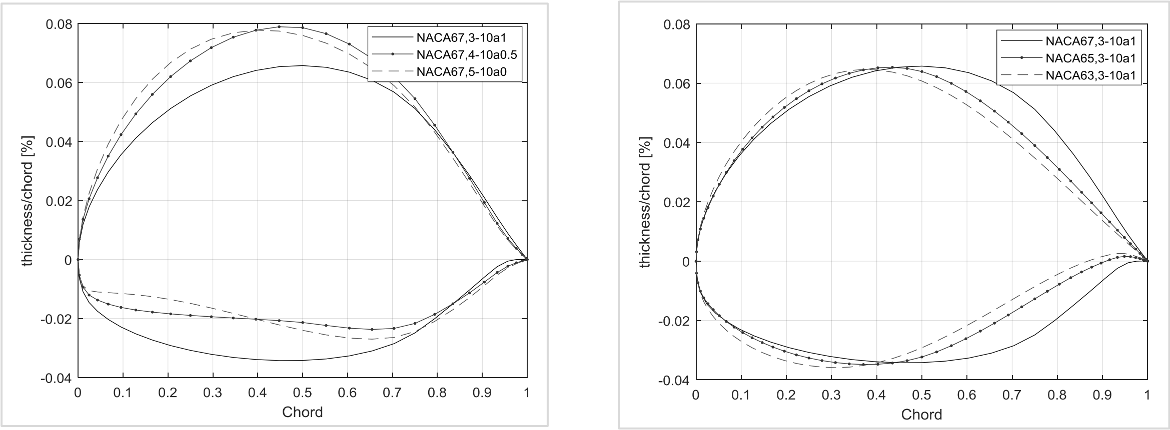
In the same way as for the NACA 4 series, a lot of airfoils issued from the NACA 6 series have been studied, and they can be selected using digits bounds. Indeed, airfoils selected from the series 6 which have the minimum pressure position between 30 % to 70 % of the chord, a lift range from 0.3 to 0.5 tenths, a lift coefficient from 0.3 to 0.5 tenths, a thickness from 10 % to 14% of the chord and all mean line type (from 0 to 1 with a 0.1 step) were tested.

All airfoils corresponding to parameters precised for the NACA series 4 or the series 6 have been included in the airfoil database considered. As a reminder, to be balanced in cruise, an aircraft needs to generate downward lift by its tail. Consequently, all the airfoils considerate in the database were inversed vertically (i.e. the upper surface became the inner surface, and inversely).



a) Comparison between different thickness

b) Comparison between different design cl



c) Comparison between different mean line type

d) Comparison between different position of minimum pressure

Figure 5: NACA 6 series range of shapes

Then, for a selected flight condition (altitude, gross weight, Mach number, and center of gravity), each airfoil was implemented into the model defined in Fig. 3, and a corresponding cost was attributed. This cost is expressed in Eq. (3), and reflects the fact that the airfoil allows the aircraft to trim at this flight condition using the least possible the stabilizer angle. Moreover, the cost traduces that fact that the airfoil shape allows also to reduce the fuel burn (ω_f).

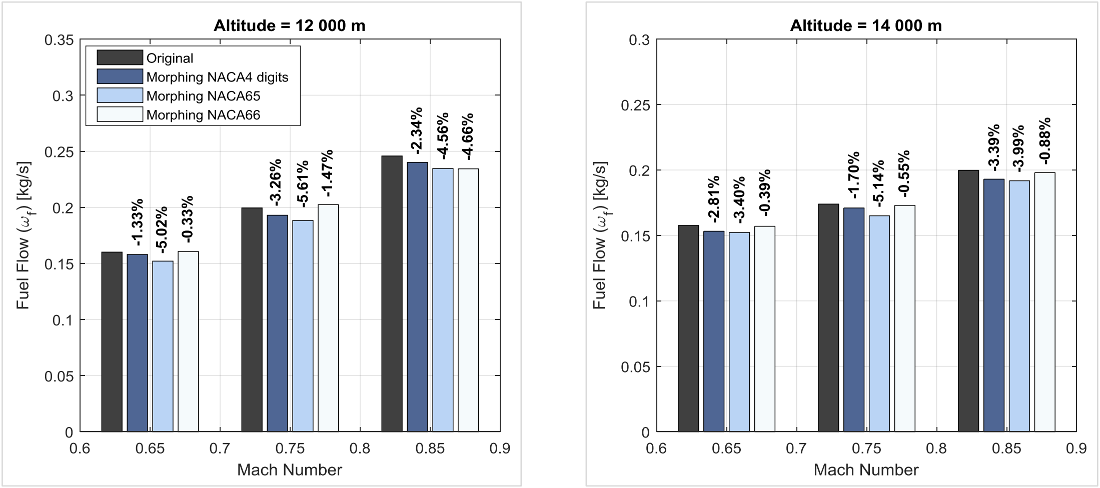
$$Cost = {\delta_{stab}}^2 + \omega_f \tag{3}$$

Therefore, when all airfoils of the same series has been tested for the given flight condition, it is then possible to sort them according to their corresponding *Cost*. Finally, the airfoil that has the lowest cost for this flight condition and this NACA airfoil series will be saved. This study was then renewed for the NACA series and several static flight conditions.

4. Results

This final section is dedicated to present results that have been obtained following the methodology previously presented. Around 2 400 airfoils coming from NACA 4 and NACA 6 series were tested. Because there are a lot of airfoils, it has been chosen to only display the most interesting series (i.e. those who gave the best results): the NACA4, the NACA65 and the NACA66 series. As a reminder, the second digit after the “6” indicates the position of the minimum pressure of the airfoil, so that for the NACA 65 and NACA 66 series, the minimum of pressure is respectively located at 50% and 60% of the chord.

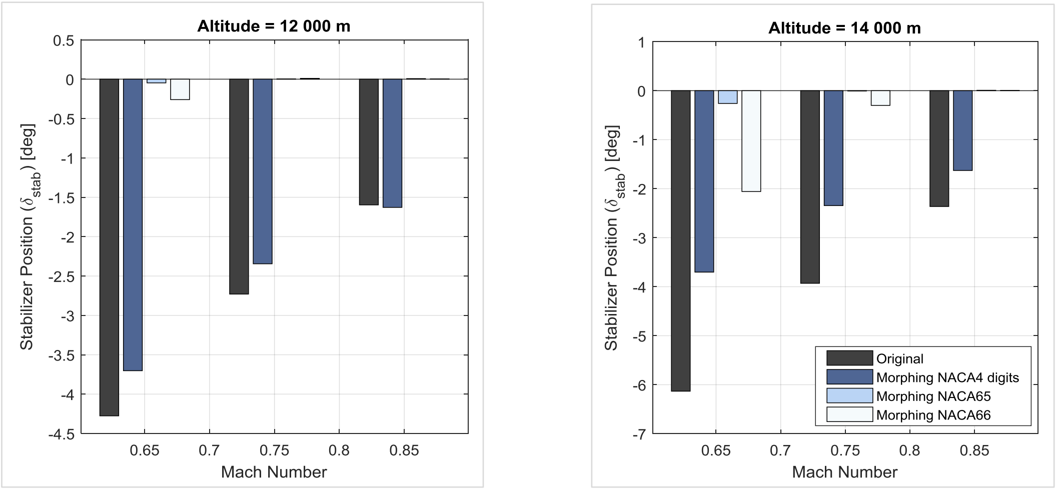
As an example, results will be displayed for 6 flight conditions representatives of the cruise regime of the Cessna Citation X. Three different speeds were tested as Mach numbers M0.65, M0.75 and M0.85 for a medium gross weight of 13 607 kg, and a low altitude of 12 000 meters. Similarly, the same conditions were tested at an higher altitude of 14 000 meters. For these 6 flight conditions, the center of gravity was set to its medium location (at 25% of the Mean Aerodynamic Chord location (MAC)). Only the airfoils that gave the lowest *Cost* per NACA series have been selected, and then displayed as results.



a) Altitude of 12 000 meters b) Altitude of 14 000 meters

Figure 6: Fuel flow obtained for several static cruise conditions when different type NACA series of airfoils are applied on the horizontal tail of the Cessna Citation X

The Figure 6 shows the fuel flow required by the Cessna Citation X to be balanced using different airfoils shapes for its horizontal tail. The relative error obtained between the fuel flow generated by the original configuration of the Citation X, and the fuel flow obtained for the different NACA airfoils series are displayed above each bar on the graphs. Results obtained for an altitude of 12 000 meters are displayed on the left hand side of Fig. 6 (i.e. Fig 6. a), and results obtained for an altitude of 14 000 meters are displayed on the right hand side of the same figure (i.e. Fig. 6. b). Similarly, Figure 7 shows the stabilizer position required to balance the aircraft with the airfoil corresponding to the minimum *Cost*.

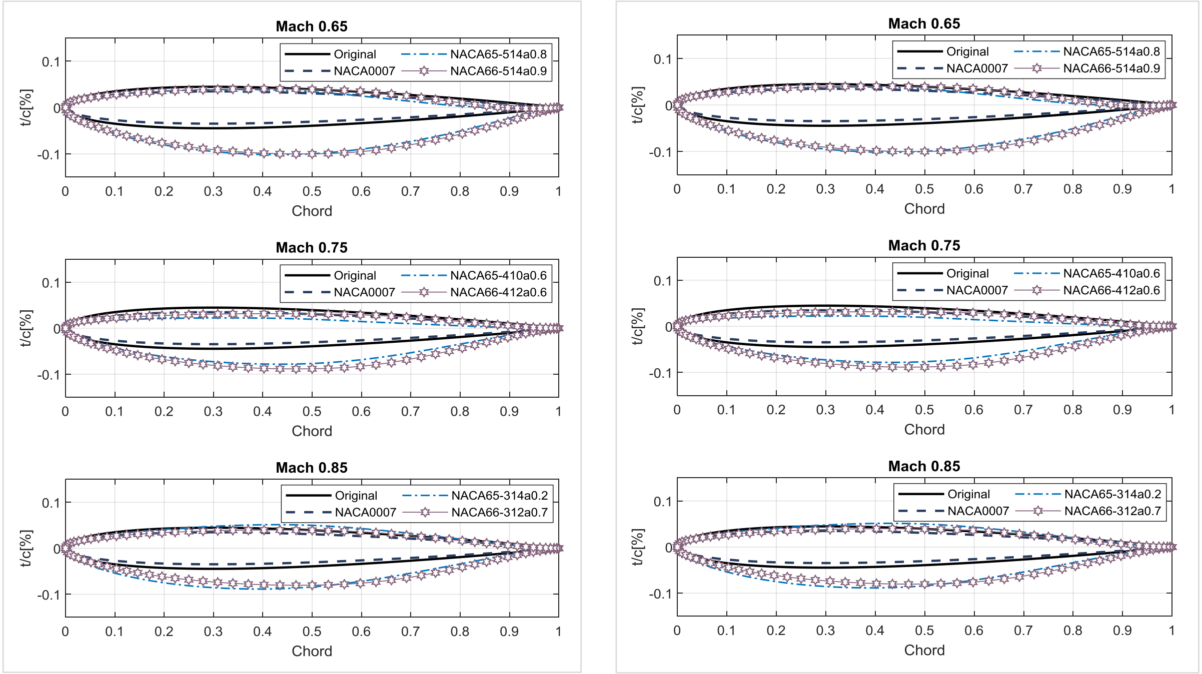


a) Altitude of 12 000 meters b) Altitude of 14 000 meters

Figure 7: Stabilizer position required to balance the Cessna Citation X conditions when different type NACA series of airfoil are applied its horizontal tail for several static cruise

The black color is dedicated to represent data corresponding to the original configuration of the horizontal tail (as presented in Table 2). The dark blue color represents data obtained for the airfoil coming from NACA 4 digits series, that have the lowest cost (Eq. (3)) for the corresponding flight condition. In the same way, the light blue and the white colors indicate respectively the results obtained for the NACA 65 and NACA 66 series.

Finally, shapes of the airfoils selected by the cost criteria (i.e. the shape of airfoils corresponding to results displayed in Fig. 6 and 7) are illustrated in Fig. 8. On the left hand side are displayed the airfoils shapes obtained for an altitude of 12 000 meters, and on the right hand side are displayed the airfoils shapes obtained for an altitude of 14 000 meters. Vertically, the airfoils shapes were sorted according to the speeds conditions.



a) Altitude 12000m

b) Altitude 14 000 m

Figure 8: “Best” Airfoils corresponding to data shown in Fig.6 and Fig. 7

Generally, the NACA 4 series allows to reduce the fuel flow between 1.33% and 3.39%. For the flight conditions shown in Fig. 8, NACA 4 series airfoil that is able to deliver these performances is the NACA0007. Between the original airfoil (NACA0009) and the “best” airfoil that is corresponding to the lowest *Cost*, only the thickness is changed. Indeed, the NACA0007 has a lower thickness than the NACA0009. As a consequence, because the airfoil is less thick, it generates less drag, and thus the fuel flow can be reduced. However, the new airfoil, the NACA0007 is not cambered, and consequently, this airfoil cannot act on the pitching moment, and requires a stabilizer motion. The stabilizer *ht* motion is generally less important than the original one, but it is still important, as it occurs from -3.70 deg to -1.63 deg (Fig. 7). For the majority of the 144 flight conditions tested, the airfoil that gives the best cost (see Eq. (3)) is not cambered. This observation could be explained by the fact that when a degree of camber is added on a NACA 4 digit airfoil, this degree is inducing too much drag on the horizontal tail and that is not advantageous.

The NACA 6 digit series has shown a better advantage than the NACA 4 digit series, especially NACA 65 and NACA 66 series. Indeed, for the NACA 65 series, up to 5.61% can be saved at 12 000 m of altitude, and 5.14% can be saved at 14 000 m of altitude (Fig. 6). The NACA 66 series has shown the same range of gain, up to 4.66% at 12 000 m of altitude, and 0.88% at 14 000 m of altitude (Fig. 6). Unlike the NACA 4 digits series, best airfoils selected for the series NACA 65 and NACA 66 are cambered (Fig. 8). Consequently, the pitching moment coefficient of the horizontal tail is not equal to zero for these airfoils. As a matter of fact, these airfoils help to balance the Cessna Citation X, and therefore it is less necessary to use the stabilizer motion. This fact can be seen on Fig. 7, where the stabilizer needs to move from -0.0025 to -0.2600 degrees for the NACA65 series, and from -0.005 to -2.058 degrees for the NACA66 series. The negative sign indicates that the stabilizer needs to move downward.

According to this last observation, it can be concluded that the NACA65 series could be the most appropriate to apply on the horizontal tail of the Cessna Citation X for a morphing study. Thus, up to 5.61% on the fuel flow could be saved, without using the stabilizer position to trim the aircraft. Even if stabilizer positions found in Fig. 7 for the NACA65 series are not exactly equal to zero, it will be feasible to “delete” the stabilizer motion for the cruise phase.

DOI: 10.13009/EUCASS2019-494

Indeed, new computations could be done with a smaller step between the NACA65 parameters (digits), and an airfoil that is able to trim the airfoil itself (i.e. stabilizer position exactly equal to zero) could be found.

In order to have a larger range of results, this study has been conducted for the 168 static flight conditions presented in Table 3.

Table 3: Static Cruise Conditions

Parameter	**Min value**	**Max value**	**step**
Altitude [m]	3 048 *(10 000 ft)*	13 716 *(45 000 ft)*	1 524 *(5 000 ft)*
Mach number [-]	0.65	0.85	0.1
Gross Weight [kg]	12 246 *(27 000 lb)*	15 875 *(35 000 lb)*	453 *(1 000 lb)*

Generally, for the flight conditions tested, on average 1.11% of the fuel flow can be save for the NACA series 4 digits, 2.92% for the NACA 65 series and 0.89% for the NACA 66 series. Moreover, the stabilizer needs to move from -4.80 and 0.17 degrees to balance the Citation X with airfoils of the NACA 4 series, from 0 to 1.77 degrees for the NACA 65 series and from 0 to -2.77 degrees for the NACA 66 series. As a global view, the fuel flow tends to the one of the original configuration with the increasing flight altitude. This observation could be explained by the fact that the original geometry of the horizontal tail should be already optimized for the longest phase of the flight, so for high altitude cruise.

5. Conclusion

This paper has for goal to show that it is feasible to reduce the fuel consumption of the Cessna Citation X by applying a morphing technique on its horizontal tail. The morphing here consisted in changing the airfoils shape of the horizontal tail for several static cruise conditions according to known shapes of NACA airfoils series. Different series were tested as NACA 4 digits and NACA 6 digits, and gave different results.

Generally, the NACA 4 series allows to slightly reduce the fuel consumption, but airfoil found are not able to act on the pitching moment without inducing a lot of drag due to their camber.

The NACA 6 series has shown the best results especially for a minimum pressure location at 50% and 60% of the chord (NACA65 and NACA66 series). For these series, up to 5.61% of fuel flow has been saved, without needing a big motion of stabilizer (lower than 1.77 degree). As a reminder, the least possible motion of the stabilizer was important in order to prevent the weight added by the morphing system on the horizontal tail. Indeed, the goal was to replace the mechanism allowing the position of the stabilizer by the morphing system of airfoils.

To conclude, it has been shown that is feasible to trim the Cessna Citation X using NACA6 series airfoils while reducing its fuel consumption by on average of 2.92%.

References

[1] R. S. Félix Patrón, Y. Berrou, and R. Botez, "Climb, Cruise and Descent 3D Trajectory Optimization Algorithm for a Flight Management System," in *Aviation Technology, Integration, and Operations*, 2014.

[2] R. S. Félix Patrón and R. Botez, "Flight trajectory optimization through genetic algorithms coupling vertical and lateral profiles," in *ASME 2014 International Mechanical Engineering Congress and Exposition*, 2014, pp. V001T01A048-V001T01A048.

[3] R. S. Félix Patrón, A. Kessaci, and R. Botez, "Horizontal Flight Trajectories Optimization for Commercial Aircraft through a Flight Management System," *Aeronautical Journal*, vol. 118, 2014.

[4] A. Murrieta-Mendoza, L. Ternisien, B. Beuze, and R. Botez, "Aircraft Vertical Route Optimization by Beam Search and Initial Search Space Reduction," *Journal of Aerospace Information Systems*, vol. 15, pp. 157-171, 2018.

[5] A. Hamy, A. Murrieta-Mendoza, and R. Botez, "Flight Trajectory Optimization to Reduce Fuel Burn and Polluting Emissions using a Eerformance Eatabase and Ant Colony Optimization Algorithm," 2016.

DOI: 10.13009/EUCASS2019-494

[6] A. Murrieta Mendoza, "Application of Metaheuristic and Deterministic Algorithms for Aircraft Reference Trajectory Optimization," École de technologie supérieure, 2017.
[7] A. Murrieta-Mendoza, B. Beuze, L. Ternisien, and R. Botez, "New Reference Trajectory Optimization Algorithm for a Flight Management System Inspired in Beam Search," *Chinese Journal of Aeronautics,* vol. 30, pp. 1459-1472, 2017.
[8] A. Murrieta-Mendoza and R. Botez, "Methodology for Vertical-Navigation Flight-Trajectory Cost Calculation using a Performance Database," *Journal of Aerospace Information Systems,* vol. 12, pp. 519-532, 2015.
[9] A. Murrieta-Mendoza, J. Gagné, and R. Botez, "New Search Space Reduction Algorithm for Vertical Reference Trajectory Optimization," *INCAS Bulletin,* vol. 8, p. 77, 2016.
[10] G. Agnew, M. Bozzolo, R. R. Moritz, and S. Berenyi, "The Design and Integration of the Rolls-Royce Fuel Cell Systems 1MW SOFC," in *ASME Turbo Expo 2005: Power for Land, Sea, and Air*, 2005, pp. 801-806.
[11] K. Rajashekara, J. Grieve, and D. Daggett, "Hybrid Fuel Cell Power in Aircraft," *IEEE Industry Applications Magazine,* vol. 14, 2008.
[12] AirFrance-KLM, "2017 Annual Report," 2017.
[13] ICAO, "Environmental Report," 2016.
[14] ICAO, "Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)," 9 August 2018.
[15] S. Barbarino, O. Bilgen, R. M. Ajaj, M. I. Friswell, and D. J. Inman, "A Review of Morphing Aircraft," *Journal of Intelligent Material Systems and Structures,* vol. 22, pp. 823-877, 2011.
[16] A. D. Finistauri, "Conceptual Design of a Modular Morphing Wing," Bachelor of Engineering, Ryerson University, 2005.
[17] A. Koreanschi, O. Sugar Gabor, and R. Botez, "Drag Optimisation of a Wing Equipped with a Morphing Upper Surface," *The Aeronautical Journal,* vol. 120, pp. 473-493, 2016.
[18] O. Sugar Gabor, "Validation of Morphing Wing Methodologies on an Unmanned Aerial System and a Wind Tunnel Demonstrator," Ph. D, École de Technologe Supérieure, 2015.
[19] M. Segui, O. Sugar Gabor, A. Koreanschi, and R. Botez, "Morphing Wing Application on Hydra Technologies UAS-S4," *[Proceeding] Modelling, Identification and Control (MIC) 2017,* 2017.
[20] O. Sugar Gabor, A. Simon, A. Koreanschi, and R. Botez, "Application of a Morphing Wing Technology on Hydra Technologies Unmanned Aerial System UAS-S4," in *The ASME 2014 International Mechanical Engineering Congress & Exposition, Montreal, Que., Canada*, 2014.
[21] B. Howard. (2016). *MIT's Ultra-Light Composite Morphing Aircraft Wing Harkens Back to the Wright Brothers (ExtremeTech ed.)*. Available: https://www.extremetech.com/extreme/238954-mits-ultra-light-composite-morphing-aircraft-wing-harks-back-wright-brothers
[22] J. Fincham and M. Friswell, "Aerodynamic Optimisation of a Camber Morphing Aerofoil," *Aerospace Science and technology*, vol. 43, pp. 245-255, 2015.
[23] C. Y. Herrera, N. D. Spivey, S.-f. Lung, G. Ervin, and P. Flick, "Aeroelastic Airworthiness Assesment of the Adaptive Compliant Trailing Edge Flaps," 2015.
[24] A. Koreanschi, O. Sugar Gabor, J. Acotto, G. Brianchon, G. Portier, R. Botez, *et al.*, "Optimization and Design of an Aircraft's Morphing Wing-tip Demonstrator for Drag Reduction at Low Speed, Part I–Aerodynamic Optimization Using Genetic, Bee Colony and Gradient Descent Algorithms," *Chinese Journal of Aeronautics*, vol. 30, pp. 149-163, 2017.
[25] A. Koreanschi, O. Sugar Gabor, J. Acotto, G. Brianchon, G. Portier, R. Botez, *et al.*, "Optimization and Design of an Aircraft's Morphing Wing-Tip Demonstrator for Drag Reduction at Low Speeds, Part II-Experimental Validation using Infra-Red Transition Measurement from Wind Tunnel tests," *Chinese Journal of Aeronautics*, vol. 30, pp. 164-174, 2017.
[26] S. Kota, P. Flick, and F. S. Collier, "Flight Testing of FlexFloilTM Adaptive Compliant Trailing Edge," in *54th AIAA Aerospace Sciences Meeting*, 2016, p. 0036.
[27] D. Communier, R. Botez, and T. Wong, "Experimental Validation of a New Morphing Trailing Edge System Using Price–Païdoussis Wind Tunnel Tests," *Chinese Journal of Aeronautics*, 2019.
[28] M. Segui, R. Botez, "Cessna Citation X Climb and Cruise Performance Improvement Using Adaptive Winglet," presented at the Advanced Aircraft Efficiency in a Global Air Transport System, Toulouse, France, 2018.
[29] R. Derksen and T. Rogalsky, "Bezier-PARSEC: An Optimized Aerofoil Parameterization for Design," *Advances in Engineering Software,* vol. 41, pp. 923-930, 2010.
[30] R. Botez, C. Hamel, G. Ghazi, Y. Boughari, F. Theel, and A. Murrieta Mendoza, "Level D Research Aircraft Flight Simulator use for Novel Methodologies in Aircraft Modeling and Simulation," 2015.
[31] M. Segui, M. Mantilla, G. Ghazi, and R. Botez, "New Economical Cruise Methodology for the Cessna Citation X Business Jet by an Original Morphing Horizontal Tail Application," in *2018 Modeling and Simulation Technologies Conference*, 2018, p. 3895.

DOI: 10.13009/EUCASS2019-494

[32] M. Segui, "Mesure de l'impact de la technologie d'aile déformable sur les performances en croisière de l'avion d'affaire Cessna Citation X," Master, Aerospace, École de Technologie Supérieure, Montreal, 2018.

[33] R. A. McDonald, "Interactive Reconstruction of 3D Models in the OpenVSP Parametric Geometry Tool," in *53rd AIAA Aerospace Sciences Meeting, American Institute of Aeronautics and Astronautics, Kissimmee, FL*, 2015, pp. 1-10.

[34] J. Broeze, E. F. van Daalen, and P. J. Zandbergen, "A Three-Dimensional Panel Method for Nonlinear Free Surface Waves on Vector Computers," *Computational mechanics*, vol. 13, pp. 12-28, 1993.

[35] J. E. Williams and S. R. Vukelich, "The USAF Stability and Control Digital Datcom. Volume I. Users Manual," McDonnell Douglas Astronautics co St Louis mo1979.

[36] F. W. Riegels, "Aerofoil Sections," ed: Butterworths, London, 1961.

[37] I. H. Abbott, A. E. Von Doenhoff, and L. Stivers Jr, "Summary of Airfoil Data," 1945.