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Development and verification of AeroMech tool for rapid estimation of airplane aerodynamic characteristics during early design stages

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Abstract. The aerodynamic characteristics of airplanes (i.e., coefficients and derivatives) are essential for the airplane design and optimization process. Generally, accurate calculations of these characteristics are complex and time-consuming. However, the level of accuracy can be adjusted depending on the design phase, problem complexity, and available time for analysis. Thus, diverse tools ranging from simple analytical methods to complex numerical simulations are used to calculate these characteristics during different design steps. This paper presents an efficient tool to expedite the calculation of the aerodynamic characteristics of airplanes with acceptable accuracy based on a combination of analytical and empirical approaches. The goal is to develop a a program tool (AeroMech) that can be used during the airplane preliminary design steps to rapidly assess a large number of alternative configurations and select the best ones for further detailed analysis. For this, enormous empirical relations that are typically represented in charts are digitized and implemented in the developed tool together with the analytical-empirical equations to facilitate and speed up the calculations. Cessna-182 and Cessna-310 airplanes are selected as two case-studies to verify the developed tool against the most common tools such as Digital DATCOM and XFLR5. Finally, the developed tool is partially validated with the available published experimental data for the case-study airplanes. The results show that the tool is able to predict the aerodynamic characteristics with reasonable accuracy for the preliminary design steps, which saves time and resources in the early design stages.

Nomenclature

C_{L_0} = Lift coefficient at zero-angle of attack
C_{L_α} = Lift curve slope, $[rad^{-1}]$
$\mathrm{C}_{L_{Max.}}$ = Maximum lift coefficient
C_{m_0} = Pitching moment coefficient at zero-angle of attack
C_{m_α} = Pitching moment curve slope, $[rad^{-1}]$
C_{D_u} = Change in drag coefficient due to change in speed
C_{L_u} = Change in lift coefficient due to change in speed
C_{m_u} = Change in oitching moment coefficient due to change in speed
$C_{T_{X_u}}$ = Change in thrust coefficient due to change in speed

Nomenclature continue

$C_{m_{T_u}}$ = Change in thrust moment coefficient due to change in speed
$C_{m_{T_\alpha}}$ = Change in thrust momment coefficient due to change in angle of attack, $[rad^{-1}]$
$C_{L_{\dot{\alpha}}}$ = Change in lift coefficient due to change in rate of angle of attack, $[rad^{-1}]$
$C_{m_{\dot{\alpha}}}$ = Change in pitching momment coefficient due to change in rate of angle of attack, $[rad^{-1}]$
C_{y_β} = Change in side-force coefficient due to change in angle of sideslip, $[rad^{-1}]$
C_{l_β} = Change in rolling momment coefficient due to change in angle of sideslip, $[rad^{-1}]$
C_{n_β} = Change in yawing momment coefficient due to change in angle of sideslip, $[rad^{-1}]$
$C_{n_{T_\beta}}$ = Change in thrust yawing momment due to change in angle of sideslip, $[rad^{-1}]$
C_{L_q} = Change in lift coefficient due to change in pitch rate, $[rad^{-1}]$
C_{m_q} = Change in pitching moment coefficient due to change in pitch rate, $[rad^{-1}]$
C_{y_p} = Change in side-force coefficient due to change in roll rate, $[rad^{-1}]$
C_{l_p} = Change in rolling momment coefficient due to change in roll rate, $[rad^{-1}]$
C_{n_p} = Change in yawing momment coefficient due to change in roll rate, $[rad^{-1}]$
C_{y_r} = Change in side-force coefficient due to change in yaw rate, $[rad^{-1}]$
C_{l_r} = Change in rolling momment coefficient due to change in yaw rate, $[rad^{-1}]$
C_{n_r} = Change in yawing momment coefficient due to change in yaw rate, $[rad^{-1}]$

1. Introduction

The aerodynamic coefficients of airplanes (e.g., lift coefficient, drag coefficient, and moment coefficient) are essential for predicting the airplane performance as they provide information about the forces and moments acting on it. Whereas the aerodynamic derivatives (e.g. stability and control derivatives) are a set of parameters that describe the airplane response to various inputs, such as changes in angle of attack or control surface deflections. Additionally these derivatives include parameters such as pitch and yaw damping, and roll rate. Such derivatives are essential for analyzing the airplane stability and control characteristics.

The evaluation of these Aerodynamic characteristics (i.e., coefficients and derivatives) can be performed using different approaches, such as analytical, empirical, numerical, and experimental. Each approach has its advantages and limitations, and the choice of the method depends on the design phase and the degree of accuracy required. The analytical approach is a mathematical method for evaluating the aerodynamic characteristics and stability and control derivatives of an airplane. This method provides theoretical insights into the aerodynamic behavior of the aircraft of simple geometries and flow configurations, and it is inexpensive. However, it has limitations in handling complex geometries and various flow configurations which consequently, is highly dependent on the accuracy of the mathematical models used. This section will discuss the advantages and disadvantages of the analytical approach in evaluating the aerodynamic characteristics and stability and control derivatives of an airplane in different design processes [1, 2].

For the empirical approach, it is relatively simple and requires less computational resources compared with numerical methods, it can provide quick estimates of the flow around the aircraft. However, empirical methods rely on experimental data that may not be readily available for novel designs, and the accuracy of the methods depends on the quality and quantity of the data used to develop them. Empirical methods can also be limited in their ability to predict complex flow phenomena and do not provide insight into the underlying physics of the flow, making it difficult to understand the impact of design changes on the aerodynamic characteristics and stability and control derivatives [3, 4].

The Analytical-Empirical Approach is a combination of theoretical and empirical methods to develop a mathematical model for predicting airplane behavior under various flight conditions [5]. While this approach has advantages over traditional experimental methods, such as cost and time savings, it also has drawbacks that must be considered. The models can predict airplane behavior without physical experiments and explore a wider range of scenarios. They can also perform sensitivity analyses to assess the impact of design changes on performance. However, the accuracy of the predictions depends on the quality of the data used to develop the models. In addition it may not capture all complex flow phenomena or be suitable for non-conventional airplane designs. Also, empirical data used to validate the models may not cover all flight conditions or scenarios [1, 6].

Table 1: Comparison between Digital DATCOM, XFLR5 and the AeroMech tool

Aspect of Comparison	**Digital DATCOM**	**XFLR5**	**AeroMech tool**
Creation date	1960s	2000s	2020s
Base	Analytical-empirical approach	Numerical approach	Analytical-empirical approach
Friendly user Interface	✗	✓	✓
Ease of inputs	✗	✓	✓
Calculate Aerodynamic characteritics	✓	✓	✓
Calculate Stability derivatives	✓	✓	✓
Graphical Output	✓	✓	✗
Support for Non-Standard configurations	✗	✓	✗
Availability of Open-source Code	✗	✗	✓
Documentation Quality	✗	✓	✓
The ability of integration with other software	✗	✗	✓

Numerical methods provide accurate and detailed predictions by combining analytical equations and computational simulations. They can optimize airplane design and evaluate the impact of design changes relatively inexpensively. Numerical methods, however, can introduce errors and inaccuracies into the predictions. They can also be computationally expensive and require validation with experimental data. Nonetheless, numerical methods are a valuable tool for airplane design and offer insights into a wide range of geometries and flow conditions [7, 8]. Computational fluid dynamics (CFD) simulations provide detailed information about the flow around an airplane and can accurately predict the effects of complex flow phenomena. They are relatively inexpensive compared to wind tunnel testing. However, CFD simulations rely on computational power and require validation with experimental data [9, 10, 11].

The experimental approach involves conducting wind tunnel or in-flight tests to obtain the aerodynamic data and provides insights into complex flow phenomena that may not be captured by other approaches. However, the experimental approach is expensive, and the data can be influenced by various factors that may affect the accuracy of the results. Furthermore, experimental data may be limited in scope and may not cover all flight conditions or scenarios [1, 12, 13, 14].

The choice of the appropriate approach depends on the specific design requirements, available resources, and level of accuracy required. The analytical and empirical approaches are suitable for the preliminary design phase, while the numerical, and experimental approaches are suitable for the detailed design phase. A combination of analytical, empirical, numerical, and experimental methods may be necessary to fully characterize the aerodynamic behavior of an airplane and optimize its design.

The most commonly used tools in the early design steps are Digital DATCOM and XFLR5. Digital DATCOM is an old tool based on empirical method, while XFLR5 is a modern tool based on numerical method. The objective of this paper is to develop an AeroMechanics tool (AeroMech) to expedite the calculations of aerodynamic characteritics with satisfactory accuracy in the early design steps. Table 1 presents a brief comparison between the commonly used tools and the new developed tool (AeroMech).

2. Methodology

The goal of this section is to present a procedure for developing develop a tool that enables the designer to obtain a comprehensive understanding of the airplane aerodynamic characteristics with the limited data that are typically available during the early stages of design. The targeted aerodynamic characteristics are the lift, drag, and pitching moment coefficients as well as the following derivatives (speed, angle of attack, angle of sideslip, rate of angle of attack, rate of angle of sideslip, roll rate, pitch rate, yaw rate). To accomplish this, all necessary analytical-empirical equations presented in [15] are implemented into a Matlab code. Additionally, a large number of empirical charts are digitized and included in this code to make the calculation process easier and more efficient. fig. 1 presents a flowchart that describes the main steps for predicting the airplane aerodynamic characteristics. The next subsection explain these main steps.

2.1. Evaluating lift and pitching moment

The method for calculating lift characteristics involves several key steps. These include determining the zero-lift angle of attack, lift curve slope, linear range of angle of attack, angle of attack for maximum lift, and constructing the wing lift curve.

This can be estimated using empirical data and text book analytical equations. The lift curve is constructed by plotting the lift coefficient as a function of the angle of attack. This curve provides a comprehensive overview of the lift characteristics of the airplane which is essential for determining the overall performance of the airplane.

For calculation of pitching moment characteristics, determine the zero-lift pitching moment coefficient of the airplane C_{m_0} which is a measure of the aircraft's natural tendency to pitch up or down in the absence of any lift. The next step is to calculate the airplane pitching moment curve slope C_{m_α}. This slope is a measure of how the pitching moment changes with angle of attack, and it is an important parameter in predicting the aircraft's stability and control characteristics. Once the pitching moment curve slope has been determined, the next step is to calculate the aerodynamic center shift. This shift is a measure of how the aerodynamic center moves as the angle of attack changes, and it is crucial in predicting the aircraft's stability and control characteristics. The prediction of stable or unstable pitch break is the next step in this method. A pitch break is a sudden change in the aircraft's pitching moment curve slope, which can cause the aircraft to become unstable. By predicting the pitch break point, designers can ensure that the aircraft remains stable and controllable throughout its flight envelope. Finally, the method involves the construction of the wing pitching moment curve. This curve is a graphical representation of the pitching moment as a function of angle of attack, and it is a critical parameter in predicting the aircraft's stability and control characteristics.

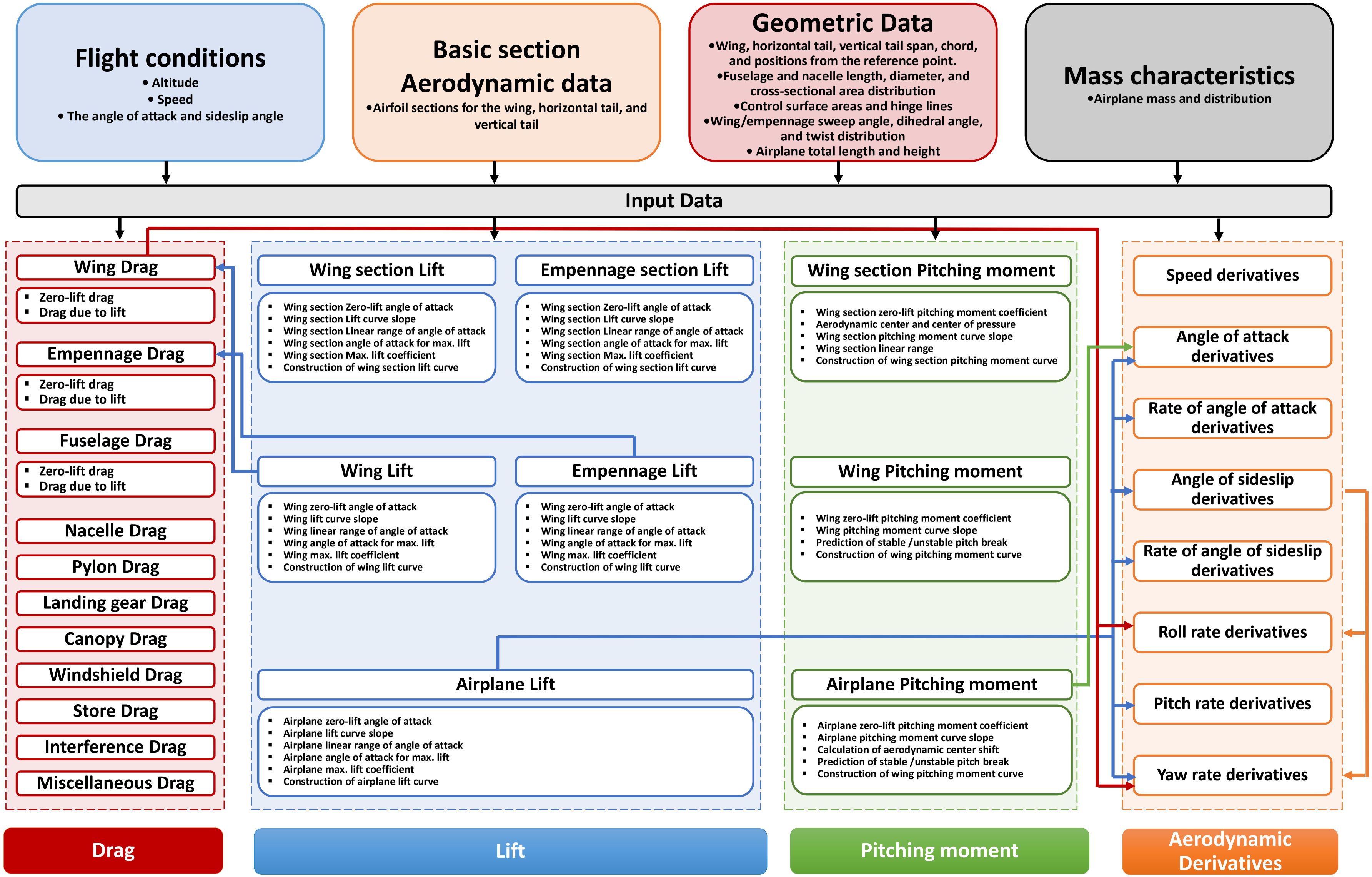


Figure 1: Procedure for developing the AeroMech tool.

2.2. ***Evaluating drag***

The method involves breaking down the sources of drag into various components as shown in fig. 1. This breakdown includes wing drag, empennage drag, fuselage drag, nacelle drag, pylon drag, landing gear drag, canopy drag, store drag, interference drag, and miscellaneous drag. The calculation of each component involves the use of various analytical methods and empirical data, which are combined to produce an overall estimate of the aircraft's drag. Wing drag is calculated based on wing area A, and lift coefficient C_L, while empennage drag is determined based on tail area, and lift coefficient. Fuselage drag is calculated using fuselage length and diameter, while nacelle drag is estimated based on nacelle length and diameter. Pylon drag is determined by analyzing the geometry and flow conditions around the pylon, while landing gear drag is calculated based on the area and configuration of the landing gear components. Canopy drag is calculated based on the canopy area and shape, while store drag is estimated based on the size and shape of the external stores. Interference drag is a composite drag that results from the interaction between various components of the aircraft. This drag is calculated using empirical data, which take into account the flow conditions around the airpalne and the effect of one component on the other. Finally, miscellaneous drag includes all other sources of drag that cannot be accounted for by the above components (e.g., drag from antennas, probes, or other small components). By following this method, an accurate estimate of the total drag of an aircraft can be obtained.

2.3. ***Evaluating Stability derivatives***

The method to calculate the stability derivatives involves many steps. First, the reference point of the airplane is determined (which is the point about which moments are calculated). This point is usually located at or near the center of gravity of the airplane. Then calculating the aerodynamic forces and moments acting on the airplane in each flight condition of interest. This requires determining the lift, drag, and pitching moment coefficients of the wing, tail surfaces, and other components of the airplane. The derivatives of the lift, drag, and pitching moment coefficients with respect to changes in the airplane angle of attack and sideslip angle are calculated. These derivatives are known as the lift, drag, and pitching moment stability derivatives, respectively. The stability derivatives represent the linearized response of the airplane to small changes in these angles. The derivatives of the rolling, yawing, and pitching moments with respect to changes in the airplane roll, yaw, and pitch rates, respectively. These derivatives are known as the rolling, yawing, and pitching moment damping derivatives, respectively. The damping derivatives represent the rate at which the airplane responds to changes in these rates are calculated based on the longitudinal and lateral stability limits for each airplane configuration.

In the next section, the developed tool is used to calculate the aerodynamic characteristics of two convensional case-study airplanes (i.e., Cessna-182 and Cessna-310).

3. Application on a case-study Airplane

The present study aims to compare the aerodynamic characteristics calculated wing AeroMech tool for Cessna-182 and Cessna-310 with the available published data and the data obtained from two widely used aerodynamic analysis software (Digital DATCOM and XFLR5).

The choice of these particular aircraft is based on the following:

- Cessna-182 and Cessna-310 are both widely used and popular airplanes models. As such, they are likely to be familiar to many readers and may serve as useful reference points for comparing our findings to previous research in the field.
- The two airplanes have distinct differences in their design and performance characteristics. The Cessna-182 is a single-engine, high-wing aircraft primarily used for general aviation

purposes, while the Cessna-310 is a twin-engine, low-wing aircraft typically used for light business and commercial applications. By comparing the performance of these two distinct aircraft types, this paper findings aim to provide a broader understanding of the factors that contribute to aircraft performance and validate the accuracy of the presented tool and highlight any discrepancies in performance results that may exist in comparison with the previous findings.

Overall, this comparison will provide a valuable opportunity to explore the factors that influence airplane performance. The Cessna-182 shown in fig. 2 is a single-engine light aircraft with a high-wing configuration, designed primarily for general aviation purposes. The Cessna-310 shown in fig. 3 is a twin-engine light aircraft with a low-wing configuration, designed for both general aviation and business travel purposes. Table 2 shows the specifications of each of them.

Figure 2: Cessna-182 airplane.

Figure 3: Cessna-310 airplane.

Table 2: Specifications of the two case-study airplanes

Parameter	Value		Unit
	Cessna-182	Cessna-310	
Maximum takeoff weight	1406	2087	kg
Empty weight	894	1523	kg
Wingspan	10.97	11.25	m
Total length	8.84	9.74	m
Height	2.84	3.25	m
Wing area	16.2	16.6	m^2
Cruise speed	269	330	km/h
Max power	230	285	hp
No. of engines	1	2	-
Powerplant	Lycoming IO-540-AB1A5	Continental IO-520-MB	-

4. AeroMech Verification

In order to verify the aerodynamic characteristics obtained from the AeroMech tool, Digital DATCOM and XFLR5 are used to obtain aerodynamic characteristics of the two case studies and the results are compared. This comparison will help to determine the reliability of our AeroMech tool in predicting the aerodynamic characteristics of the airplane. After that, published data are used to validate the AeroMech tool results. This validation will provide an additional level of confidence in the accuracy and reliability of our AeroMech tool.

4.1. ***Digital DATCOM***

The Digital DATCOM is a computer program that utilizes a systematic approach to estimate the aerodynamic, stability, and control characteristics of an airplane. This program is designed to provide rapid and economical estimations, which are essential in preliminary design operations. In these operations, designers need to obtain estimates of these characteristics quickly, but complex automated estimation procedures can be time-consuming and computationally expensive. Hand-calculation procedures are also inefficient as they require significant man-hours, especially when configuration trade studies or estimates over a range of flight conditions are involved [16, 17]. The Digital DATCOM program is developed based on the philosophy of the USAF Stability and Control Datcom, which aims to provide a systematic summary of methods for estimating stability and control characteristics in preliminary design applications [18]. The Digital DATCOM program utilizes a modular approach to estimate the aerodynamic characteristics of the airplane. It consists of various modules that are specialized in estimating different characteristics such as lift, drag, pitching moment, rolling moment, yawing moment, and control derivatives. The program also includes modules to estimate the static stability derivatives, which are the derivatives that describe the tendency of the airplane to return to its trimmed condition after a disturbance [19].

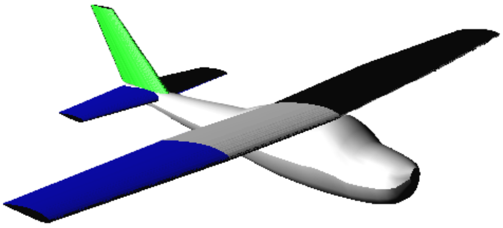


Figure 4: Cessna-182 3D-model in Digital DATCOM.

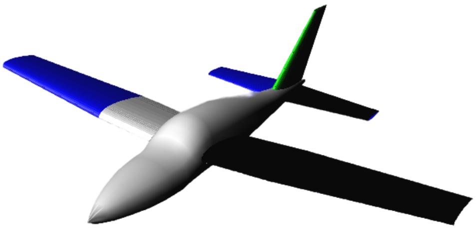


Figure 5: Cessna-310 3D-model in Digital DATCOM.

The Digital DATCOM program allows the designer to input the airplane geometry, including wing planform, fuselage geometry, and control surface deflections. The program then calculates the corresponding aerodynamic derivatives, which are essential inputs to the stability and control analysis of the airplane. The accuracy of the Digital DATCOM program depends on the accuracy of the input geometry and the limitations of the program figs. 4 and 5 show the two case-studies.

4.2. ***XFLR5***

XFLR5 is a popular computer program that is used to analyze and calculate the aerodynamic characteristics of aircraft. The program is based on the potential flow theory, which assumes that the air around an aircraft moves in a predictable manner and that the flow is irrotational, inviscid, and incompressible. XFLR5 uses numerical methods to solve the equations that describe the airflow around an aircraft, and it can provide a wide range of information about the aircraft's performance, including lift and drag coefficients, pitching moments, and pressure distributions [3]. XFLR5 is a widely used tool for aircraft design and analysis, and it has been validated through extensive experimental data and comparison with other numerical methods. The program has been used in various research studies and has been cited in numerous scientific publications [20].

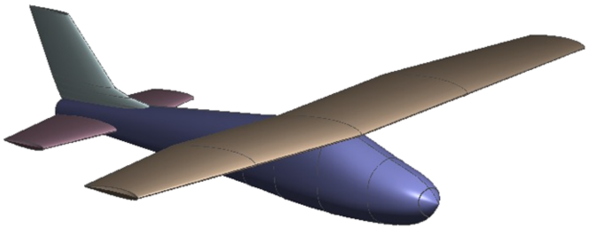


Figure 6: Cessna-182 3D-model in XFLR5.

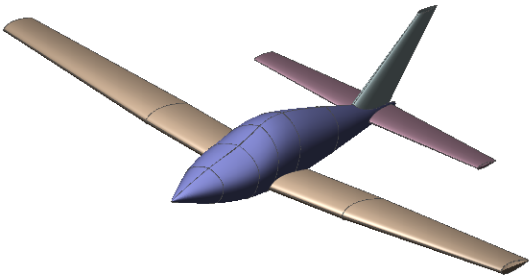


Figure 7: Cessna-310 3D-model in XFLR5.

To calculate the aerodynamic characteristics of an aircraft using XFLR5, the user must first create a 3D model of the aircraft along with its physical properties, such as its wing span, wing area, and airfoil sections. XFLR5 has a built-in airfoil database that contains a large number of commonly used airfoils, and the user can also import custom airfoil data. Once the aircraft model is set up, the user can simulate various flight conditions, such as different angles of attack, velocities, and altitudes. XFLR5 calculates the aerodynamic characteristics of the aircraft by solving the potential flow equations using a panel method. The program divides the surface of the aircraft into small flat panels and calculates the velocity and pressure at each panel. The program then uses these values to calculate the lift, drag, and pitching moment coefficients of the aircraft. Also the software provides graphical outputs, such as pressure distributions over the aircraft surface and streamlines of the airflow.

The first step in using XFLR5 to calculate aerodynamic characteristics for the case-study airplane was to create a three-dimensional digital model of the airplane's geometry. This was accomplished using a computer-aided design (CAD) internally in the program to create a solid model of the airplane's fuselage, wings, tail, and other components. The model was then imported into XFLR5 for analysis. The next step was to divide the airplane's geometry into small computational sections, each with a specific shape and orientation. These sections are commonly referred to as "panels" and are used to represent the airplane's geometry. The number and size of the panels can be adjusted to balance accuracy with computational efficiency. After the panels have been defined, XFLR5 predict the aerodynamic forces acting on the airplane. These forces include lift, drag, and moment, which are essential for predicting the airplane's performance. The angle of attack and airspeed of the airplane are varied in the simulation to determine the lift, drag, and moment coefficients as a function of these parameters.

The results of the simulation are then analyzed to determine the airplane's key aerodynamic characteristics, including its maximum lift coefficient, stall speed, drag polar, and stability derivatives. The drag polar provides a plot of the drag coefficient as a function of the lift coefficient, which is critical in determining the airplane's performance in terms of range, endurance, and fuel consumption. The stability derivatives provide information on the airplane's longitudinal, lateral, and directional stability, which is essential for predicting its handling qualities figs. 6 and 7 show the output CAD of the two case-studies.

4.3. ***Discussion of results***

The aerodynamic characteristics of airplanes that investigated using our AeroMech tool based on an analytical-empirical method. The results obtained from this tool were compared with those obtained from Digital DATCOM and XFLR5. Overall, the results showed good agreement with the reference software, although some logical differences were observed.

The discrepancies between the results obtained by the AeroMech tool and the reference software can be attributed to a number of factors. One possible explanation is that the analytical-empirical method used by the AeroMech tool is based on simplified models of aerodynamic phenomena, which may not capture all the complexities of real-world conditions. In contrast, the softwares employs more sophisticated numerical methods, which can better account for the intricacies of the flow field. Another potential source of discrepancy is the underlying assumptions used in the different softwares, as they may make certain assumptions about the airplane configuration or operating conditions. These differences in assumptions can lead to variations in the predicted aerodynamic characteristics.

All these results shown in figs. 8 to 32 also demonstrate good agreement with published data, with some differences. These differences can be attributed to a number of factors, including differences in the computational methodologies employed, variations in the experimental data utilized for comparison, and inherent limitations in the modeling assumptions used in the analytical-empirical approach.

The lift curve for both the Cessna-182 and Cessna-310 shown in figs. 8 and 9 airplane demonstrates that the lift coefficient values obtained from the XFLR5 and AeroMech software tools exhibit a high degree of similarity, while the Digital DATCOM method demonstrates minimal deviation in the curve slope. These results indicate a satisfactory level of agreement with the published data. The results of the pitching moment curve conducted on the Cessna-182 and Cessna-310 shown in figs. 10 and 11 indicate that the three corresponding curves produced using AeroMech tool, Digital DATCOM, and XFLR5 demonstrate comparable values. Despite Digital DATCOM presenting a marginal variance in the zero lift pitching moment coefficient for Cessna-182 and XFLR5 revealing a slight deviation in the same parameter for Cessna-310, all three curves exhibit a high degree of consistency with the published data. The drag curve analysis of Cessna-182 and Cessna-310 figs. 12 and 13 indicates that the three approaches produce highly similar curves, with minimal differences between them. Moreover, all three tools generate results that are consistent with published data.

The C_{L_q} derivatives findings of the two case studies indicate that the AeroMech tool produces values that are moderately close to the published data. However, the discrepancies observed can be attributed to the variations in flight conditions, geometric data of all airplane components, propulsion data, as well as the lift and pitching moment of the airplane. The C_{n_β} derivatives analyses of the two case studies as C_{L_q} in addition to the dependency on the pitching moment of the airplane. The findings from the analysis of the C_{y_p}, C_{n_p}, and C_{y_r} derivatives of both the Cessna-182 and Cessna-310 indicate that the values generated using the AeroMech tool are moderately close to the published data. However, these differences can be attributed to variations in the inputs of flight conditions, as well as the geometrical data of all components of the airplane, the propulsion data, and the airplane's lift, pitching moment, drag, and angle of sideslip derivatives. the rest of the derivatives results of the two case studies demonstrate a high degree of similarity between the computed values using the AeroMech tool and the published data. It is important to note that accurate prediction of these parameters is crucial for ensuring the safety and efficiency of flight operations. Therefore, further studies are warranted to enhance the precision of the AeroMech tool for reliable and precise predictions of airplane performance All these results shown in figs. 14 to 32. Despite these differences, the tool has proven to be an effective means of assessing the aerodynamic characteristics of airplanes and represents a promising approach for predicting them.This tool offers a fast and efficient means of generating predictions, making it well-suited for early-stage design analysis.

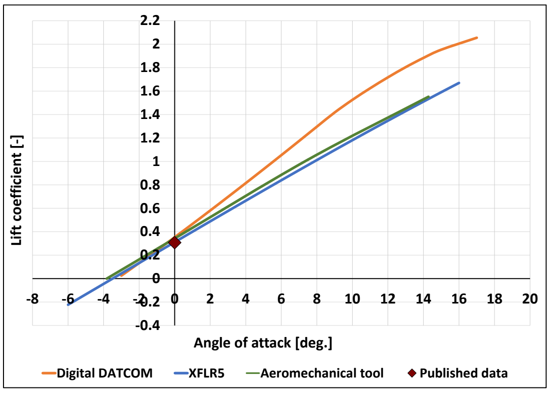


Figure 8: Lift curve for Cessna-182.

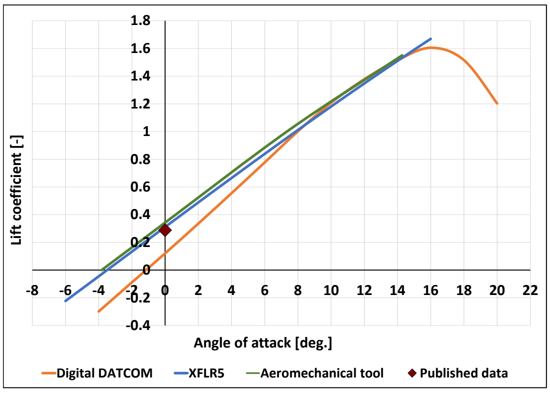


Figure 9: Lift curve for Cessna-310.

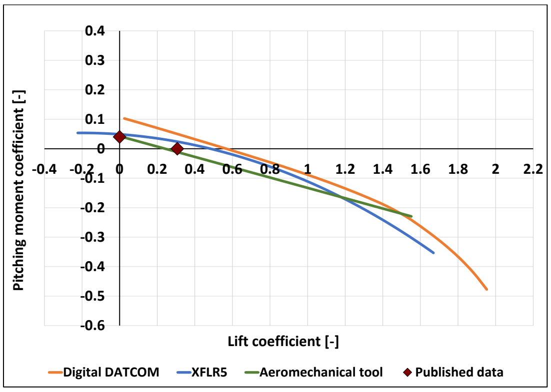


Figure 10: Pitching moment curve for Cessna-182.

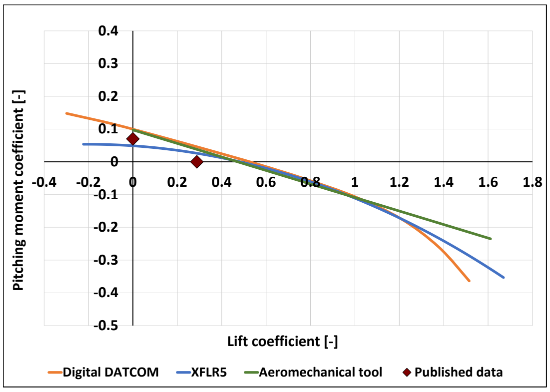


Figure 11: Pitching moment curve for Cessna-310.

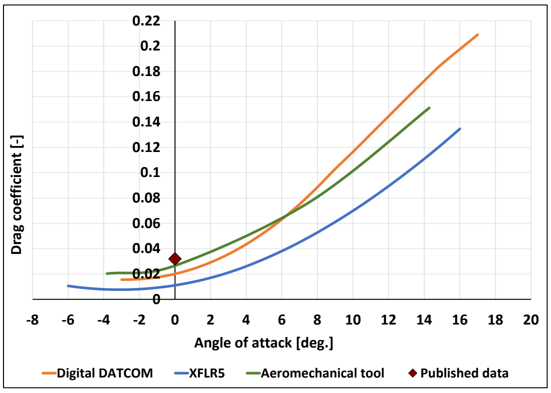


Figure 12: Drag curve for Cessna-182.

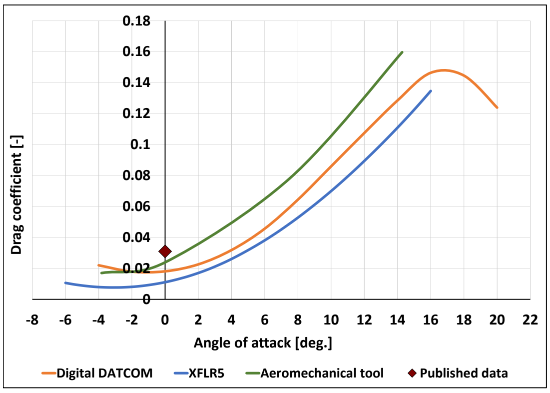


Figure 13: Drag curve for Cessna-310.

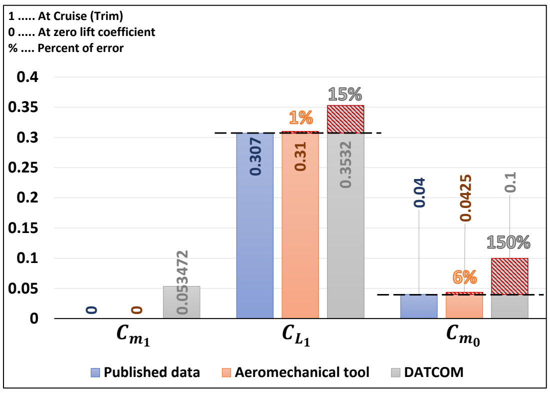


Figure 14: Aerodynamic coefficients for Cessna-182

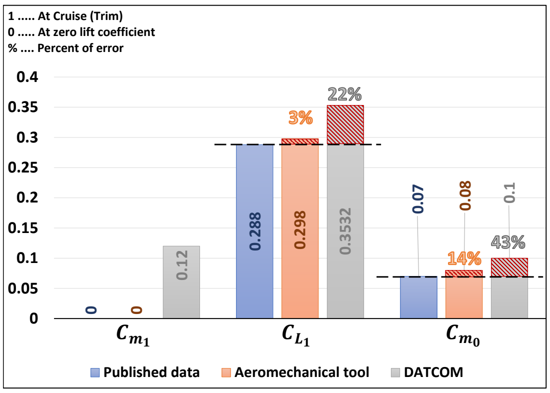


Figure 15: Aerodynamic coefficients for Cessna-310.

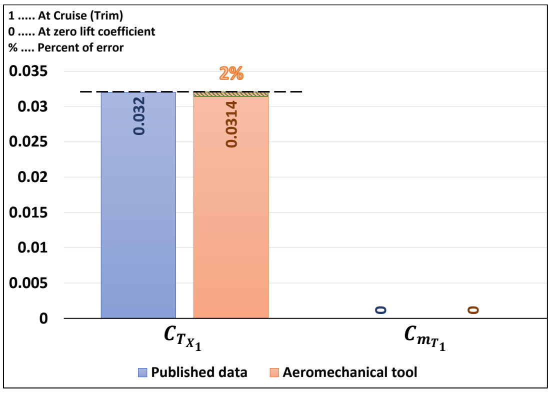


Figure 16: Steady-state derivatives for Cessna-182.

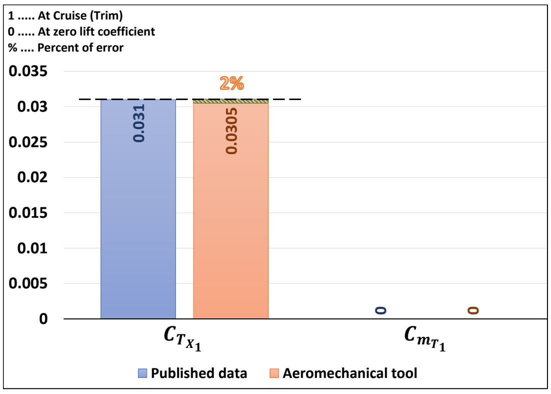


Figure 17: Steady-state derivatives for Cessna-310.

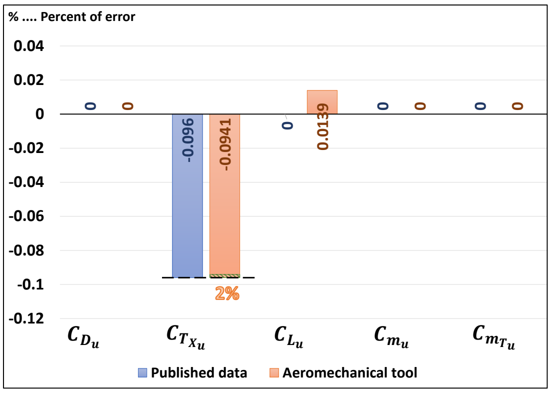


Figure 18: Speed derivatives for Cessna-182.

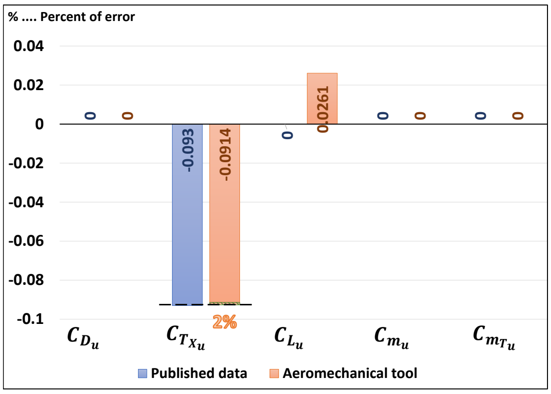


Figure 19: Speed derivatives for Cessna-310.

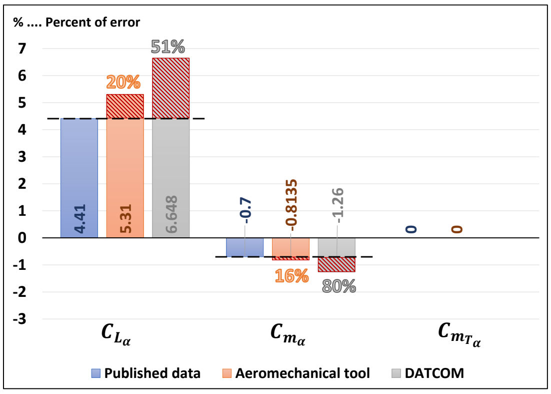


Figure 20: Angle of attack derivatives for Cessna-182.

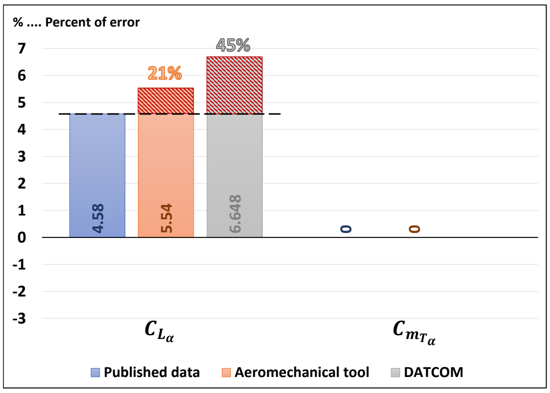


Figure 21: Angle of attack derivatives for Cessna-310.

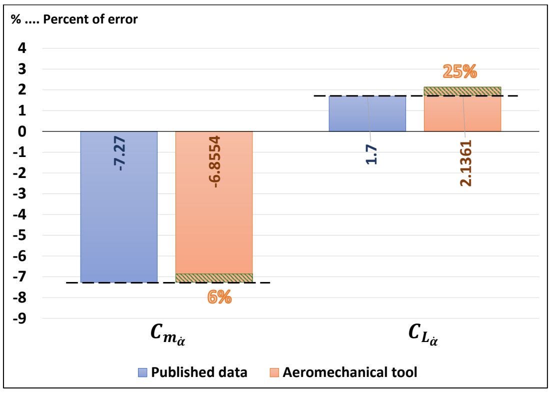


Figure 22: Rate of angle of attack derivatives for Cessna-182.

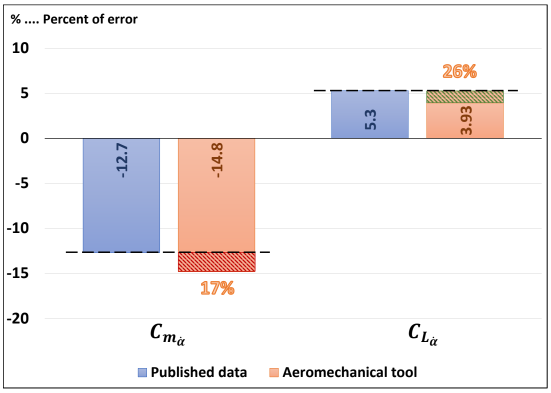


Figure 23: Rate of angle of attack derivatives for Cessna-310.

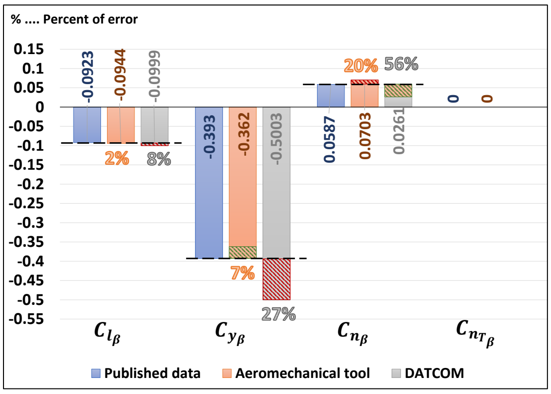


Figure 24: Sideslip angle derivatives for Cessna-182.

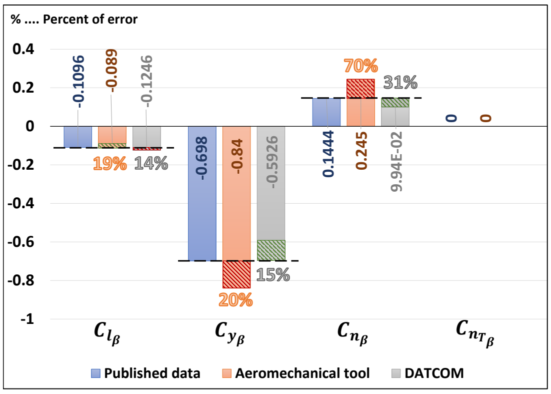


Figure 25: Sideslip angle derivatives for Cessna-310.

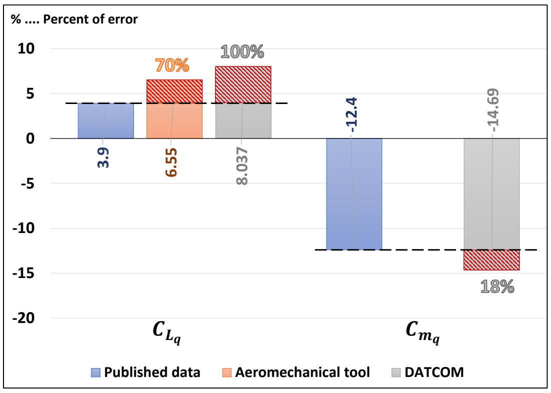


Figure 26: Pitch rate derivatives for Cessna-182.

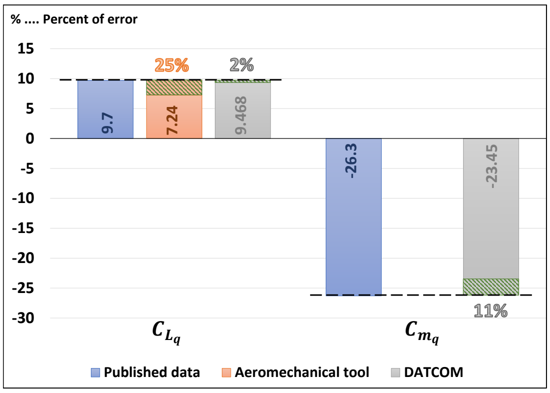


Figure 27: Pitch rate derivatives for Cessna-310.

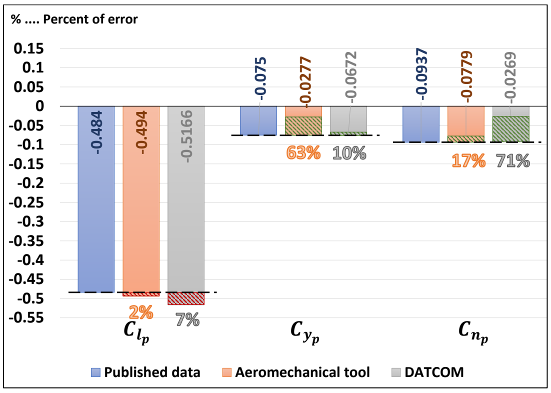


Figure 28: Roll rate derivatives for Cessna-182.

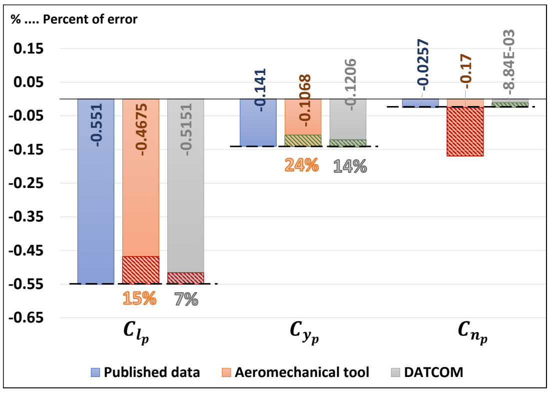


Figure 29: Roll rate derivatives for Cessna-310.

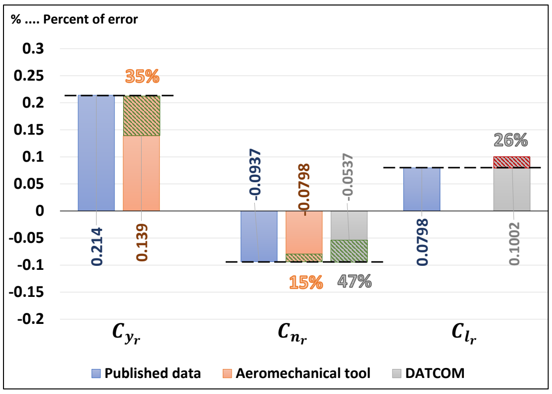


Figure 30: Yaw rate derivatives for Cessna-182.

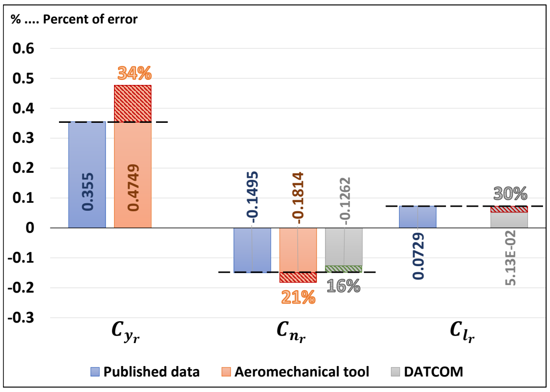
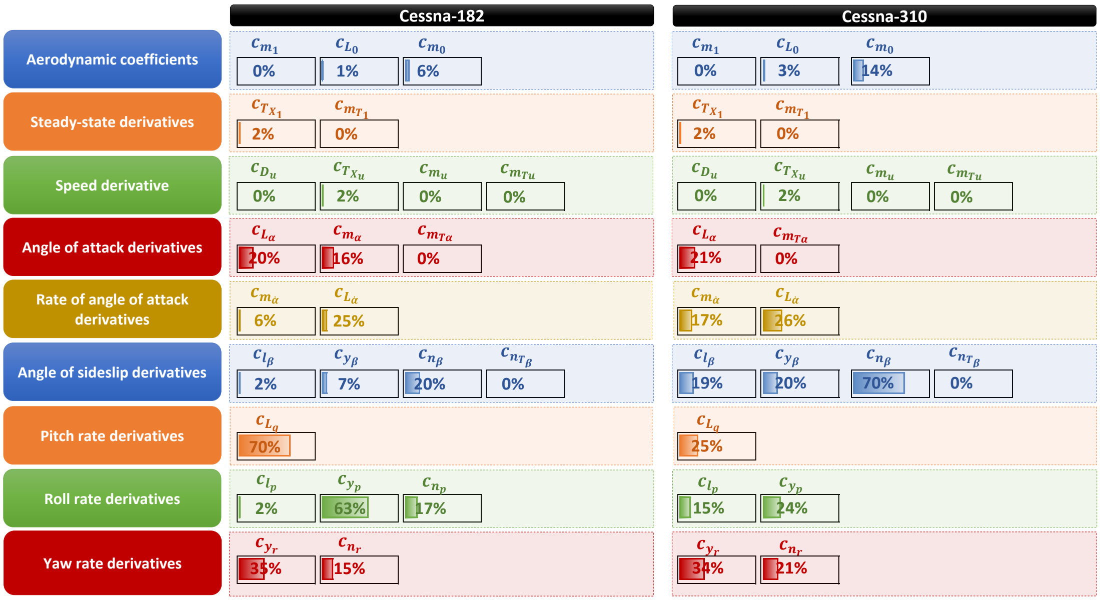


Figure 31: Yaw rate derivatives for Cessna-310.



	Cessna-182	Cessna-310
Aerodynamic coefficients	c_{m_1} 0% c_{L_0} 1% c_{m_0} 6%	c_{m_1} 0% c_{L_0} 3% c_{m_0} 14%
Steady-state derivatives	$c_{T_{X_1}}$ 2% $c_{m_{T_1}}$ 0%	$c_{T_{X_1}}$ 2% $c_{m_{T_1}}$ 0%
Speed derivative	c_{D_u} 0% $c_{T_{X_u}}$ 2% c_{m_u} 0% $c_{m_{Tu}}$ 0%	c_{D_u} 0% $c_{T_{X_u}}$ 2% c_{m_u} 0% $c_{m_{Tu}}$ 0%
Angle of attack derivatives	c_{L_α} 20% c_{m_α} 16% $c_{m_{T\alpha}}$ 0%	c_{L_α} 21% $c_{m_{T\alpha}}$ 0%
Rate of angle of attack derivatives	$c_{m_{\dot\alpha}}$ 6% $c_{L_{\dot\alpha}}$ 25%	$c_{m_{\dot\alpha}}$ 17% $c_{L_{\dot\alpha}}$ 26%
Angle of sideslip derivatives	c_{l_β} 2% c_{y_β} 7% c_{n_β} 20% $c_{n_{T_\beta}}$ 0%	c_{l_β} 19% c_{y_β} 20% c_{n_β} 70% $c_{n_{T_\beta}}$ 0%
Pitch rate derivatives	c_{L_q} 70%	c_{L_q} 25%
Roll rate derivatives	c_{l_p} 2% c_{y_p} 63% c_{n_p} 17%	c_{l_p} 15% c_{y_p} 24%
Yaw rate derivatives	c_{y_r} 35% c_{n_r} 15%	c_{y_r} 34% c_{n_r} 21%

Figure 32: Error of results of AeroMech tool.

5. Conclusion

This study provides valuable insights into the strengths and limitations of different approaches for evaluating aerodynamic characteristics and stability derivatives and can inform the selection of appropriate methods for specific aircraft design and analysis applications. Each of the different approaches used in this study has its strengths and limitations, and it is important to understand the underlying assumptions and limitations of each approach when using it to calculate aerodynamic characteristics and stability derivatives. By comparing the results obtained from different approaches, this study provides a useful benchmark for validating and improving the accuracy of these tools for the design and analysis of aircraft. Further research could focus on improving the accuracy of the models used in each approach and refining the assumptions made to reduce errors and uncertainties in the calculated values.

This paper describes the development and verification of a tool for rapid estimation of airplane aerodynamic characteristics during early design stages. The tool was successfully used to calculate the aerodynamic characteristics of two airplanes, Cessna-182 and Cessna-310. The results obtained were verified using two different methods, Digital DATCOM and XFLR5, which rely on empirical and numerical methods, respectively.

The verification process indicated that the results obtained from the tool were in good agreement with the results obtained from both Digital DATCOM and XFLR5. Additionally, the results were also validated using published data for the same airplanes, which further confirmed the accuracy of the tool. It is important to note that the different methods used to verify the results have their own logical differences, which can result in some variation in the final results. For example, the empirical method used in Digital DATCOM relies on experimental data and empirical relations, while the numerical method used in XFLR5 solves the governing equations numerically. However, the results obtained from all three methods were in agreement and confirmed the accuracy of the tool. Overall, the developed tool provides a rapid and accurate estimation of airplane aerodynamic characteristics during early design stages, which can significantly reduce the design cycle time and costs. The successful verification and validation of the tool using different methods and published data confirm its reliability and effectiveness in the field of aircraft design.

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