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Computational numerical analysis of drag force on a standard AeroDesign wing in accordance with winglet application

Análise numérica computacional da força de arrasto em uma asa padrão AeroDesign de acordo com a aplicação do winglet

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Resumo
O objetivo deste trabalho é alcançar um melhor desempenho em voo e coadjuvar no carregamento da maior carga paga possível. O setor de aerodinâmica atua na melhoria da eficiência aerodinâmica da aeronave, portanto, o aerodinamicista procura a melhor solução que contribua para a eficácia da aeronave, tal como a redução das forças de arrasto. O arrasto induzido provém da força de sustentação e relaciona-se com os vórtices de fuga que surgem nas pontas da asa, além de ser o componente do arrasto que apresenta maior relevância comparado aos demais. A utilização de componentes estruturais, como *winglets*, auxilia na redução desses vórtices e na redução do arrasto total da aeronave. No contexto da competição SAE Brasil *AeroDesign*, o emprego destes componentes pode atender aos requisitos do projeto, visto as restrições de regulamento. A

metodologia empregada foi a simulação utilizando o software *ANSYS CFX®* para asas modeladas com diferentes configurações de *winglet* e mesmas condições de contorno, no intuito de verificar a melhor aplicação para a asa em estudo. Fixou-se o ângulo de diedro do *winglet* em 45°, manteve as cordas e utilizou a altura do *winglet* como parâmetro a ser estudado. Nas simulações, variou-se o ângulo de ataque da asa para obter a variação da força de arrasto. Nos resultados obtidos ´foi possível verificar que as forças de sustentação das asas com *winglet* de h=10% da semi envergadura, além de possuir valores menores de força de arrasto, apresentam valores superiores de força de sustentação, para todos os ângulos analisados, com uma variação de até mais de 6 N de força de sustentação em relação a asa sem *winglet*. Conclui-se que foi possível observar uma melhoria de desempenho da asa com a aplicação do *winglet*, no contexto do *AeroDesign*, e que a compensação no ganho de eficiência pode auxiliar nas equipes de competição a levarem mais carga na aeronave, devido ao aumento de sustentação, e, também, auxiliar nas manobras de decolagem e pouso da aeronave.
Palavras-chave: Arrasto induzido. *Winglets*. Aerodinâmica.

Abstract
This work goal is to achieve a better flight performance and to support the loading of the highest payload possible. The aerodynamics sector works to improve the aircraft aerodynamic efficiency; therefore, the aerodynamicist looks for the best solution to contribute to the aircraft efficiency by reducing drag forces. The induced drag comes from the lift force, it is related to the escape vortices which occur at the wing tips and it is the most relevant drag component. The use of structural components, as winglets, helps to reduce these vortices and the total aircraft drag. In the context of the SAE Brazil AeroDesign competition, the use of these components can support the project requirements due to the regulatory restrictions. The methodology employed was a simulation using the ANSYS CFX® software for wings modeled with different winglet configurations and the same boundary conditions to verify the best application for the studied wing. The winglet dihedral angle was set at 45°, the strings were maintained and the winglet height was used as a parameter. In the simulations, the wing attack angle was varied to obtain the variation of the drag force. With the obtained results, it was possible to verify that the wings lift forces with h=10% of the half-span winglet have lower values of drag force and present higher values of lift force, for all the analyzed angles, with a variation of up to 6 N of lift force, regarding to the wing without winglet. It is concluded the possibility to observe an improvement in the performance of the wing with the application of the winglet, in the above-mentioned context, and the compensation of a higher efficiency can help competition teams to carry more load on the aircraft due to the lift increase, and to assist the aircraft takeoff and landing handling.
Keywords: Induced drag. Winglets. Aerodynamics.

1. Introduction

Aerodynamics studies are a part of fluid mechanics responsible for studying the interactions and forces acting between the air and an object immersed in it. It has a wider application then the land or air vehicles designers are in a constant search for aerodynamic improvements to increase the overall efficiency of these vehicles.

Barbosa et al. (2018) emphasize that, for aircrafts, one of the main searched components for aerodynamic optimization are the wings, "since it is responsible for generating the majority forces needed to preserve the aircraft in flight”. However, wings are responsible for creating a portion of the aircraft drag forces. According to Weng et al. (2017), most of the spent energy on transportation is due to drag, being essential to reduce it.

Drag can be largely categorized, including pressure drag. It is common that ninety percent of the vehicle total drag is characterized as pressure drag. The pressure drag unfolds into two other types: induced drag and shape drag (CASTEJON, 2011).

In Giuberti’s (2013) study, he clarifies that the factor that presents the greatest contribution to the aircraft total drag is the induced drag, reaching values close to forty percent of a commercial aircraft total drag. The author also adds that for low speeds and during a take-off, the induced drag can reach a mark of eighty to ninety percent of the total drag generated by the aircraft, becoming the most critical factor.

For the SAE AeroDesign competition context, the teams’ main goal is to carry as much load as possible. Therefore, teams generally select high lift profiles with low Reynolds numbers to set the aircraft wing and to look for ways to reduce the overall drag. Therefore, induced drag corresponds to a significant portion of the total drag and it is strongly related to lift, wing geometry and wing tip vortices caused by three-dimensional flow. According to Narayan and John (2016), this can be explained by Prandtl's Sustaining Line Theory. Thus, one form to minimize induced drag and improve aircraft performance is to optimize wing geometry or use wing tip devices that will increase the aerodynamic efficiency.

Belferhat et al. (2013) explain that during the flight, the pressure difference of the wing intro and extro soar, from the lift process creates vortices at the wing tip. It is known that this is an extra component which can be minimized. Therefore, a winglet concept was developed, changing the velocity and pressure field it diffuses the created vortex and reduces the downwash. Consequently, the induced drag is also reduced (JOHANSEN & SORENSEN, 2006; PANAGIOTOU et al. 2014).

The analysis of airflow of aircraft is very complex due to the several three-dimensional properties that the flow has. Thus, the purely analytical calculation becomes laborious and sometimes is impractical to determine the forces and moments acting in the aircraft. However, wind tunnel tests and Computational Fluid Mechanical Analysis tools are of great value in predicting the aerodynamic efforts that the aircraft may be subject to.

Due to the complex nature of wing tip vortices, the effects of winglet application can vary and it can bring losses or gains in the aircraft performance. Therefore, it is imprescriptible to test and evaluate different winglet configurations before installing it on a wing. Consequently, the development and optimization of these devices has been the subject of several studies. In a pioneering study, Krishnan et al. (2020) investigated the application of a Rüppell's Griffon Vulture (RGV) type winglet to a rectangular wing. The results showed that by using an RGV winglet, there was an increase of 25% to 75% in aerodynamic efficiency compared to other types of winglet configurations. Liauzun et al. (2018) studied the concepts of morphing winglets which are wingtip devices with variable surfaces. Toor et al. (2016) checked the effects of varying the winglet parameters on the overall winglet performance, such as dihedral, incidence and bending angle, wingspan and tapering. Using ANSYS Fluent®, Munshi et al. (2018) investigated the effect of the winglet dihedral angle at different angles of attack on the ONERA M6 wing. The wing without winglet was compared with the wing with winglet and an improvement up to 25% in aerodynamic efficiency in a transonic regime was obtained. However, the performance decreases when the angle of attack is increased to 6 degrees. The effects of different dihedral angles at different angles of attack were also investigated by Beechook and Wang (2013) and Abdelghany et al. (2016).

In a study related to Unmanned Aerial Vehicles (UAVs), with similar aircrafts to those competing in the SAE Brazil AeroDesign competition, Kontogiannis and Ekaterinaris (2013) used Computational Fluid Dynamics (CFD) to evaluate the aerodynamic characteristics of the design and their included in the study an analysis of the use of winglet in the aircraft. The researchers concluded that its use contributes to reducing the effects of vortices in the wing tip and, consequently, it minimizes the induced drag.

According to Guerrero et al. (2018), there are several types of wing tip devices, however, the final purpose is always the same, to reduce the induced drag. Thus, the objective of this work is to verify the best winglet configuration applied in a wing in accordance with the variation of its height, aiming to obtain a lower induced drag and maybe a better overall performance for the standard AeroDesign aircraft. In order to achieve this goal, a simulation via ANSYS CFX® of the same wing with different winglet configurations will be performed.

One of the requirements for AeroDesign projects is to minimize the airplane drag. Thus, the proposed study and its results will allow a knowledge of the best arrangement for the winglet, providing an improvement of the aircraft performance. According to Zhang *et al.* (2019), the use of the winglet is very effective to reduce induced drag.

2. Material and Methods

The main goal of this work is to develop a winglet that presents aerodynamic benefits for an AeroDesign type wing. The used parameter in the winglet optimization was the height. Narayan and John (2016) used the height of the winglet as 10% of the semi wingspan and Giuberti (2013) used a winglet height value around 19% of the semi wingspan.

For Elham and Tooren (2014), adding winglets to a wing can bring aerodynamic improvements, but it can also lead to structural problems and increase wing weight. According to Eguea et al. (2018), winglets can also increase the viscous drag component, which can negatively impact the aircraft performance. Hence, considering 19% of the semi-span as a high measurement, it could interfere with the structure of the analyzed AeroDesign aircraft. The present study analyzed 4 different configurations for the same wing.

The first configuration was the wing without winglets. The second one, the same wing with a winglet of 5% of the wingspan. The third one, a wing with a winglet of 10% of the half-span. The fourth on, a wing with 15% of the half-span. All wing configurations were analyzed according to a winglet dihedral angle (θ) of 45 degrees, varying the angle of attack (α) between 0 and 10 degrees.

To perform the analyses SolidWorks® and ANSYS CFX® softwares were used, having the necessary tools for three-dimensional modeling and computational analysis.

Finally, the results obtained were analyzed and compared with each other to verify the influence of the winglets in the wing drag force and the aerodynamic efficiency.

In this work, the wing used was designed based on the characteristics of the most used AeroDesign competition aircraft, at size and shape. In order to simplify the calculations and to reduce the computational effort in the simulations, half of the selected wing was used, cut by a plane symmetry at its center. Table 1 exhibits the dimensions of the used wing.

Table 1 - Wing configurations.

Aerodynamic Profile	NACA 4412
Semi-span (b/2)	1200 mm
Root string (RS)	450 mm
Tip string (TS)	200 mm
Average Aerodynamic string (AAS)	395 mm
Aspect Ratio (AR)	6.360
Wing tip offset	170 mm
Projected Area (PA)	0.905 m²

It is a rectangular-trapezoidal wing, where the central region is rectangular and, after a 500 mm wingspan, the wing changes its geometry to a trapezoid as shown in Figure 1.

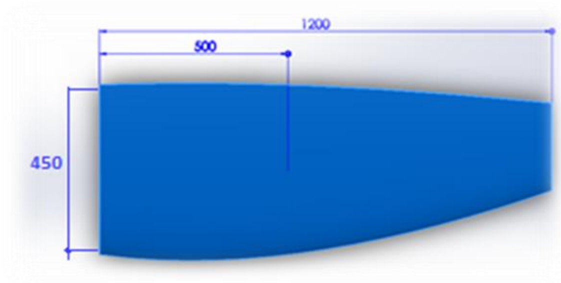

Figure 1 - Wing configuration (Strings in mm).

For the winglet configuration, the dihedral angle was fixed at 45°. This angle was chosen considering the studies of Alzin et al. (2011), Ashrafi and Sedaghat (2014) and Azeez et al. (2019). They verified different configurations of winglets in low subsonic flow regime and low Reynolds numbers. This situation is similar to the aircraft participating in SAE Brasil AeroDesign competition. Therefore, it was found that winglets with a dihedral angle of 45º presented a higher lift coefficient and high aerodynamic efficiency compared to the wing without winglets or with winglets with different dihedral angles. Fixing the dihedral angle at 45°, its height (h) was varied, as illustrated in Figure 2. Table 2 presents the general geometric dimensions of the winglets.

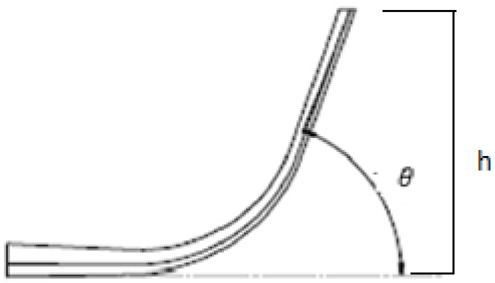

Figure 2 - Winglet Geometric representation. Source: Adapted from Narayan and John, 2016.

Table 2 – Winglets Geometric Parameters.

Aerodynamic Profile	NACA 0010
Winglet dihedral angle, θ	45°
Root string, RS	200 mm
Tip string, TS	100 mm
Average aerodynamic string, AAS	150 mm
Winglet tip offset	50 mm

Once the parameters were defined, SolidWorks® software was used to design the geometries 3D models and then transferred to ANSYS®. Figures 3 and 4 exhibit the designs of the wing without and with the winglet, respectively.

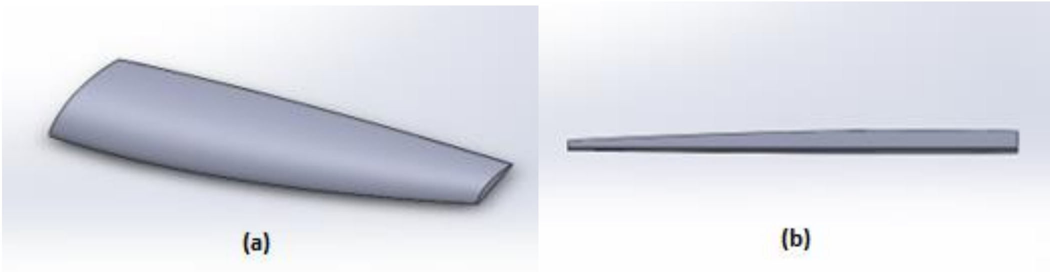

Figure 3 - CAD drawing of the wing without winglet. (a) Isometric view; (b) Front view.

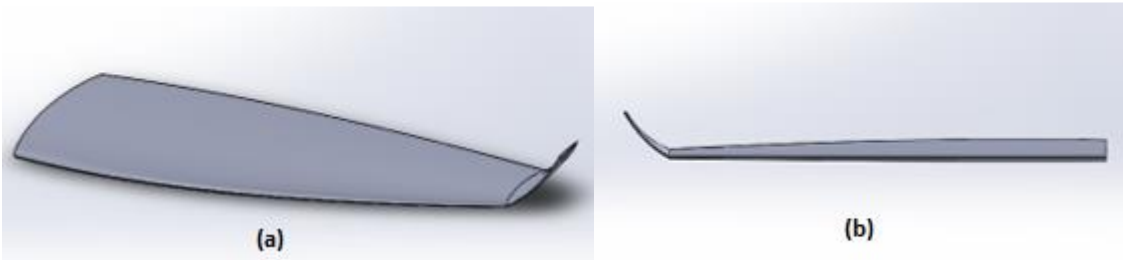

Figure 4 - CAD drawing of the wing with winglet (a) Isometric view; (b) Front view.

After creating the project in Computer Aided Design (CAD) software, the following stage is the CFX simulation. It should be noted that in CFD, the flow has a finite domain, the fluid (the air) that flows around the wing is bordered on all sides, defining the domain around the wing.

The process of generating an efficient mesh consists of using several methods available within CFX-Meshing. Initially, the Body Sizing tool, which delimits the influence body around the wing (Figure 5), was used to improve refinement in that region and to save computational time during the performing of the numerical simulation. For Body Sizing, it was used $2x10^{-2}$ m with a growth rate of 1.2.

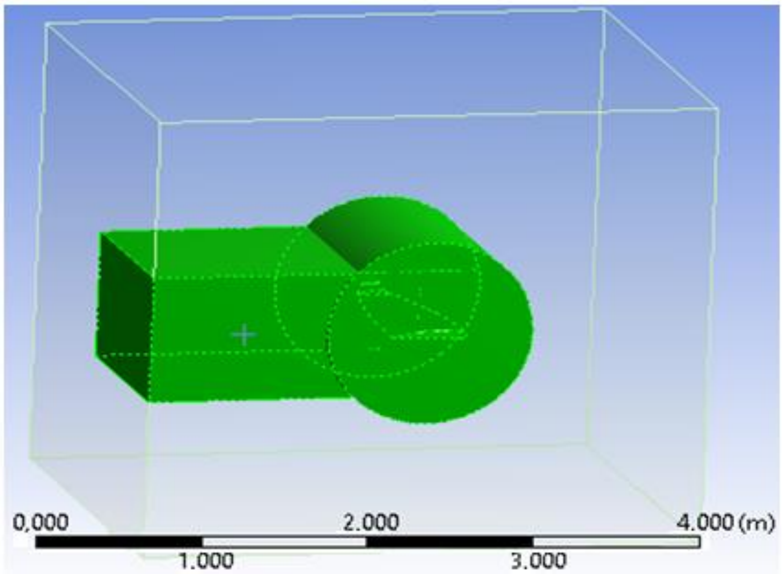

Figure 5 - Delimitation of the Body of Influence around the wing.

Finally, the Inflation tool was used in the wing surface. This tool allows creating prismatic elements in the selected contour, the wing, and is used in order to generate a more uniform and organized mesh, facilitating the capture of the flow conditions in the region. Inflation was applied in the entire wing surface with a maximum of 20 layers of prismatic elements at a growth rate of 1.4.

Figures 6, 7 and 8 present the mesh created for the wing. It can notice the differentiation between the mesh elements of the influence body and the rest of the domain. It is possible to examine the level of created mesh refinement in the wing surface due to the use of Inflation tool.

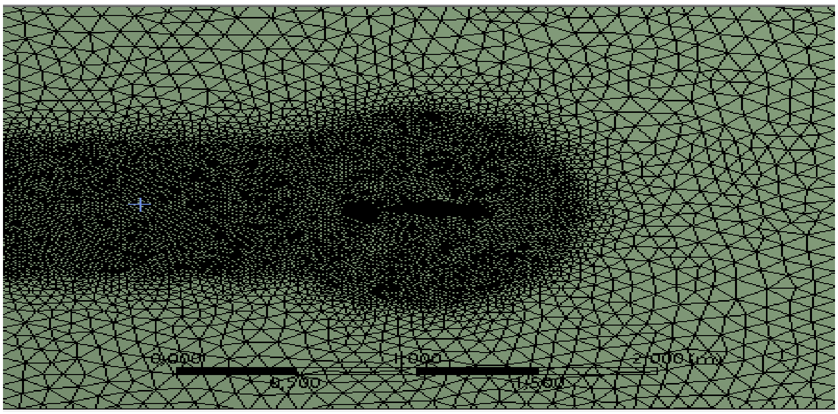

Figure 6 - Mesh generated across the domain.

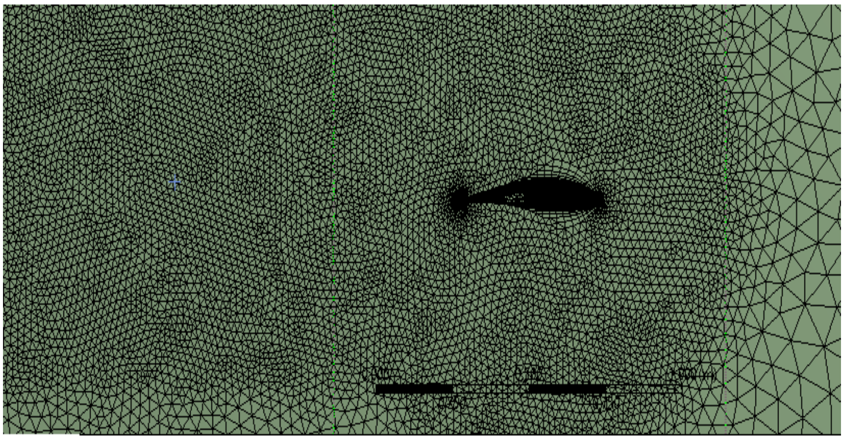

Figure 7 - Detail of the mesh generated by the Influence Body.

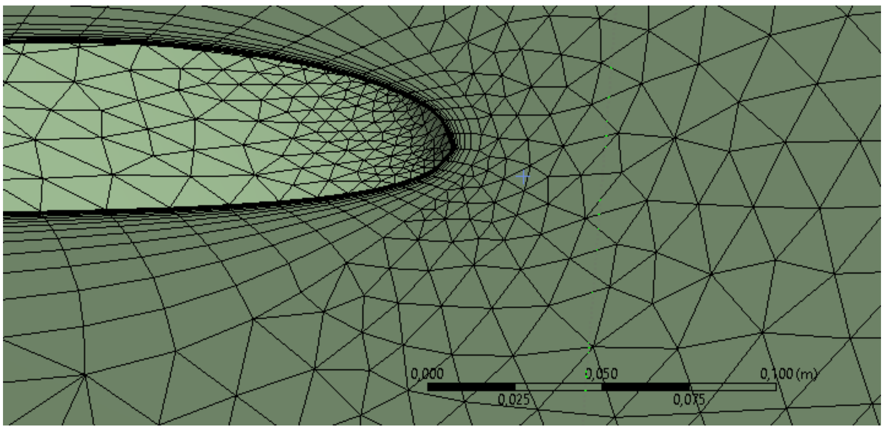

Figure 8 - Mesh refinement near the profile.

In this work it was considered that the wing flies at 13 m/s, which is the typical average speed for an AeroDesign’s aircraft. Air was applied as fluid considered as an ideal gas at a reference pressure of 1 atm. Figure 9 schematizes the boundary regions of the problem, which are the same for all wing configurations.

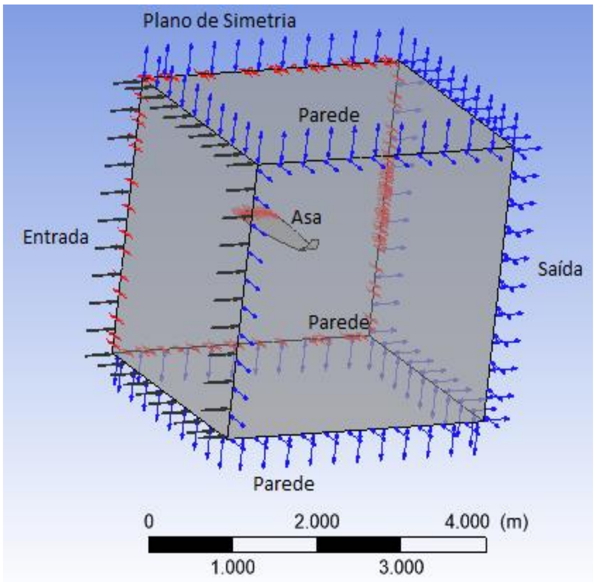

Figure 9 - Boundary conditions schematic.

Table 3 presents the boundary conditions adopted for the present work. Table 4 presents important parameters used in the simulation, regarding the fluid.

Table 3 - Boundary conditions.

Outline	Configurations	
Inlet	**Type**	Inlet
	Location	Entrance
	Flow Regime	Subsonic
	Mass And Momentum	Normal
	V	13 [m/s]
	Turbulence	Medium Intensity and Eddy Viscosity Ratio
Exit	**Type**	Opening
	Location	Exit
	Flow Regime	Subsonic
	Mass And Momentum	Opening Pres. And Dirn
	Relative Pressure	1 [atm]
	Flow Direction	Normal to Boundary Condition
	Turbulence	Medium (Intensity = 5%)
Symmetry Plane	**Type**	Symmetry
	Location	Symmetry
Walls	**Type**	Opening
	Location	Exit
	Flow Regime	Subsonic
	Mass And Momentum	Opening Pres. And Dirn
	Relative Pressure	1 [atm]
	Flow Direction	Normal to Boundary Condition
	Turbulence	Medium (Intensity = 5%)
Wing	**Type**	Wall
	Location	Wing
	Mass And Momentum	No Slip Wall
	Wall Roughness	Smooth Wall

Table 4 - Fluid Properties.

Materials	Ideal Air Gas
Morphology	Continuous Fluid
Reference Pressure	1 [atm]
Heat Transfer Model	Isothermal
Fluid Temperature	25 [°C]
Turbulence Model	SST
Turbulent Wall Functions	Automatic

3. Results and Discussion

In the present work, the convergence criterion was the one in which the residuals should be equal to 1x10-4 in order to obtain a reliable result with acceptable accuracy.

After defining all the characteristics, configuring the setup and performing the simulations via CFX ANSYS® software, the following results were obtained for the different types of wings, as presented in Table 5.

Table 5 - Drag force for the different wings

Wing Type	Wing without Winglet	Wing with 5% of height winglet	Wing with 10% of height winglet	Wing with 15% of height winglet
Angle of Attack (°)	Drag Force (N)			
0	2.40856	3.33392	2.26496	2.53245
5	6.48479	7.58269	6.34267	11.8106
10	10.4637	17.7144	10.3123	19.8387

For a better representation and visualization of the force variation, in accordance with the angle of attack, it can be considered the graph of Figure 10.

Figure 10 - Drag force (N) versus Angle of Attack (°C) for the different conditions.

By analyzing the data in Table 5 and the graph in Figure 10, it was observed that the wing, winglet of 5% of the half-span, has the highest value of drag force at angle 0° among all of configurations and, therefore, the winglet does not have geometry capable of reducing wing tip vortices.

It is noticeable for an angle close to 5° the configuration presents a significant increase in drag force, which shows that the winglet is inefficient.

However, the wing with winglet of h = 15% of the half-span presents an insignificant drag force for the angle of attack at 0°, but the winglet does not present efficiency with the increase of the angle of attack, which is probably due to the contribution of a portion of the drag force of the increment of shape drag, since it is a structure that can be considered significant for the AeroDesign aircraft.parameters.

Lastly, the wing with winglet of h = 10% of the half-span presents drag force values significantly similar to the wing without winglet, being different by a significantly lower percentage, as presented in Figure 10.

According to Seshaiah *et al.* (2021), a higher value of aerodynamic efficiency allows a lower buoyant force to lift the wings in the air. Thus, fuel consumption is reduced, as explained by Azeez *et al.* (2020) and Gavrilović (2015). Therefore, the aerodynamic efficiency of the wing with winglet of h = 10% of the half-span and the wing without winglet was verified, according to the data obtained in the numerical simulation, accounted in Table 6 and represented in Figure 11.

Table 6 - Lift force and lift/drag ratio.

Wing Type	Wing without winglet	Wing with 10% height winglet
Angle of Attack (°)	**Lift force (N)**	
0	28.7608	29.5071
5	60.6111	66.2380
10	92.3868	98.6522
Angle of Attack (°)	**Lift/Drag**	
0	11.9411	13.0276
5	9.3467	10.4432
10	8.8293	9.5665

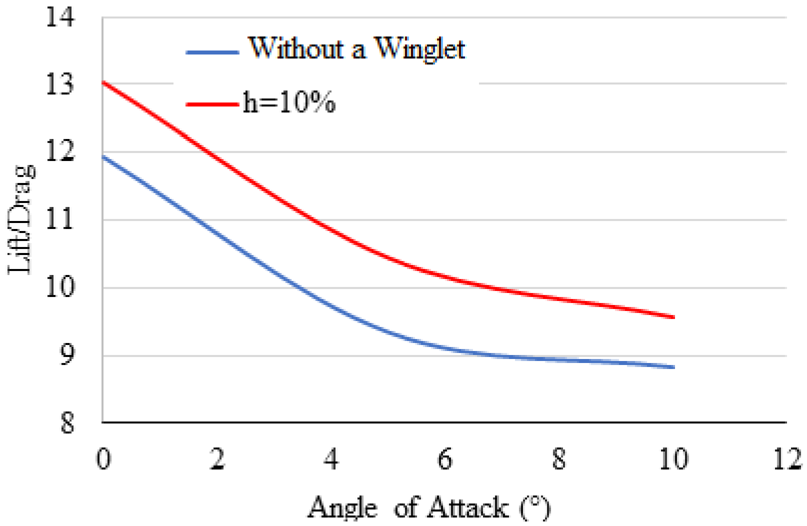

Figure 11 - Lift/drag ratio versus angle of attack (°C) for the different conditions.

When verifying the lift forces of both wings, it is noted that the wing with a winglet of h = 10% of wingspan has lower values of drag force and presents higher values of lift force, for all the angles analyzed, with a variation of up to 6 N regarding the wing without winglet. According to Table 6 and Figure 11, it is possible to see that the wing with winglet has a higher aerodynamic efficiency than the wing without winglet, presenting a lift-to-drag ratio of approximately 10% higher. An increase of this ratio suggests less strain in an aircraft's engine, when aircraft is carrying the same load. In another situation, with the same engine effort, this aircraft can reach higher speeds with a flight more stable and secure, helping especially in landings and takeoffs, where the flight speed is reduced and the lift is higher, due to the need for a larger angle of attack to perform these maneuvers.

3. Conclusion

It was possible to verify the global perception of physical phenomena due to the interaction of the viscous fluid with the submitted aerodynamic bodies. It is noteworthy that the induced drag is related to the escape vortices that are provided by the pressure difference between the upper and lower layer at the wing tip. The drag was the main factor of interest, being studied the possibility to reduce it through winglets. Since the use of the winglet increases the shape drag and reduces the induced drag, the proposed methodology aimed to verify the best winglet configuration to obtain the lowest overall drag and the best aerodynamic performance.

Regarding the obtained results, the winglet with a height of 10% of the wingspan showed significant results with a reduction of overall drag in relation to the wing without winglet which provided an increase in force of approximately 6 N, between the angles of 5 degrees to 10 degrees. These angles are practiced in aircraft during take-off. Therefore, this wing configuration presented around 10% more aerodynamic efficiency when comparing the lift-to-drag ratio between this wing and the wing without winglets to overcome the winglets of h = 5% and h = 15%, which increased the overall drag compared to the wing without winglets.

It is concluded from this project, that it was possible to observe an improvement in the wing performance with the application of the winglet, in the context of AeroDesign, and the compensation in the efficiency improve can help the competition teams to carry more load in the aircraft due to the increase in lift and also to assist in take-off and landing handling of the aircraft.

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References

Abdelghany, E. S., Khalil, E. E., Abdellatif, O. E., & Elhariry, G. (2016). Air craft winglet design and performance: Cant angle effect. 14th International Energy Conversion Engineering Conference, 1–13. https://doi.org/10.24218/jrmer.2016.14

Ashrafi, Z. N., & Sedaghat, A. (2015). Improving the Aerodynamic Performance of a Wing with Winglet Improving the Aerodynamic Performance of a Wing with Winglet. International Journal of Natural and Engineering Sciences, 8 (3), 52–57. Available in: <http://www.ijnes.org/index.php/ijnes/article/view/209/187>. Accessed on: August 4, 2021.

Azeez, A. A., Gadala, M., Khudhiri, N. Al, & Dol, S. S. (2019). Aerodynamics optimization of RC plane winglet. 2019 8th International Conference on Modeling Simulation and Applied Optimization, ICMSAO 2019, 1–5. https://doi.org/10.1109/ICMSAO.2019.8880426

Azlin, M., Taib, C. F. M., Kasolang, S., & Muhammad, F. (2011). CFD Analysis of Winglets at Low Subsonic Flow. Proceedings of the World Congress on Engineering,1. Available in:<http://www.iaeng.org/publication/WCE2011/WCE2011_pp87-91.pdf>. Accessed on: August 3, 2021.

Barbosa, H. V. S., Paula, T. R. de, & Buchner, P. C. (2018). Análise do arrasto sobre a asa para diferentes condições da ponta da asa para o AeroDesign. X Congresso Nacional de Engenharia Mecânica, Salvador, BA, Brasil.

Beechook, A., & Wang, J. (2013). Aerodynamic analysis of variable cant angle winglets for improved aircraft performance. ICAC 2013 - Proceedings of the 19th International Conference on Automation and Computing: Future Energy and Automation, 217–222. Available in: <https://ieeexplore.ieee.org/document/6662041>. Accessed on: August 3, 2021.

Belferhat, S., Meftah, S. M. A., Yahiaoui, T., & Imine, B. (2013). Aerodynamic optimization of a winglet design. EPJ Web of Conferences, 45, 18–21. https://doi.org/10.1051/epjconf/20134501010

Castejon, D. V. (2011). Métodos de redução do arrasto e seus impactos sobre a estabilidade veicular. Dissertação de Mestrado, Escola de Engenharia de São Carlos da Universidade de São Paulo, São Carlos, SP, Brasil.

Eguea, J. P., Catalano, F. M., Abdalla, A. M., De Santana, L., Venner, C. H., & Silva, A. L. F. (2018). Study on a camber adaptive winglet. 2018 Applied Aerodynamics Conference. https://doi.org/10.2514/6.2018-3960

Elham, A., & Van Tooren, M. J. L. (2014). Winglet multi-objective shape optimization. *Aerospace Science and Technology*, *37*, 93–109. https://doi.org/10.1016/J.AST.2014.05.011

Gavrilović, N. N., Rašuo, B. P., Dulikravich, G. S., & Parezanović, V. B. (2015). Commercial aircraft performance improvement using winglets. FME Transactions, 43(1), 1–8. https://doi.org/10.5937/fmet1501001G

Giuberti, M. C. (2013). Avaliação de winglets para AeroDesign: análise da redução do arrasto induzido utilizando DFC. Projeto de Graduação, Universidade Federal de Viçosa, Viçosa, MG, Brasil.

Guerrero, J., Sanguineti, M., & Wittkowski, K. (2018). CFD Study of the Impact of Variable Cant Angle Winglets on Total Drag Reduction. *Aerospace*, *5*(4), 126. https://doi.org/10.3390/aerospace5040126

Johansen, J., & Sørensen, N. N. (2006). Aerodynamic investigation of Winglets on Wind Turbine Blades using CFD. Risø National Laboratory, (February), 1–17.

Kontogiannis, S. G., & Ekaterinaris, J. A. (2013). Design, performance evaluation and optimization of a UAV. *Aerospace Science and Technology*, *29*(1), 339–350. https://doi.org/10.1016/J.AST.2013.04.005

Krishnan, S. G., Ishak, M. H., Nasirudin, M. A., & Ismail, F. (2020). Investigation of aerodynamic characteristics of a wing model with RGV winglet. *Journal of Aerospace Technology and Management*, *12*(1), 1–18. https://doi.org/10.5028/jatm.v12.1108

Liauzun, C., David, J.-M., Joly, D., & Paluch, B. (2018). Study of morphing winglet concepts aimed at improving load control and the aeroelastic behavior of civil transport aircraft. Aerospace Lab Journal, 14, 1–15. https://doi.org/10.12762/2018.AL14-10

Munshi, A., Sulaeman, E., Omar, N., & Ali, M. Y. (2018). CFD analysis on the effect of winglet and angle on aerodynamics of ONERA M6 wing. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences, 45(1), 44–54. Available in: <https://www.akademiabaru.com/submit/index.php/arfmts/article/view/2180/1169>. Accessed on: August 3, 2021.

Narayan, G., & John, B. (2016). Effect of winglets induced tip vortex structure on the performance of subsonic wings. Aerospace Science and Technology, 58, 328-340. https://doi.org/10.1016/j.ast.2016.08.031

Panagiotou, P., Kaparos, P., & Yakinthos, K. (2014). Winglet design and optimization for a MALE

Seshaiah, T., Vasu, B., Kumar Reddy, K. V., & Bridjesh, P. (2021). Analysis on air craft winglet at different angles by using CFD simulation. Materials Today: Proceedings, https://doi.org/10.1016/j.matpr.2021.02.073

Toor, Z., Masud, J., Abbas, Z., & Ahsun, U. (2016). Part i: Uncertainty analysis of various design parameters on winglet performance. *54th AIAA Aerospace Sciences Meeting*, *January*, 1-15. https://doi.org/10.2514/6.2016-0556

UAV using CFD. Aerospace Science and Technology, 39, 190–205. https://doi.org/10.1016/j.ast.2014.09.006

Weng, R., Zhang, H., Yin, L., Rong, W., Wu, Z., & Liu, X. (2017). Fabrication of superhydrophobic surface by oxidation growth of flower-like nanostructure on a steel foil. RSC Advances, 7(41), 25341–25346. https://doi.org/10.1039/c6ra28239c

Zhang, L., Ma, D., Yang, M., & Wang, S. (2020). Optimization and analysis of winglet configuration for solar aircraft. *Chinese Journal of Aeronautics*, *33*(12). https://doi.org/10.1016/j.cja.2020.04.008