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EFFECT OF A 90^{O} WINGLETS WITH CANT ANGLE IN THE GENERATION OF VIBRATIONS ON A HALF WING WITH A SYMMETRICAL NACA 0018 AIRFOIL

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EFFECT OF A WINGLETS WITH 90^{O} CANT ANGLE IN THE GENERATION OF VIBRATIONS ON A HALF WING WITH A SYMMETRICAL NACA 0018 AIRFOIL

Resumen del reporte técnico en español :

Movimiento del flujo de aire alrededor del ala, modificando así el campo de presiones a su alrededor y, en consecuencia, las fuerzas aerodinámicas que actúan sobre ella y generando ondas vibratorias que afectan a toda la aeronave. Todos estos factores influyen directamente en la eficiencia de un avión, aumentando así el consumo de combustible. La adición de winglets puede reducir la resistencia aerodinámica, el tamaño de los vórtices que genera y, por tanto, tener un impacto ecológico más favorable y reducir los costes energéticos al disminuir el consumo de combustible. En este proyecto realizamos una comparación de los parámetros de vibración generados por el ala sin winglets y el ala con winglets, realizando un análisis en túnel de viento. Para completar la comparación estudiamos: cómo afectan las vibraciones a la eficiencia aerodinámica; las causas de la creación de vibraciones y vórtices en las puntas de las alas; las innovaciones en el diseño de las alas que se han creado para ayudar a aumentar la eficiencia aerodinámica. Después seleccionamos el perfil del winglet, diseñamos los archivos CAD de las dos medias alas, las fabricamos con tecnología aditiva y realizamos un análisis aerodinámico en el túnel de viento de la universidad, utilizando un sensor de vibraciones Micro Strain G-LINK-200-40g. El análisis vibratorio demostró que, en efecto, **los dispositivos de punta de ala o winglets, consiguen reducir la magnitud de las vibraciones en un 29,89% de media**, para todos los ángulos de ataque y velocidades a los que se ensayaron ambas medias alas.

Resumen del reporte técnico en inglés :

Movement of the air flow around the wing, thus modifying the pressure field around it and, as a result, the aerodynamic forces acting on it and generating vibrational waves that affect the entire aircraft. All these factors directly influence the efficiency of an aircraft, thus increasing fuel consumption. Adding winglets can reduce the drag, the size of the vortices it generates, and therefore have a friendlier ecological impact and reduce energy costs by reducing fuel burn. In this project we made a comparison of vibration parameters generating by wing without winglets and wing with winglet, performing a wind tunnel analysis. To complete the comparison we studied: how vibrations affect aerodynamic efficiency; the causes of the creation of vibrations and vortices in the wing tips; the innovations in wing design that have been created to help increase aerodynamic efficiency. Than we selected winglet profile, designed the CAD files of the two half wings, and manufactured using additive technology and performed an aerodynamic analysis in the university's wind tunnel, using a Micro Strain G-LINK-200-40g vibration sensor. Vibrational analysis showed that, in effect, ***wing tip devices or winglets, manage to reduce the magnitude of vibrations by an average 29.89%***, for all angles of attack and speeds at which both half wings were tested.

Palabras clave: Aircraft Wing, Wing vibration, Aerodynamics forces, Winglets, Variation of stress, Cant angle, Cambered winglets

Usuarios potenciales (del proyecto de investigación)

The presenting results of the research can be used in the design and production of airplanes, drones and other unmanned aerial vehicle (UAV). Also, some parts of the project (Half wings design, Half wings manufacturing, Vibration analysis in Wind tunnel) can be used for learning purpose in Industrial, Manufacturing and Aeronautics programs.

Reconocimientos

We would like to express our gratitude to:

- IIT administration for the opportunity to use laboratory equipment to perform experiments within the framework of this project;
- Ford Manufacturing Center of St. Clear College (Windsor, Ontario, Canada) for their support in this project;
- JULIO CÉSAR CUÉLLAR MATA, (157575) graduate student for the help to complete laboratory experiments.

1. Introducción

A wing generates high pressures on its lower surface and low pressures on its upper surface. The resultant of these pressures is a supporting force or lifting force. However, due to that pressure difference, a swirling motion is created at the wingtip, with air moving from the high pressure region to the upper surface. [1].

This movement combined with the speed of air flow, and amplified by the downdraft generated by each wing section along the wingspan, generates vortices that emanate from the tips and drag in a continuous direction [1]. The vortices of the tips affect the movement of the entire flow field around the wing, thus modifying the pressure field around it and, as a result, the aerodynamic forces acting on it and generating vibrational waves that affect the entire aircraft [1]

Vibrations occur for different reasons, in addition to vortices. Aerodynamics in general, mechanical malfunctions, and external factors such as atmospheric turbulence can cause vibrations in aircraft. All vibrations have associated frequencies and magnitudes that can be easily detected or barely perceptible to the flight crew and passengers [2].

All these factors directly influence the efficiency of an aircraft, thus increasing fuel consumption. On the other hand, an alternative for reducing vibrations is light and flexible wings, since a light and flexible aircraft wing benefits from the flexibility of the structure, and presents high aerodynamic performance and fuel efficiency [3].

Additionally, while most wing shapes used today create turbulent wake vortices, the wing geometry can be designed to reduce or eliminate wingtip vortices almost entirely [4]. It is for this reason that the proper design of the wings in an aircraft has proven to considerably increase efficiency and decrease fuel consumption, winglets being one of the main wing configurations in use today [5]. Adding winglets can reduce the drag of a given aircraft, the size of the vortices it generates, the frequency of vibrations throughout the aircraft, and therefore have a friendlier ecological impact and reduce energy costs by reducing fuel burn [1].

For this reason, this project seeks to make a comparison between aircraft without winglets and aircraft with winglet, performing a wind tunnel analysis. These analyzes will be compared and the effect of the winglets on the generation and frequency of vibrations and on the formation of vortices will be observed, in order to obtain conclusions and verify the effect on the aerodynamic efficiency of each half wing.

Venkatesan, Beemkumar, Jayaprabakar and Kadiresh [6] conducted a study on the characteristics of the vibrations of the aircraft wing, the deformation and stress acting on the wing model with and without winglet were studied. The wing of the A300 aircraft with the NACA 64215 profile was used for the investigation. The analysis was performed on the wing by considering that one end (root chord) of the wing is fixed, while the other end (tip chord) is free. A numerical validation procedure was carried out with the structural analysis and the analysis of the model to find the total deformation and the frequency of the wing without and with winglets at different angles of inclination or cant angle (18º and 45º).

Venkatesan, Beemkumar, Jayaprabakar y Kadiresh [6] concluded that when comparing the wing without winglet, the wing with the 18° cant angle winglet and the wing with the 45° cant angle winglet, the 18° cant angle winglet is more optimal and could be used to improve wing stability. The variation of the deformation and the variation of the normal and shear stresses clearly shows that the winglet with 18° provides the optimized results that ensure a good structure to the wing. Therefore, the flap with a cant angle of 18° is more reliable, efficient and safe to use to improve the stability of the wings.

Likewise, Beechook y Wang [7] performed an aerodynamic analysis on variable cant angle winglets to improve aircraft performance. CFD simulations and wind tunnel test results from that analysis showed that different winglet configurations have different aerodynamic characteristics when the angle of attack is varied. Figure 1 shows the winglet configurations used for this study.

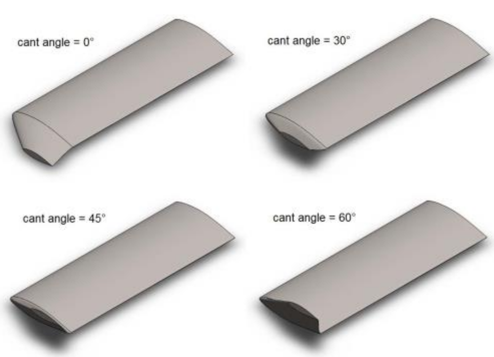


Figure 1: Winglets configurations [7].

At low angles of attack, ideally at the cruising angle of attack, the 45° and 60° cant angle winglets showed better aerodynamic performance in terms of lift and drag coefficients. 45° and 60° winglets did not provide optimal performance at high angles of attack, for example, at a higher angle of attack, 45° winglets produced more lift compared to other winglet configurations [7].

Therefore, varying the cant angle of the winglets in different phases of flight can improve the efficiency of the aircraft and optimize performance. From this study, it could be concluded that the implementation of variable cant angle winglets may appear to be a promising alternative to traditional fixed winglets [7].

Moving on, different wingtip geometries were compared at an angle of attack equal to that used at cruising speed of a medium-range tactical UAV. According to the results, the wingtip design with blended winglet has shown that its aerodynamic efficiency and performance for the given aircraft configuration is the most optimal since, they provided the least amount of pressure in the places closest to the middle chord. on the suction side [8].

Similarly, Eguea, Pereira and Martini, conducted a study to improve fuel efficiency in a business jet using a morphological camber winglet concept. To achieve this improvement, a genetic algorithm was used to optimize the curvature of the winglet in different phases of flight [9].

A comparison was made between the performance of a wing with a fixed geometry winglet (FGW) and a wing with a morphological winglet (CMW) and showed a theoretical 6% reduction in fuel consumption in the maximum range mission block. Considering the average cruising fuel consumption of the CMW setting per nautical mile, the concept of morphological winglets can allow an increase of 8 passengers for a maximum range mission or a 700 nautical mile increase in the range of the aircraft. with 4 passenger payloads, which has the same fuel consumption as the fixed geometry configuration on a mission 3125 nautical miles [9].

On the other hand, Azeez, Gadala, Al Khudhiri and Dol performed an analysis on a remote-controlled aircraft, making modifications to the wingtips, adding winglets and comparing different angles of inclination of these. Figure 2 shows the wingtip models and configurations used in this analysis [10].

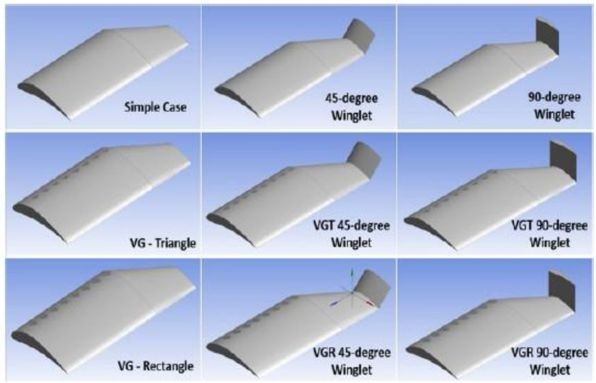


Figure 2: Wing tip configurations used [10].

The wing design modification was made to find that 45° camber winglets are the best aerodynamic model, have the highest lift force, and have the least drag.

One of the biggest worries in the aviation industry is, without a doubt, fuel consumption and all the ecological and economic issues that this topic encompasses. More clearly, the emissions produced by aircraft represent, today, one of the biggest triggers in terms of environmental pollution. That is why the aeronautical industry has tried to reduce these emissions while also minimizing fuel consumption, which in turn translates into great economic savings for airlines and companies in the sector.

The optimal design of the aircraft plays a crucial role in saving fuel. Therefore, emphasis should be placed on reducing vibrations and reducing the formation of vortices, since these two factors directly affect the aerodynamic forces that act on any aircraft. Thus, the use of winglets in aircraft helps reduce vibrational magnitudes in flight, thus improving efficiency and reducing fuel consumption.

2. Planteamiento

2.1 Antecedentes

2.1.1 Wing Aerodynamics

Aircraft wings are designed to make the air move faster over the top of the wing. When the air moves faster, the air pressure decreases. So, the pressure at the top of the wing is less than the pressure at the bottom of the wing. The pressure difference creates a force on the wing that lifts it into the air. There are 4 forces that act on the aircraft when it is in flight, which are: lift, drag, thrust and weight [11], these forces are shown in figure 3.

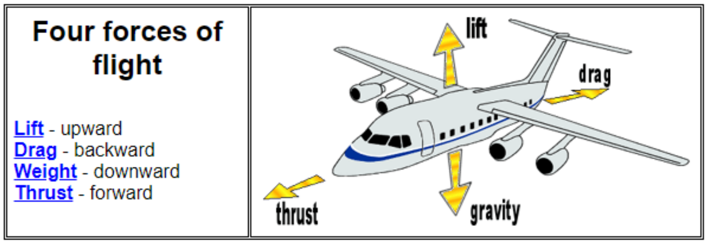


Figure 3: Aerodynamic forces on aircraft [11].

2.1.2 Airfoil

The airfoil is the cross-sectional shape of a wing, blade (of a propeller, rotor, or turbine), or sail. The airfoil represents the DNA of the wing platform and provides the fundamental characteristics of 2-D aerodynamic performance, measured in coefficient of lift and coefficient of drag [13].

An airfoil-shaped body that moves through a fluid produces an aerodynamic force. The component of this force perpendicular to the direction of motion is called the lift. The component parallel to the direction of motion is called drag. Subsonic airfoils have a characteristic shape with a rounded leading edge, followed by a sharp trailing edge, often with a symmetrical curvature of the upper and lower surfaces [13] as shown in figure 4.

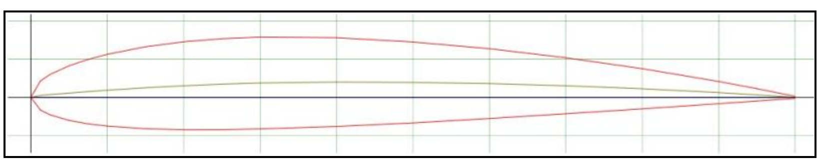


Figure 4: Subsonic NACA 2412 airfoil [14] .

2.1.3 Symmetrical Airfoils

The symmetrical airfoil is commonly used in control surfaces such as the horizontal stabilizer and the vertical stabilizer (Rudder and Elevator). This symmetric airfoil is defined in the 4-digit family, but the first two digits are designated as zeros. The symmetrical airfoil has no camber, it only has thickness. Figure 5 shows the geometry of a symmetric NACA 0018 airfoil.

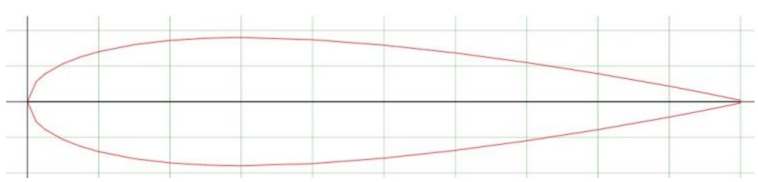


Figure 5: Symmetrical NACA 0018 airfoil [15].

2.1.4 Lift Coefficient

The coefficient of lift, generally abbreviated as Cl, is a number used to compare the performance of profiles and wings. The lifting coefficient is also one of the variables that goes into the lifting equation or lifting formula. [17]. The lift coefficient is a number that engineers use to model all complex dependencies of shape, slope, and some flow conditions on elevation. This equation is simply a rearrangement of the lift equation where the lift coefficient is solved in terms of the other variables [18]. Equation 1 shows the lift coefficient formula.

$$C_L = \frac{2L}{\rho S V^2}$$

Equation 1: Lift Coefficient [10].

Where:
- *CL* = Coefficient of lift
- *L* = Lift force
- *S* = Wing area
- *V* = Fluid velocity
- ρ = Fluid density

The lifting coefficient expresses the relationship between the lifting force and the force produced by the dynamic pressure multiplied by the area.

2.1.5 Drag Coefficient

The drag coefficient is a dimensionless quantity that is used to quantify the drag or resistance of an object in a fluid environment, such as air or water. It is used in the drag equation in which a lower drag coefficient indicates that the object will have less aerodynamic or hydrodynamic drag. The drag coefficient is always associated with a particular surface area [19].

The drag coefficient of any object comprises the effects of the two basic contributors to fluid dynamic drag: skin friction and shape drag. The aerodynamic drag coefficient of an airfoil also includes the effects of lift-induced drag. [19]. Equation 2 shows the formula for the drag coefficient.

$$C_D = \frac{2D}{\rho S V^2}$$

Equation 2: Drag Coefficient [10].

Where:

- CD = Coefficient of drag
- D = Drag force
- S = Wing area
- V = Fluid velocity
- ρ = Fluid density

The drag coefficient expresses the relationship between the drag force and the force produced by the dynamic pressure multiplied by the area.

2.1.6 Winglets

Wingtip devices or winglets are aerodynamic devices used on the wingtips of new commercial aircraft designs. They are usually intended to improve the efficiency of fixed-wing aircraft [2]. They are generally shaped like a fin upward at the end of the wing but can take on different geometries. Winglets reduce drag by recovering some of the energy in the vortex or vortex of the wingtips. This provides an effective increase in the aspect ratio of the wing, and therefore a reduction in lift-induced drag, for less increase in the extension, weight and strength of the profile compared to simply increasing the wingspan of the wing [21]. Figure 6 shows the difference in the vortex formation of an aircraft with and without a winglet.

Figure 6: Effect of winglets on vortex formation [21].

The winglets reduce drag, but also generate lift at the tip, which increases the bending moment at the root of the wing and requires the structure to be reinforced, adding weight, that is why some manufacturers offer versions with and without the device on the same aircraft model, because sometimes very short flights can even be counterproductive and would not generate the expected savings [21].

2.1.7 Winglet Design

The winglets were introduced as sweeping upward extensions of the wing by Richard Whitcomb at NASA's Langley Research Center. In his NASA technical notes document, he presented design considerations for these devices and their effects on aerodynamic forces, moments, and wing loads. For the configuration investigated by Whitcomb, the winglets reduced induced drag by approximately 20% with a resulting increase in the wing lift / drag ratio of approximately 9% for the design Mach number of 0.78. The basic design parameters of the winglets are shown in figure 7 [5].

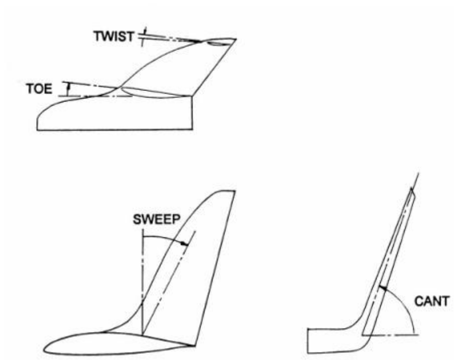


Figure 7: Parameters for winglet design [5].

Classic winglet design, such as that employed by Whitcomb, is a trade-off between aerodynamic efficiency and structural weight or induced drag and viscous resistance. It's also often a trade-off between low-speed and high-speed features with a reasonably light weight. In other words, the goals of reducing strength, weight, and complexity (which translates to manufacturing and maintenance costs) are often in conflict [5].

Adding wingtip extensions can reduce drag on a given aircraft but will generally require increasing the structural weight. Weight increases are due to the weight of the wingtip extension member as well as the required reinforcement of the existing wing structure to support the bending moments exerted by the wingtip extension device [5].

2.2 Marco teórico

2.2.1 Vibrations in an aircraft

The vibrations are oscillations, reciprocities or any other periodic movement of a rigid or elastic body forced from a position or state of equilibrium. If the frequency and magnitude of the vibration are constant, the vibration is said to be harmonic. When the frequency and magnitude vary over time, the vibration is random [24].

Buffet is a form of vibration generally caused by aerodynamic flow. It is usually random and is associated with a separate airflow. For example, the buffet can be felt during the extension of the speed brakes or during turbulence in the air. Flutter is an unstable condition in which unstable aerodynamics excites the natural frequencies of the structure over which the air is flowing. The resulting vibrations can grow to a magnitude that causes the structure to fail. Noise is a vibration that excites the air and can be heard. When the vibration is random, the noise is not musical or is confused. When the vibration is harmonic, the result is a tone like that produced by a musical instrument. It may sound like the hiss of a drain or a slight leak in a door [24].

Normal and abnormal vibrations occur for various reasons. Aerodynamics, mechanical malfunctions, and external factors such as atmospheric turbulence can cause vibrations in aircraft. All vibrations have associated frequencies and magnitudes that can be easily detected or barely perceptible to the flight crew and passengers. For some vibrations, such as those associated with engine operation, the flight crew has dedicated instrumentation to measure their magnitude. Other vibrations are detected by sight, sound, or sensation and may depend on the experience of the flight crew for analysis [24].

Each aircraft has a unique signature of normal vibration. This is a consequence of the mass distribution and structural stiffness that result in modes of vibration at certain frequencies. When external forces act on the aircraft, such as normal airflow over surfaces, very low-level vibrations occur. Typically, this is perceived as background noise. More noticeable, but also normal, is the reaction of the airplane to turbulent air, in which the magnitude of the vibration can be greater and therefore clearly visible and felt [24].

Operating the engine at some spool speeds can result in increased vibration because the imbalance in the coil excites the engine and transmits this vibration throughout the fuselage. Finally, the operation of some mechanical components, such as pumps, can be associated with normal noise and vibrations [24].

2.2.2 Vibrations Sensor Micro Strain G-LINK-200-40g

The G-Link-200-40g is a battery-powered 3-axis wireless accelerometer with a rugged, weather-resistant housing. The G-Link-200 provides extremely low noise waveform data, ideal for vibration, impact, shake and tilt applications. Additionally, derived vibration parameters enable long-term condition monitoring and predictive maintenance. [25].

2.2.3 Additive Manufacturing

It is a digitized production method that consists of manufacturing previously modeled objects, by deposition layer by layer of material, to form a three-dimensional object. Additive manufacturing represents a new path in terms of energy efficiency, cost effectiveness and time savings when producing objects [26]. Furthermore, it makes it possible to produce shapes and geometries that might not be possible through any other process. Possibilities include parts that have highly complex internal channels, parts that require voids, or honeycomb-like structures for weight savings. Additionally, additive manufacturing can eliminate assembly work because a part made up of small components can be built as a single piece [27].

A wide variety of parts can be created, including engine components and other parts for aircraft, medical devices, or surgical implants. It can also be used to make mold components that can actually improve the molding process [27].

3. Objetivos

General Objective: To perform an aerodynamic and vibrational analysis on a half wing with winglet and compare the results with those of a half wing without winglet with the same airfoil.

Specific Objectives:

1. Study how vibrations affect aerodynamic efficiency.
2. Study the causes of the creation of vibrations and vortices in the wing tips.
3. Study the innovations in wing design that have been created to help increase aerodynamic efficiency.
4. Study the geometric specifications necessary for the optimal design of a half wing with a winglet device.
5. Select winglet profile and cant angle.
6. Design the CAD files of the two half wings.

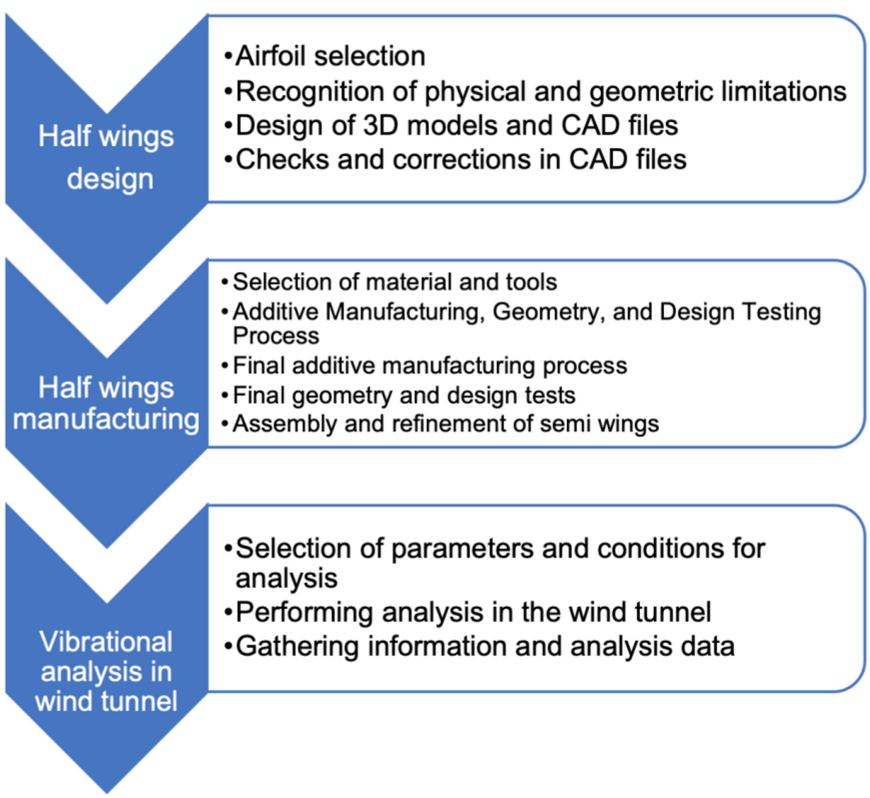
7. Manufacture two half wings (one of them with winglet) using additive manufacturing and perform an aerodynamic analysis on each one in the university's wind tunnel, using a Micro Strain G-LINK-200-40g vibration sensor.
8. Compare the results of both studies.
9. Document the results.

4. Metodología

To complete this project was used the following methodology of theoretical and experimental researches:

- ***Theoretical analyses***, as a starting point of this project.
- ***Experiment Retrospection*** - Many experimental methods were devised to investigate the airflow around the airfoil and generating vibration.
- ***Laboratory experiments*** in Wind Tunnel, using vibration sensor.
- ***Numerical Simulation***. The numerical methods were successfully applied in velocity distribution and thermal airflow.

The following diagram shows the list of the methodology followed for this project.



After the manufacturing tests of the first two designs, a 3D model was designed using the specifications of the vibration sensor data sheet, so that its correct assembly was possible. In addition, the shaft bore and space for the ferromagnetic rod were added that would help to hold the sensor inside the half wings. Additionally, it was decided to cut the models of the semi wings and add elements that would facilitate their assembly.

4.1 Additive Manufacturing and Design Testing Process

Once the final design was made, the final impression of each part of both half wings was made, in total 5 pieces were manufactured, those shown in figures 8 and 9 corresponding to the half wing without winglet, and those shown in the Figures 10, 11, 12 and 13 corresponding to the semi wing with winglet.

Figure 8: Part 1 of wing without winglet.

Figure 9: Part 2 of wing without winglet.

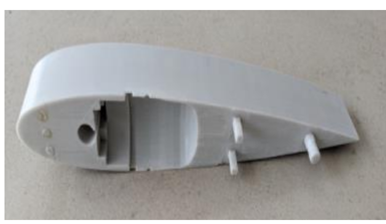


Figure 10: Part 1 of wing with winglet.

Figure 11: Part 2 of wing with winglet.

Figure 12: Part 2 of wing with winglet.

Figure 13: Part 3 of wing with winglet.

As can be seen in the previous figures, some parts were damaged, which has no impact on the final assembly, so they were ignored.

4.2 Final geometry and design tests

At this stage it was verified that both the vibration sensor, the shaft and the ferromagnetic rod, assembled correctly in their corresponding spaces. As shown in figure 14, the vibration sensor assembled almost perfectly, leaving minimal spaces as shown in the figures.

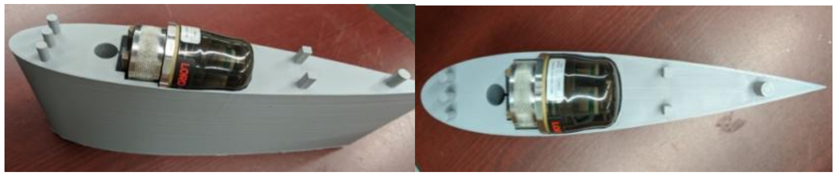
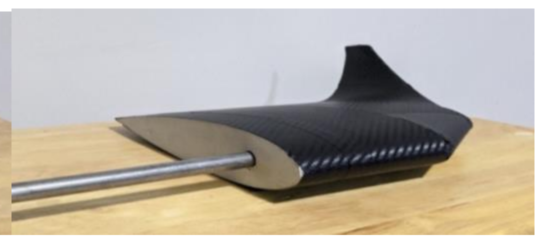


Figure 14: Sensor assembly in half wing

4.3 Assembly and refinement of wings

Once the 5 parts, the shaft and the ferromagnetic rod had been manufactured and revised, the parts were covered with a layer of black vinyl, this, to have a smoother surface and have better results in the future. analysis. Once the pieces were covered, the semi-wings were assembled. Figures 15 show the semi wing without winglet, while in figure 16 the semi wing with winglet.

Figure 15: Final wing assembly without winglet



.**Figure 16:** Final wing assembly with winglet.

4.4 Vibrational analysis in wind tunnel

For these analyzes, the half wings manufactured by means of additive manufacturing and covered with the black vinyl layer shown above were used. Figure 17 shows the half wing with winglet mounted on the wind tunnel.

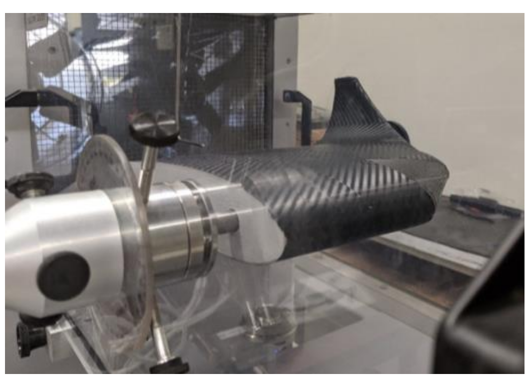


Figure 17: Half-wing with winglet mounted in wind tunnel.

4.5 Selection of parameters and conditions for analysis

Table 1 shows the parameters and conditions established to carry out the tests in the wind tunnel.

Table 1: Parameters and conditions established for the analysis in the wind tunnel

Measurement time	60 S
Wind tunnel speed 1	40 km/h
Wind tunnel speed 2	80 km/h
Wind tunnel speed 3	120 km/h
Frequency range	512 Hz
Angle of attack range	-25º a 25º
Interval of measuring	5º

As can be seen in the table, the vibrations within each half wing will be analyzed 3 times for each angle of attack and for a period of 60 seconds, for example, for the half wing without winglet at 5º angle of attack, vibrations will be measured. for the 3 speeds established in the table (60 seconds for each speed). This will be done for each angle of attack in the range set in 5º intervals.

4.6 Performing analysis in the wind tunnel

In the first instance, the sensor was turned on and installed inside the wingletless semi-wing for subsequent attachment inside the wind tunnel. The sensor manufacturer's software (Sensor Connect) was used to perform the measurements. Figure 18 shows the semi wing without winglet attached inside the wind tunnel.

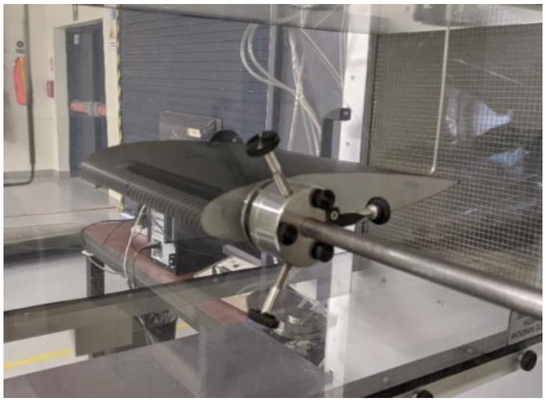


Figure 18: Wing without winglet inside the wind tunnel.

Subsequently, the wind tunnel was turned on, which was controlled with the computer and software configured to it. With the help of this software, it was possible to manipulate the air inlet velocity of the tunnel. 3 tests were carried out at 0° angle of attack, one for an input speed of 40 km / h, another for a speed of 80 km / h and a last one for 120 km / h, as shown in table 2.

Table 2: Speeds per angle of attack selected for study.

Ángulo de Ataque	Velocidades de Entrada (Km/h)		
-25	40	80	120
-20	40	80	120
-15	40	80	120
-10	40	80	120
-5	40	80	120
0	40	80	120
5	40	80	120
10	40	80	120
15	40	80	120
20	40	80	120
25	40	80	120

To manipulate and change the angle of attack of the half wings, the radial attachment of the wind tunnel was used. The tests were carried out on the half wing at 0, 5, 10, 15, 20, 25, -5, -10, -15, -20 and -25 degrees of attack angle, measuring the vibrations for each angle at the 3 input speeds mentioned. Figures 19, 20, 21, 22 and 23 show the half wing at 15, 25, -15 and -25 degrees of attack angle, respectively.

Figure 19: Wing without winglet at 0-degree AOA

Figure 20: Wing without winglet at 15-degreeAOA

Figure 21: Wing without winglet at 25-degree AOA

Figure 22: Wing without winglet at -15-degree AOA

Figure 23: Wing without winglet at -25-degree AOA

Continuing, once the data had been collected, the winglet less half wing was removed from the wind tunnel and the sensor was removed from its interior for future installation inside the winglet half wing. The semi wing was armed with winglet and secured inside the wind tunnel. For this half wing, the same tests were carried out as for the previous one, measuring the vibrations at the same 3 entry speeds for the same angles of attack. Figures 24, 25, 26, and 27 show the winglet half wing at various angles of attack inside the wind tunnel.

Figure 24: Wing with winglet at 0-degree AOA.

Figure 25: Wing with winglet at 15-degree AOA.

Figure 26: Wing with winglet at 25-degree AOA.

Figure 27: Wing with winglet at -15-degree AOA.

Once the tests established in the wind tunnel were completed, the data and information necessary to carry out the comparisons between tests and half wings were collected.

5. Resultados

Since the sensor used to measure the vibrations is a 3-axis accelerometer, the magnitude of the acceleration was measured in each axis of the sensor, to later obtain a magnitude resulting from these 3 measurements. The resulting accelerations were then averaged for comparison. Thus, table 3 shows the average vibrations, in terms of acceleration, of the half wing without winglet.

Table 3: Average vibration in wing without winglet (units $\frac{m}{s^2}$)

	Average Vibration (Units m/s2)		
	Without Winglet		
Angle of Attack	40 Km/h	80 Km/h	120 Km/h
-25	0.289226519	0.615465707	1.140057274
-20	0.215424403	0.567766931	0.788597164
-15	0.127499084	0.517993951	0.612502906
-10	0.134192023	0.494624948	0.398427414
-5	0.110829263	0.332947204	0.329075074
0	0.122491517	0.234236477	0.299969398
5	0.104431906	0.142543592	0.296574472
10	0.106305316	0.269508659	0.421082394
15	0.10923658	0.29094291	0.437742426
20	0.17453565	0.3477663	0.663228594
25	0.267433419	0.427709106	0.693013841

In this case, the semi-wing without winglet had an increase in vibration magnitudes as the angle of attack became larger, either positive or negative, having the highest average at -25º at 120 km/h, with a magnitude average of 1.14005 $\frac{m}{s^2}$.

However, Table 7 shows the results of the analysis to the winglet half wing, showing the average magnitude of vibrations for each angle of attack and the 4 entry speeds.

Table 4: Average vibration in wing with winglet (units $\frac{m}{s^2}$).

	Average Vibration (Units m/s2)		
	With Winglet		
Angle of Attack	40 Km/h	80 Km/h	120 Km/h
-25	0.274942128	0.588104986	0.98845846
-20	0.19513839	0.446264663	0.71935004
-15	0.093087631	0.194225836	0.43187339
-10	0.12905718	0.131406015	0.30545106
-5	0.109167906	0.127636669	0.32627365
0	0.071922414	0.115026443	0.13893319
5	0.077465661	0.095862564	0.2647647
10	0.080324376	0.117446495	0.27276395
15	0.07924008	0.134720939	0.33518044
20	0.116731693	0.19568946	0.44772693
25	0.185819832	0.254414352	0.52391322

As can be seen, the winglet wing exhibits, on average, a lower magnitude of vibration for all combinations of angle of attack and airspeed, compared to the wingless half wing. In addition, the magnitude of the vibrations increases as the air intake speed increases. Also, the angle of attack greatly influences the magnitude of the vibrations in each half wing, presenting lower average magnitudes at positive angles of attack.

Next, table 5 shows the percentage difference of the averages, that is, how much the magnitude of vibrations decreased in the half wing with winglet, compared to the half wing without winglet.

Table 5: Percentage difference in the magnitude of vibrations.

Percentage difference of average vibration.			
Angle of Attack	40 Km/h	80 Km/h	120 Km/h
-25	4.94%	4.45%	13.30%
-20	9.42%	21.40%	8.78%
-15	26.99%	62.50%	29.49%
-10	3.83%	73.43%	23.34%
-5	1.50%	61.66%	0.85%
0	41.28%	50.89%	53.68%
5	25.82%	32.75%	10.73%
10	24.44%	56.42%	35.22%
15	27.46%	53.70%	23.43%
20	33.12%	43.73%	32.49%
25	30.52%	40.52%	24.40%
Total Average	29.89%		

With the above table, the difference and the percentage of improvement of the winglet with winglet versus the wingletless winglet can be seen more clearly. As an example, the winglet half wing presented 24.40% less average vibrations, when both half wings were at a 25º angle of attack with a speed of 120 km/h. The biggest difference was presented when both half wings were subjected to the test at -10º angle of attack at 80 Km/h, being that the half wing with winglet presented 73.43% less vibrations than its similar without winglet, that is, the vibrational magnitudes in the wingletless half wing were almost twice as large as those of the winglet half wing.

For each measurement, a time of 60 seconds was established, and the sensor was configured so that it was throwing a data every 0.1 second. From the data collected in the measurements of both half wings, the magnitudes of vibrations were plotted. Figures 28, 29, 30, 31, 32 and 33 show the graphs that best capture the difference in the magnitudes of vibrations in both half wings, during the 60 seconds of measurement.

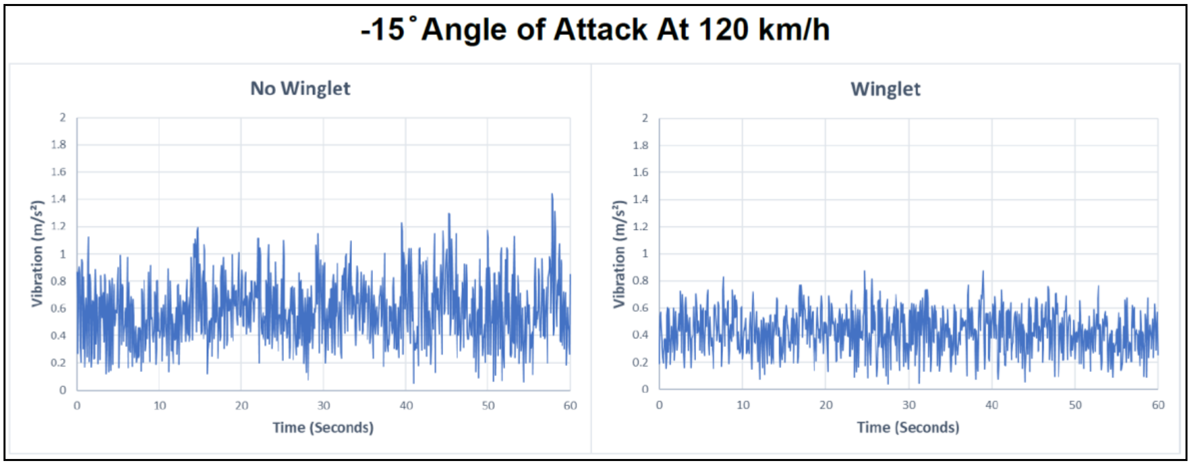


Figure 28: Wings vibrations at -15 degrees angle of attack and 120 km/h.

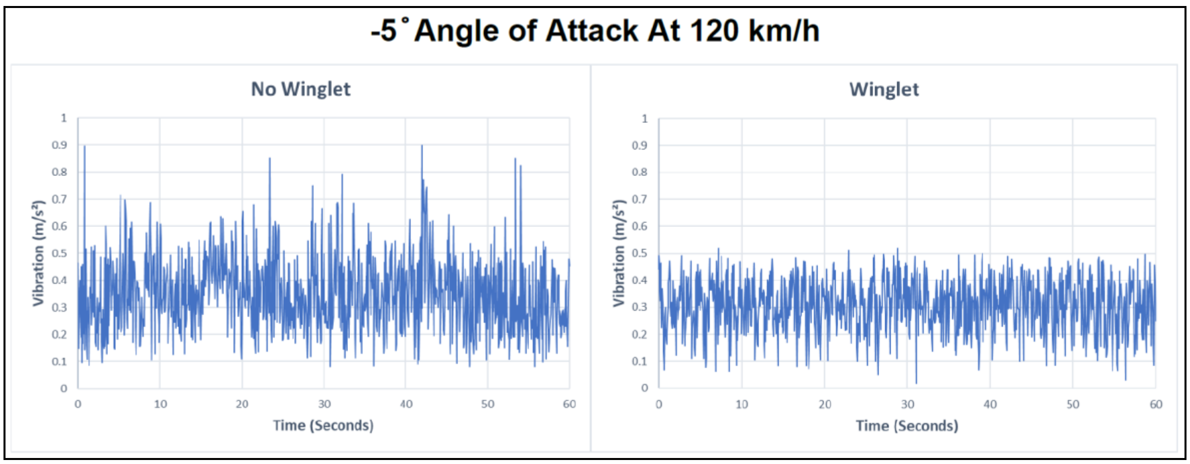


Figure 29: Wings vibrations at -5 degrees angle of attack and 120 km/h.

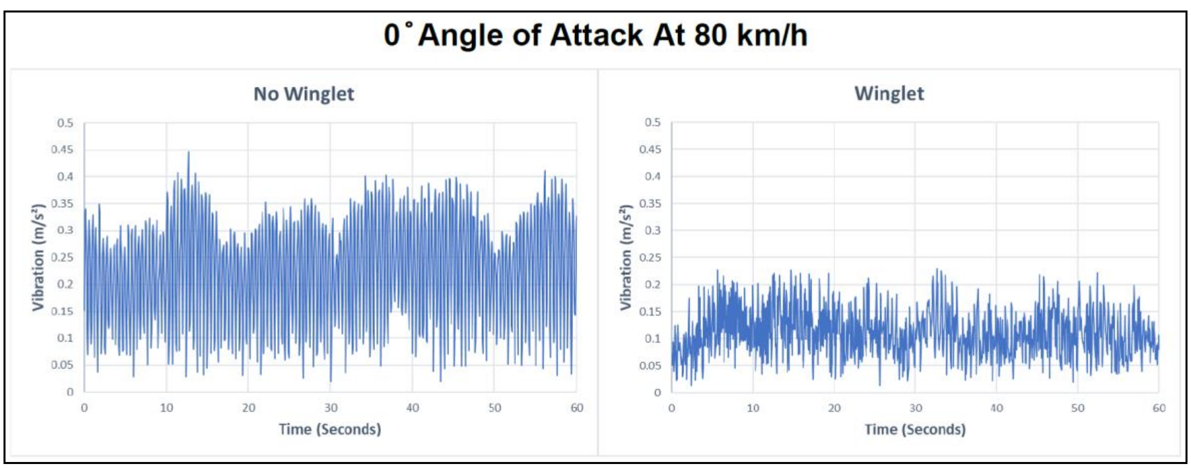


Figure 30: Wings vibrations at 0 degrees angle of attack and 80 km/h.

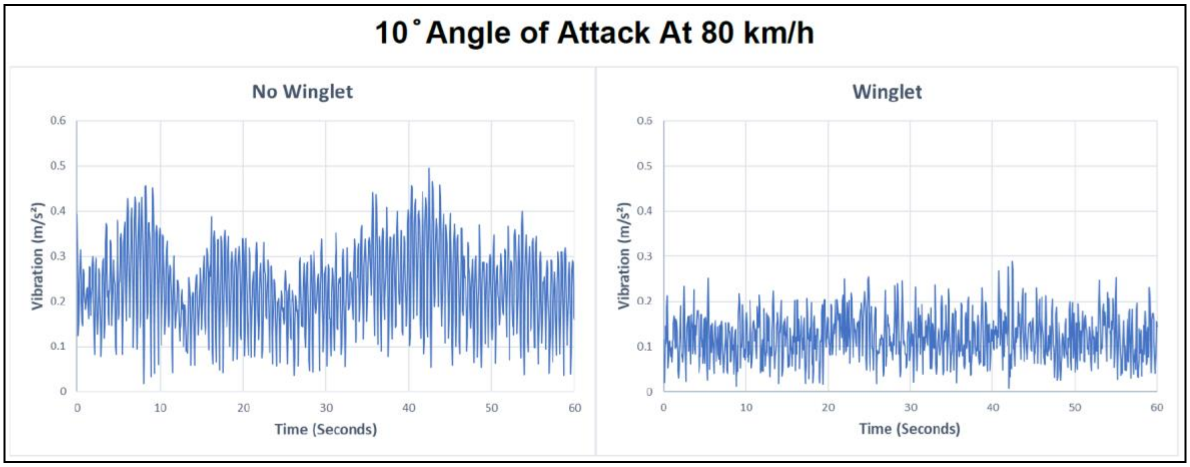


Figure 31: Wings vibrations at 10 degrees angle of attack and 80 km/h.

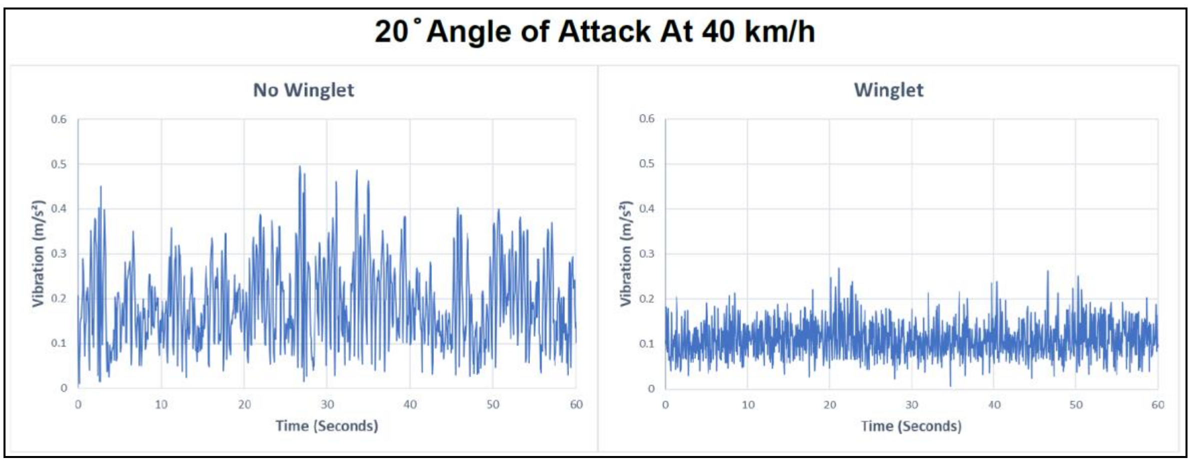


Figure 32: Wings vibrations at 20 degrees angle of attack and 40 km/h.

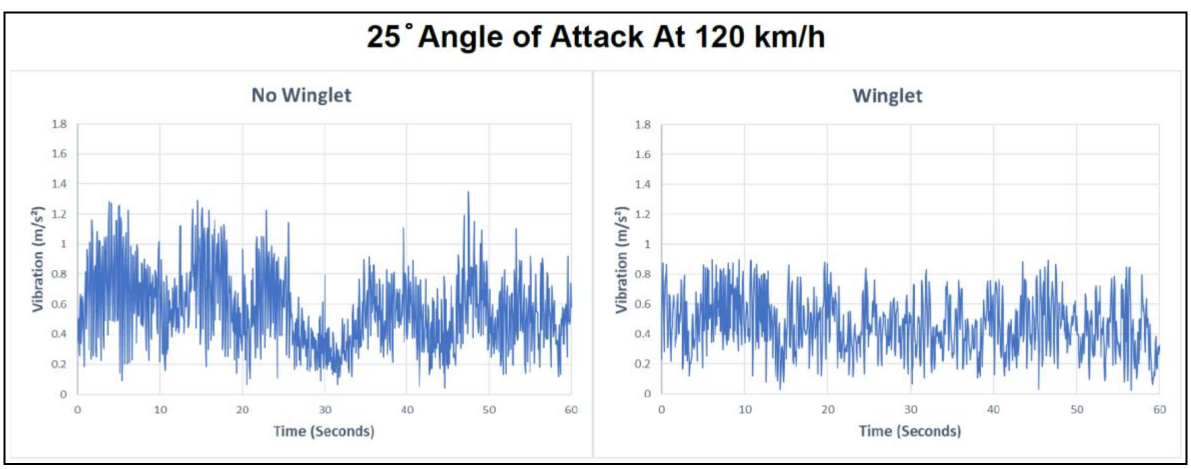


Figure 33: Wings vibrations at 25 degrees angle of attack and 120 km/h.

In these graphs the difference in the magnitude of vibrations between the two half wings is better illustrated. The half wing with winglet presented a more “stable” behavior, having vibrations “peaks” of lesser magnitude and with less frequency compared to the half wing without winglet. Also, with the graphs, the difference in magnitude is observed when the angle of attack of both half wings increases.

Combined results of vibration analysis for the half wing with and without winglets presented on the graphs below. On the Figures 34 and 35 shown the Average vibration half wing with and without winglet at three levels of airspeed.

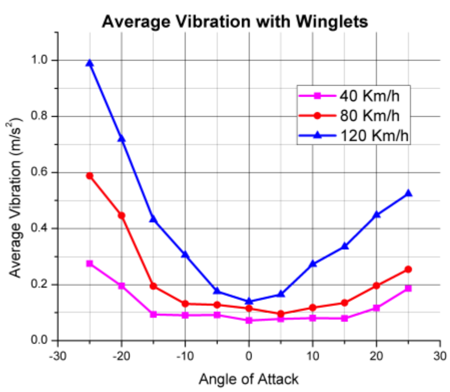


Figure 34: Average Vibration with winglets

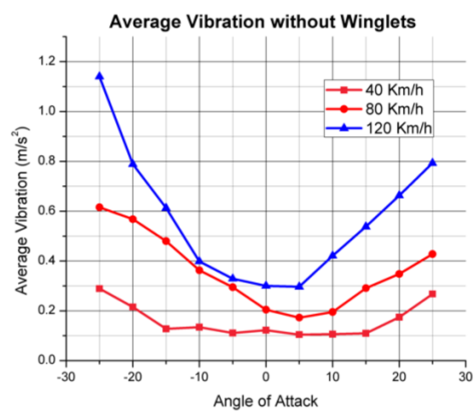


Figure 35: Average Vibration without winglets

On Figures 36, 37, and 38 show the graphs that best capture the difference in the magnitudes of vibrations in both half wings for airspeed at 40 km/h, 80 km/h and 120 km/h.

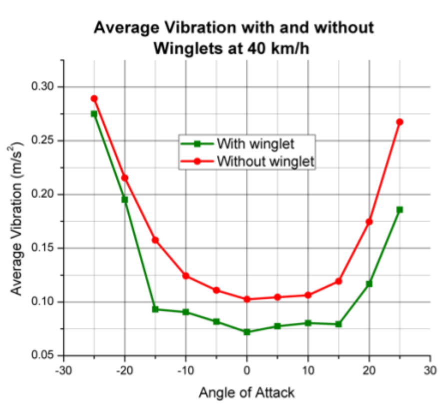


Figure 36: Average Vibration with and without winglets at 40 km/h of airspeed.

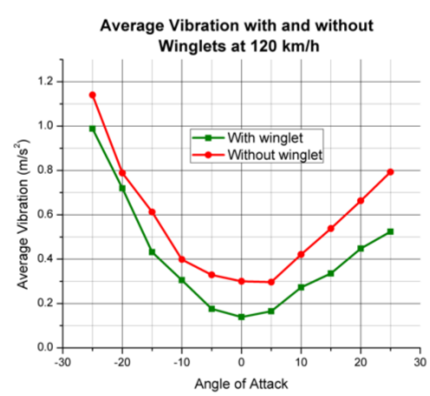


Figure 37: Average Vibration with and without winglets at 80 km/h of airspeed.

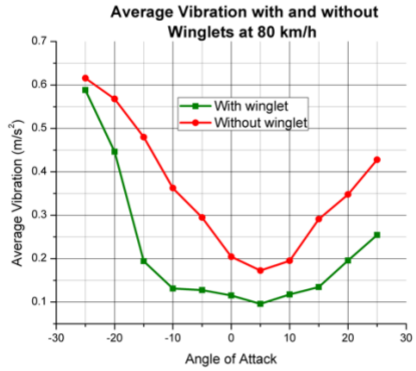


Figure 38: Average Vibration with and without winglets at 120 km/h of airspeed.

6. Productos generados

The results of this project:

1. Was presented on International conferences XXIX CONGRESO INTERNATIONAL ANUALDE LA SOMIM (20 – 22 September 2023).
2. Expected publication in the RIDE Revista journal.
3. Materials of this project were used for the Titulation thesis for undergraduate students.
4. Educational value: This project exposed the students to multiple phases of professional design in an engineering approach. The students got the opportunity to carry a design all the way to prototype testing, which was great preparation for future professional endeavors.

7. Conclusiones

Investigated how vibrations directly and indirectly affect the aerodynamics efficiency of aircraft; the advantages and disadvantages of wingtip devices were analyzed and studied, especially the effects on vibrations in the aircraft. Additive manufacturing was used to prepare half wing prototypes. Thus, having the semi-wings ready, a comparative vibrational analysis was carried out, which showed that, in effect, ***wing tip devices or winglets, manage to reduce the magnitude of vibrations by an average 29.89%, for all angles of attack and speeds at which both half wings were tested***. Finally, as recommendations for the project and similar future analyzes, it would be interesting to carry out measurements in the vibrational magnitudes of half wings on a larger scale, but at higher air intake velocities.

8. Contribución e impacto del proyecto

In general, the presenting results of the research can be used in the design and production of airplanes, drones and other unmanned aerial vehicle (UAV). Also, some parts of the project (Half wings design, Half wings manufacturing, Vibration analysis in Wind tunnel) can be used for learning purpose in Industrial, Manufacturing and Aeronautics programs.

9. Impacto económico, social y/o ambiental en la región

Completed investigation shows the way how to reduce vibration, generated by wings of aircraft. Decreasing aerodynamic drag improving fuel consamption of aircraft and lovering nois polution and contamination of the envairoment.

Also this project has educational value: this research exposed the students to multiple phases of professional design in an engineering approach. The students got the opportunity to carry a design all the way to prototype testing, which was great preparation for future professional endeavors.

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11. Anexos

11.1 Taxonomía de los Roles de Colaborador (con las actividades logradas)

Roles	Definición de los roles	Nombre de él(la) investigador(a)	Figura	Grado de contribución	Actividades logradas durante el proyecto	Tiempo promedio semanal (en horas) dedicado al proyecto
Responsable de Proyecto	Management and control all activities. Theoretical análisis. Experements. Text.	Dr.Shehret Tilvaldyev	Autor	50%	Completed all activities	4
Colaborador	Manufacturing activities in Ford Center, Canada	Mtra Mirada Kambarova	Coautor	8%	Completed all activities	1
Colaborador	Theoretical análisis, ANSYS	Dr. Uzziel Caldiño Herrera	Coautor	11%	Completed all activities	1
Colaborador	Responsible for Vibration sensor activities	Dr. Jose Omar Davalos Ramirez	Coautor	11%	Completed all activities in time	1
Colaborador	Responsible for 3D printer activities	Mtro. Arturo Paz Perez	Coautor	9%	Completed all activities in time	1
Colaborador	Responsible for 3D printer activities and material selection	Mtro. Manuel Alejandro Lira Martinez	Coautor	11%	Completed all activities in time	1

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RECONOCIMIENTO

a

Shehreth Tilvaldyev

Por su destacada participación como PONENTE con el tema "Effect of the winglets with 90° CANT angle in the generation of vibration on a half wing with a symmetrical NACA 0018 airfoil", durante el XXIX CONGRESO INTERNACIONAL ANUAL DE LA SOMIM, celebrado del 20 al 22 de septiembre de 2023 en la Universidad Autónoma de Ciudad Juárez.

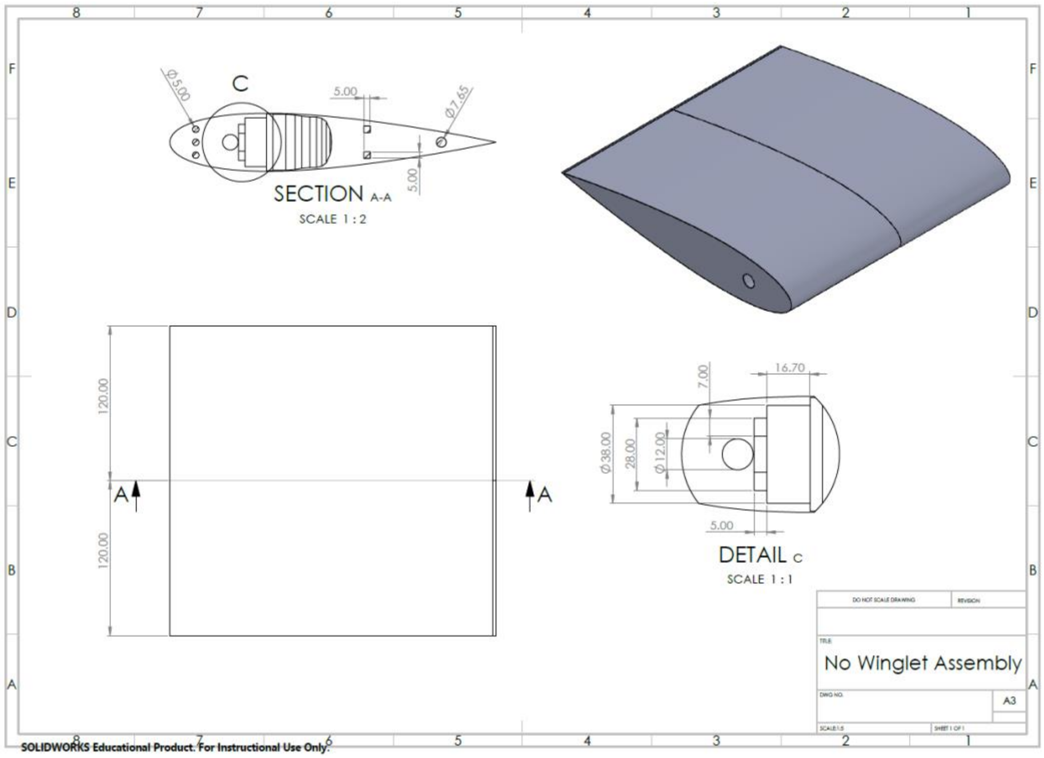
XXIX CONGRESO INTERNACIONAL ANUAL DE LA SOMIM

"Por una vida científica, por una ciencia vital"

Dr. José Manuel Riesco Ávila

Presidente de la SOMIM A.C.

Assembly drawing without winglet.



Assembly drawing with winglet.