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DESIGN, 3D PRINTING AND TESTING OF UNCONVENTIONAL GLIDER WING STRUCTURES

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ABSTRACT

With the emergence of winglets, especially aerobatic gliders, have considerably improved their aerodynamic performance by increasing lift and aerodynamic fineness. Winglets bring a benefit to the evolution of aerospace engineering and are now used on as many aircraft as possible. In addition, the implementation of the winglet with corrugations, circular or sinusoidal in shape, can be an important step in aviation development by reducing drag, which in turn increases lift. In this paper, three types of wing configurations have been designed, CFD analysed, manufactured by additive technologies and three-point bend tested, namely: conventional, circular leading edge and sinusoidal leading edge. In aerodynamic tests the sinusoidal wing showed a higher lift coefficient at negative angle of attack and zero angle of attack, while the circular wing showed better performance at positive angle of attack. From the mechanical tests, of the three 3D printed wing configurations, the conventional wing showed the highest bending strength and the highest strength to mass ratio.

Keywords: unconventional wing, glider, CFD, mechanical testing, 3D printing

1. INTRODUCTION

Advanced state of aviation is due mainly to the development of gliders. The development of the aviation industry has led to exponential improvements in the various gliders designed over the years, both in terms of aerodynamics and by modifying materials, interior structure, and control systems, with the ultimate goal of increasing safety and flight efficiency [1]. Winglets are vertical extensions of the tips of wings used to reduce drag caused mainly by vortices that form at the wing tips during flight [2]. This, in turn, leads to a fuel reduction of up to 4-6%, which means a reduction in CO_2 emissions of up to 6%, making winglets the most widely used technology in aviation for reducing fuel consumption [3]. The evolution of winglets in recent years has led to their use on most aircraft, including various gliders. Although at the beginning they did not bring a considerable benefit to glider performance, they are now found on most of them [4]. In order to develop winglets with an optimal structure, a series of checks are carried out, including checking the airflow around the winglet, carried out through a simulation using CFD software systems [5]. For such tests, various aspects are important, such as the type of winglet, the aircraft on which it is mounted, the angle of attack at which it is mounted and the airspeed [6], [7].

Over time, reducing drag and increasing lift have been important factors in the development of aviation. Among the methods discovered are the implementation of wing tips, winglets (the most common) or special active/passive flow control methods. However, the reduction in drag has been as high as 5%-7% [8]. Inspired by bird wings [9] and other animals such as the whale, various studies have been conducted showing that a sinusoidal or circular wing leading edge can positively influence aircraft performance [10]. In a study [11], the S809 airfoil was used and the two geometries for wind turbine blades (sinusoidal and circular) were modelled and analysed at different angles of attack between -2° and 24°. Following the analyses, the results revealed that the efficiency of the corrugated leading edge concept depends on the basic airfoil and works better for the case where the blade is in stall regime. In a recent study [12], the two geometries (sinusoidal and circular) were analysed using finite element analysis (buckling) and finally rapidly prototyped from polylactic acid material.

From the analysis of the current state, it can be observed that wings equipped with winglets and unconventional geometries (sinusoidal and circular) have not been analysed. Thus, in this study 3 types of winglets (conventional, sinusoidal, and circular) were designed to perform a comparative study on aerodynamic performance. Finally, the three wing configurations (conventional, sinusoidal, and circular) were 3D printed and tested for three-point bending.

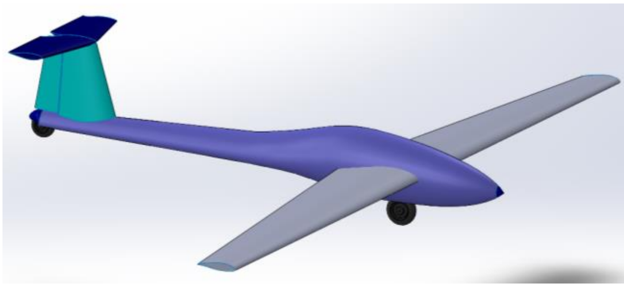
2. GLIDER WING DESIGN

For the analysis of wing tips mounted on wings with unconventional structure (wings with circular or sinusoidal leading edge), the design of the glider in the conventional version and in the two innovative versions using the SolidWorks 2020 software system, with the IS-29D2 and IS-28B2 gliders as reference. The gliders analysed in this study are at scale 1:10, based on the two IS-29D2 and IS-28B2 glider references. Some geometrical characteristics of the glider are detailed below: fuselage length 875 mm, fuselage width 320 mm, Wortmann FX 61-163 wing profile, chord at the embedment 146 mm and chord at the end 65 mm, wing span 1700 mm, horizontal tail span 330 mm, vertical tail span height 150 mm.

Therefore, the three glider versions (Fig. 1) have been designed from the basic elements found on most aircraft of this type. The circular/sinusoidal wing and winglet versions are unconventional versions and are currently at the prototype stage. Although tests show a clear improvement in flight performance, the extra weight of the winglet and the circular/sinusoidal configurations, and the difficulty of manufacturing them prevent the conventional wing from being replaced. However, tests continue in search of solutions, including the choice of lighter materials (composites) and 3D printing of some parts to ease the manufacturing process.

3. AERODYNAMIC ANALYSIS OF THE THREE TYPES OF WINGS

In order to check whether unconventional wing versions bring performance improvements to the aircraft, an aerodynamic fluid flow analysis was carried out. Computational Fluid Dynamics (CFD) aerodynamic analyses are performed in the SolidWorks Flow 2020 software system to obtain lift and drag coefficients. The three wing versions (conventional, circular leading edge, sinusoidal leading edge) are entered into the software system, setting the X-axis speed to 30 m/s. The CFD analyses were carried out at three different angles of attack (0°, -5°, 10°). Figure 2 shows the airflow velocity around the wing for each configuration.



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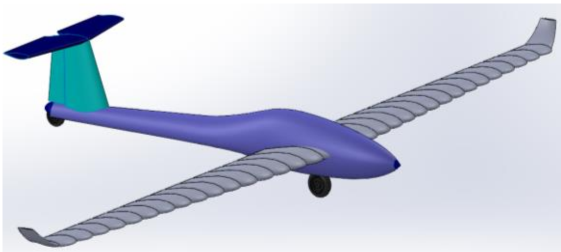

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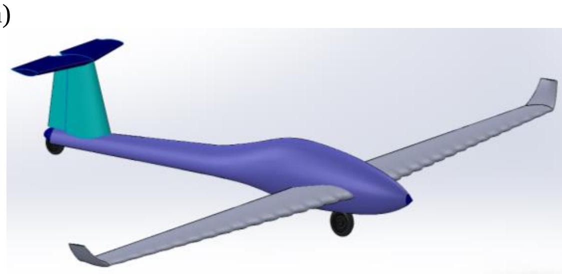

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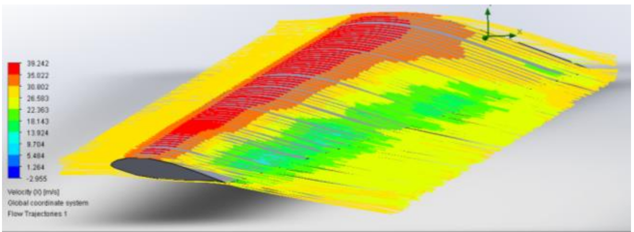
Fig. 1. Three-dimensional model of the glider: a) wing with conventional geometry, b) wing with circular geometry, c) wing with sinusoidal geometry



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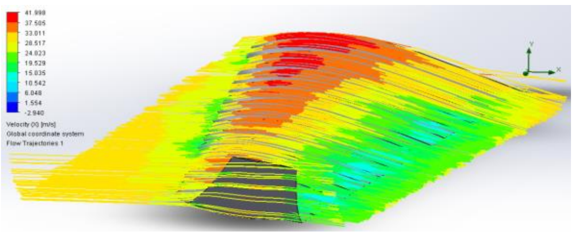

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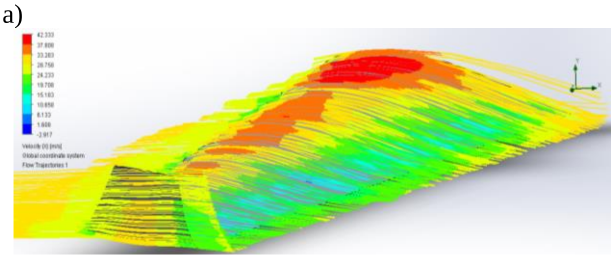


c)

Fig. 2. CFD analysis of the wing of the glider at 10° angle of attack: a) wing with conventional geometry; b) wing with circular geometry; c) wing with sinusoidal geometry

The analyses (Fig. 2) showed (at zero angle of attack) a maximum flow velocity of 48.3 m/s for the conventional configuration and a minimum value of 36.4 m/s for the circular leading edge configuration. At negative angle of attack (-5°), the values are close to 36.6 m/s for the conventional version, 38.4 m/s for the circular version and 41.7 m/s for the sinusoidal leading edge version. Finally, at positive angle (10°) the velocity will reach a maximum of 42.3 m/s for the sinusoidal configuration, a close value for the circular (41.9 m/s) and a minimum of 39.2 m/s for the conventional configuration.

As a result of simulating the airflow velocity on the three wing models, the values of lift force and drag are obtained. The calculated lift coefficients and drag coefficients are shown in Table 1. For zero angle of attack (0°), an increase of the lift coefficient in the sinusoidal wing configuration by 5.02% and a decrease of the lift coefficient in the circular configuration compared to the conventional wing is observed. For negative angle of attack (-5°), the lift coefficient decreases for the sinusoidal wing version and increases significantly for the circular leading edge version by about 15% compared to the conventional wing. Another significant increase can be observed at the 10° angle of attack where the lift coefficient for the circular configuration increases compared to that for the conventional configuration by 12.21%, while the sinusoidal version shows an increase compared to the conventional one by 5.83%. Regarding the drag coefficient, it can be observed that at two angles of attack (0° and -5°), the sinusoidal configuration has the lowest value of drag coefficient, while at positive angle, the conventional configuration has the lowest value of drag coefficient.

4. 3D PRINTING OF WING SECTIONS

The 3D printing process has been developed in recent years, due both to the relatively low cost and the availability of 3D printing equipment. From small prototypes to parts needed for products in various industries, 3D printing brings a number of significant advantages over traditional manufacturing [13], [14]: speed of prototyping, efficient production of small series of parts, reduced repair time, production of complex, customised structural models with a wide variety of materials, reduction of aircraft weight, no transport and storage costs, no cost for moulds. After the aerodynamic design and analysis stages of the three wing configurations (conventional, circular, sinusoidal), the next stage for their characterisation was the 3D printing of five wing sections each to be mechanically tested in three-point bending. For the 3D printing of the wing sections, made of polylactic acid filament (PLA), the Ultimaker S5 thermoplastic filament extrusion system was used. Table 2 shows the manufacturing parameters used for 3D printing of the mechanically tested samples.

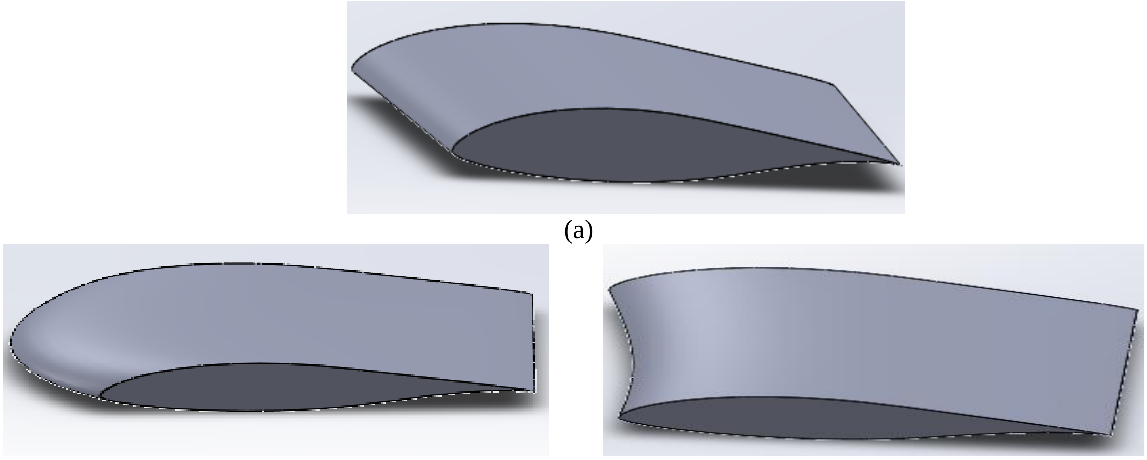
For the mechanical testing of the sections with the three configurations, the starting point was to design them in the SolidWorks 2020 software system. For all three wing models (conventional, circular, sinusoidal), a section starting from the top of the wing is chosen. The preparation for 3D printing of the wing samples was carried out in the Ultimaker Cura 4.13 software system. The samples (Fig. 3) had the following dimensions: thickness 25 mm, width 22 mm and length 150 mm.

Table 2. Parameters for manufacturing wing sections using FFF process

3D printing parameters	Value
Filament diameter [mm]	2.85
Infill density [%]	40
Layer hight [mm]	0.2
3D printing speed [mm/sec]	60
3D printing extrusion temperature [°C]	210
Building plate temperature [°C]	60
Nozzle diameter [mm]	0.4
Infill pattern	Lines

Table 1. Variation of aerodynamic coefficients as function of wing configuration and angle of attack

Wing configuration and angle of attack	Lift coefficient	Drag coefficient
Conventional (0°)	0.1363	0.0109
Circular leading edge (0°)	0.1101	0.0039
Sinusoidal leading edge (0°)	**0.1432**	**0.0037**
Conventional (-5°)	0.0400	0.0044
Circular leading edge (-5°)	0.0063	0.0053
Sinusoidal leading edge (-5°)	**0.0558**	**0.0043**
Conventional (10°)	0.2785	**0.0030**
Circular leading edge (10°)	**0.3125**	0.0048
Sinusoidal leading edge (10°)	0.2953	0.0050



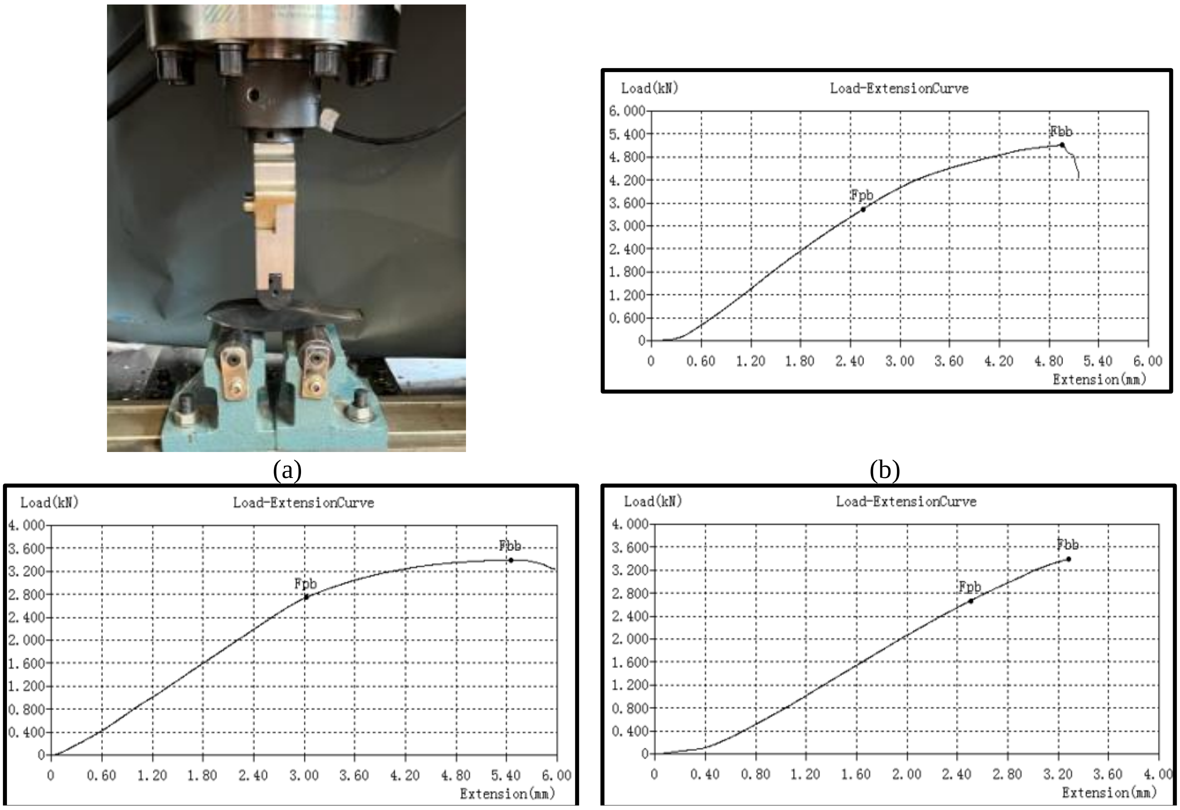
(a)

(b) (c)

Fig. 3. The sections designed for producing by additive manufacturing: a) wing with conventional geometry, b) wing with circular geometry, c) wing with sinusoidal geometry

(a) (b)

Fig. 4. 3D printed sections: a) sections with conventional geometry; b) 3D printed sections



(a) (b)

(c) (d)

Fig. 5. Results of three-point bending of the **s**ections designed and produced by additive manufacturing: a) three-point bending test of wing samples using the universal machine; plots for load – extension for: b) wing with conventional geometry; c) wing with circular geometry, d) wing with sinusoidal geometry

3D printing of the samples (Fig. 4) was performed without any problems and the printing times and filament consumed are detailed below:

- wing with conventional configuration – 9 hours 10 minutes and 150 g of filament,
- wing with circular leading edge – 10 hours 8 minutes and 169 g of filament,
- wing with sinusoidal leading edge – 8 hours 43 minutes and 144 g of filament.

5. THREE-POINT BENDING TEST OF WING SAMPLES

Previously 3D printed sections are mechanically tested for three-point bending, with tests performed on the WDW-150S universal machine (Fig. 5a). In order to get a comprehensive analysis, 5 sections of each configuration were printed, each being positioned so that the distance between the supports is 70 mm, and the loading speed is kept at 10 mm/min for all the samples. After the three-point bending tests were carried out, the bending strength of the wing sections is assessed until they break, thus determining, for each wing type, the load it can withstand during flight. The load - displacement curves (Figures 5b, 5c and 5d) have been extracted from the software system of the test equipment, and their shape is similar: a linear increase, followed by a peak and a maximum of reaction force, at which the sample breaks/fails.

Starting from the mean bending strength obtained for each sample and from the mean of their masses (30 g conventional wing, 34 g circular wing, 29 g sinusoidal wing), a specific ratio was obtained, indicating the efficiency of the wing.

Table 3. Strength to mass ratio analysis of the wing specimens

	Bending strength [MPa]		
	Conventional wing	**Circular wing**	**Sinusoidal wing**
1	44	31	30
2	44	29	30
3	38	29	29
4	37	34	30
5	33	37	29
Mean strength [MPa]	39.2	32	29.6
Mean mass [g]	30	34	29
Strength to mass ratio [MPa/g]	1.3	0.94	1.02

After calculating the averages for each configuration, the highest bending strength value was obtained for the conventional wing type (39.2 MPa), a lower bending strength value for the circular type (32 MPa) and a lower bending strength of 29.6 MPa for the sinusoidal type. These averages of bending strength indicate that the conventional sections showed the highest strength in the mechanical tests, while the sinusoidal sections were the least resistant. After performing the specific ratio, it was indeed observed that the highest efficiency is gained using the conventional wing (1.3). Although the average resistance was minimum in the sinusoidal configuration, the minimum ratio is obtained in the circular configuration (0.94) due to the higher mass.

6. CONCLUSIONS

In conclusion, wings with unconventional structures have both advantages and disadvantages, at the moment. Although aerodynamic tests showed a considerable increase in lift and, consequently, in lift coefficient, mechanical tests showed much higher values for bending strength and specific ratio for the conventional wing configuration than for the other two configurations. Although not yet used in the aircraft industry, the corrugated configuration has become increasingly used in wind turbine blades and it is starting to be tested by an increasing number of aircraft companies. As an innovative concept, numerous experimental tests are needed to determine whether they can indeed be used successfully in aviation, as they involve an investment in the manufacturing process and validation of unconventional wing concepts. As with any breakthrough, there is a degree of scepticism, but prototype analyses suggest that unconventional wings could be used in the future on various types of aircraft (UAVs, light aircraft, gliders and motor gliders) due to their increasingly high aerodynamic and structural performance.

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