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THE CONCEPTUAL DESIGN OF A SUSTAINABLE REGIONAL AIRCRAFT

Abstract: *This paper aims to present the conceptual design of a sustainable regional aircraft. In previous studies, the hypothesis of this paper was determined: the purpose is to design a concept sustainable regional aircraft, propelled by electric engines powered with batteries, that can transport up to 18 passengers on distances of 1 000 km. The most suitable configurations for the wing and empennage are chosen and then modelled, according to the dimensions driven by the cabin size. The result is a 3D model of the concept aircraft that allows further studies into the feasibility and rate of success of such a project.*

Key words: *aircraft, sustainability, design, concept, airframe.*

1. INTRODUCTION

Mankind has had many dreams throughout history but perhaps flying has been the greatest one. Once the basic notions of flight were put into place, the aviation and aerospace industries had a quick development during the 20th century. However, these industries are not the only ones that had a prosperous evolution and along with many companies from various fields, they have been having a negative cumulative impact on the environment, mainly due to the use of fossil fuels, the most pollutant energy source.

Therefore, flight is a dream come true, but it has a harmful contribution to the climate crisis we find ourselves in. It facilitates the collapse of the ecosystems, which seems inevitable according to scientists unless we do something about it [1].

In order to slow down climate change, aviation must bring its own positive contribution by approaching sustainable strategies. Only this way can we be assured that there will be a safe and responsible future of this industry.

Sustainability in aviation is based on three closely related concepts: the impact of aviation on the environment (climate, air quality, noise pollution), renewable energy sources and social factors that determine the need to use air transportation.

The reduction of the pollution levels is almost entirely possible only by using the appropriate propulsion systems, that work on nonpolluting fuels, attained from renewable sources. By implementing an efficient solution, combined with modernized airframes, a decrease in emissions is guaranteed. As long as actions are taken towards a sustainable approach in the production of the aircraft themselves, the materials used, the factories, it is certain that aviation will have a carbon footprint close to none.

A sustainable airplane, just like any other aircraft ever designed, begins just as a concept, an idea that takes root in a person's mind and flourishes through engineering and design tools. In the phase of conceptual design, certain conditions must be taken into considerations, the input of a variety of domains must be analyzed, from structures to engines.

The beauty of the concept phase of a project perhaps stands in the opportunity to explore ideas and break barriers. A designer is free to do his best and most original work since, at this time in the project, the product has the least amount of requirements. Once the preliminary phase or even detailed phase has been reached, the freedom to explore the design is limited by many more constraints.

This article shows a fraction of a concept phase in the design of a regional sustainable aircraft. Previous analysis of this aircraft has determined some basic data, shown in Figure 1.

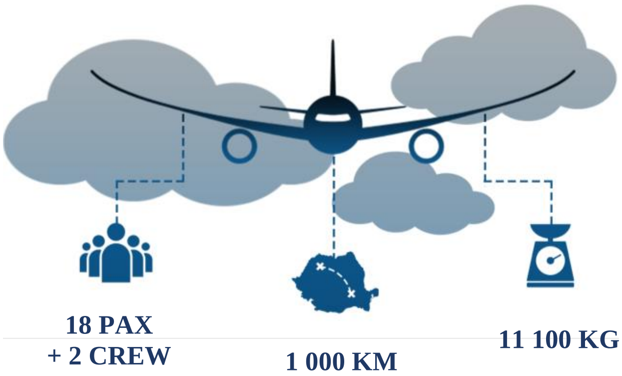

Figure 1 Concept airplane specifications infographic.

2. DESIGN CONSIDERATIONS

In order to provide more stability for flight maneuvers and create a placement space for the propulsion systems, a high wing configuration (Figure 2) is chosen. The high wing is mounted on top of the fuselage and has a sturdier structure, to ensure it can support the weight of the electric engines and the weight of the fuselage in flight. It is suitable for the desired top speeds (160 knots ~ 300 km/h), it allows the placement of the fuselage closer to the ground and allows crew and passengers to walk easier around the aircraft. Moreover, the high positioning of the wing, implicitly the engines, keep the propulsion systems and the propellers further away from possible damaging objects [2] such as debris from the runaway.

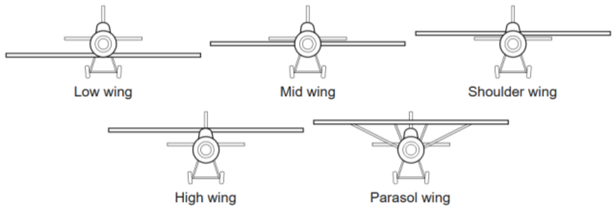

Figure 2 Wing configurations [3].

Furthermore, the straight wing for this case is best designed as slightly tapered since it causes a decrease in drag and consequently an increase of the lift coefficient. This configuration is more popularly known as a trapezoidal wing (Figure 3).

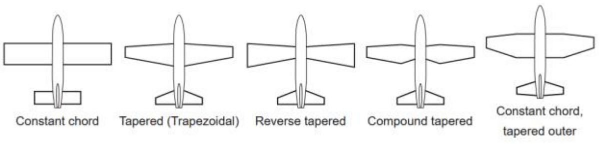

Figure 3 Wing configurations [3].

The wing definition is followed by the empennage. After careful considerations, the selected configuration is a T-tail (Figure 4). It has a main disadvantage represented by the increased weight, owed to the reinforced structure of the vertical tailplane needed to support the horizontal component. However, thanks to the endplate effect (Figure 5), the T-tail configuration allows the use of a smaller vertical fin. The horizontal stabilizer is placed high enough from the fuselage that it does not intersect with the turbulent air outboard of the wing, therefore making it more efficient. Additionally, in this way it is possible to reduce the buffeting effect on the horizontal tailplane, reducing the structural fatigue.

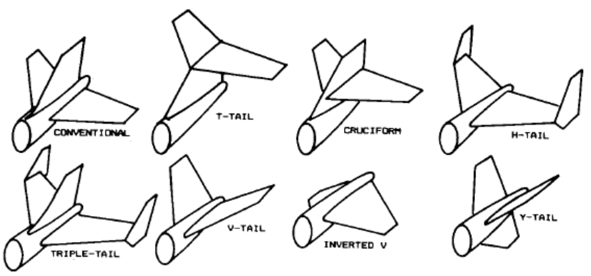

Figure 4 Empennage configurations [2].

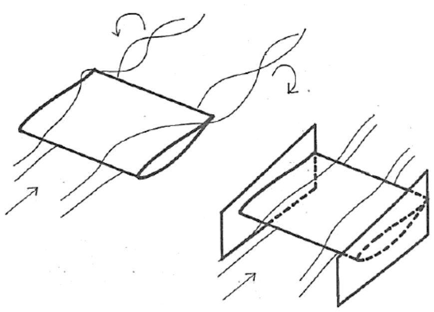

Figure 5 Influence of endplate effect on an airfoil placed in an airstream [4].

3. GEOMETRICAL CONSIDERATIONS

Having decided upon the principal determinant factors that guide the design of the airframe, they should be associated with the right dimensions.

For a relevant definition of the parameters that define the aircraft size, a simplified sketch is created (Figure 6). Built from basic shapes (rectangles, triangles), the sketch shows the exact placements of the seats within the cabin, the cockpit and the dimensions of the main features. The seats are considered to measure 50 cm in width, 5 cm above industry standard. As far as the distance between seats is concerned, there is a 75 cm pitch, aligned with the industry average. The single-aisle is dimensioned at 80 cm wide, placing it at a business-jet level in terms of space with 30 cm over the usual dimensioning.

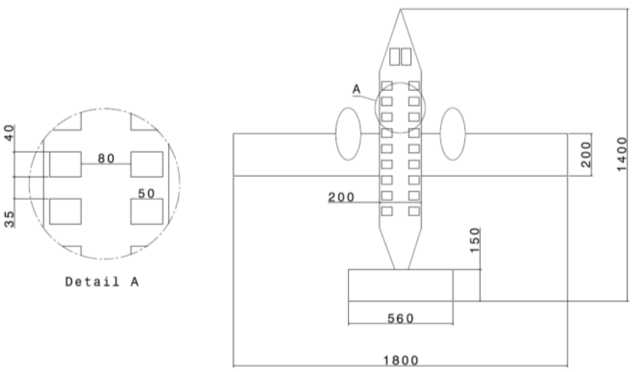

Figure 6 Simplified sketch displaying airframe and cabin size parameters.

The passengers' seats positioning determines the length of the cabin and therefore the dimensions of the fuselage, which shall also contain all the batteries under the cabin floor. This acts as a guiding measurement for the rest of the parameters such as the wingspan and tail span.

Having decided upon the size of the wing and the sweep angle of the tapered configuration (5°), a relevant specification can be determined, the aspect ratio:

$$AR = \frac{b^2}{S} \quad (1)$$

where AR – Aspect ratio (Figure 7)
b – wingspan
S – wing surface

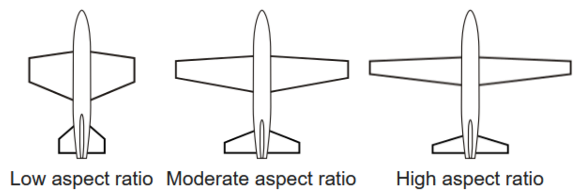

Figure 7 Aspect ratio possibilities [3].

Using formula (1), the aspect ratio of the wing determined is ~9, thus a moderate-high one. This parameter, historically considered to define wing efficiency [2], is of importance due to its impact on lift, represented in Figure 8. The graph shows the way lift increases with aspect ratio, constituting how a higher AR is preferred.

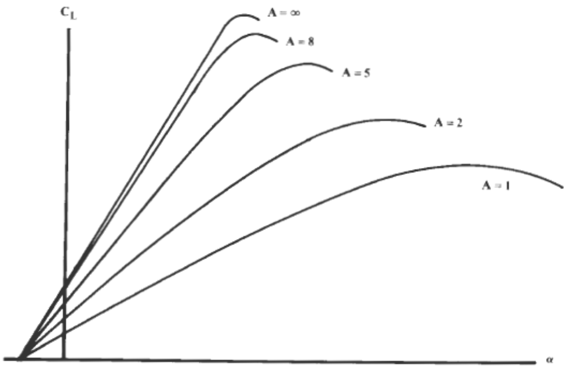

Figure 8 The effect of aspect ratio on lift (lift coefficient) [2].

The next step taken toward defining the concept design is choosing the airfoils for the main surfaces. For this, a public database needs to be used, therefore the NACA airfoils represent the best choice due to the simplicity of obtaining profile coordinates (Figure 9).

For the wing, NACA2414 is a fitting option, with a maximum camber of 2%, located 40% from the leading edge and a maximum thickness of 14 % of the chord [5].

For the vertical empennage, the symmetrical airfoil chosen is NACA 0010 (Figure 10), with a thickness of 10%. As far as the horizontal stabilizer is concerned, NACA 2414 constitutes a suitable choice (Figure 11).

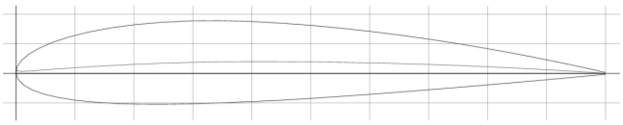

Figure 9 NACA2414 airfoil – selected for wing [5].

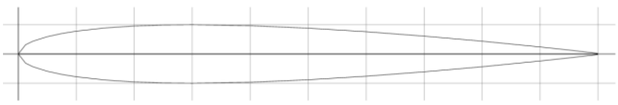

Figure 10 NACA 0010 airfoil – selected for vertical tail [5].

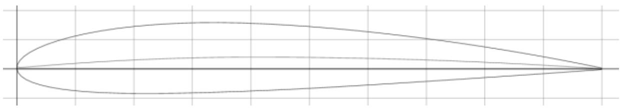

Figure 11 NACA 2414 airfoil – selected for horizontal tail [5].

4. MODELLING

The previous chapters have introduced all the necessary data for sketching the aircraft concept. For this, the CAD software used is Catia V5, a multi-platform engineering software developed by Dassault Systèmes.

The concept is created using the Generative Shape Design workbench, which allows the creation and manipulation of complex curves and surfaces. The global axis system is defined according to the latest aviation industry standards, with the origin in the nose of the aircraft, the X-axis along the fuselage towards the rear and the Z-axis opposite to the ground.

Chosen work methodology is established by the creation and use of geometrical sets to organize the geometric elements. Furthermore, only the left-hand side of the aircraft is modelled, the right one being mirrored, for simplicity (Figure 12).

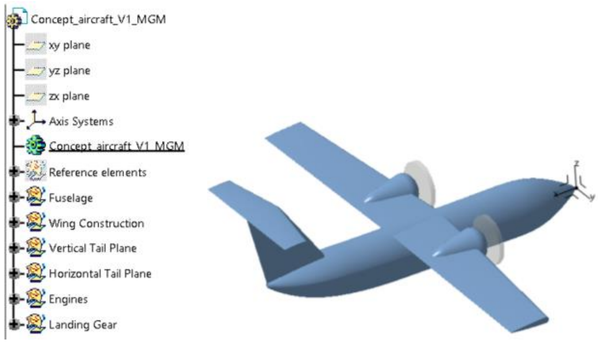

Figure 12 Modelled concept aircraft – axis system and tree.

The fuselage is designed using multi-surface commands that connect previously created splines, constrained by the imposed dimensions. The height of the fuselage is adapted to fit all the necessary batteries for the electric engines under the cabin.

For the wing, the NACA 2414 airfoil is imported from a Microsoft Excel file and with the help of a macro, a spline is defined with the specified coordinates. The spline is then swept across half-wingspan on two guiding curves that represent no other than the leading edge and the trailing edge.

The same working method is applied for the construction of the vertical and horizontal empennages, with their corresponding airfoils (Figure 13).

Figure 13 Final design of the concept aircraft, version 1.

Two engine nacelles are positioned symmetrically on the wings, representing the mounting spots for the electric propulsion systems. In order to simulate the rotation of the propellers, two transparent cylinders are placed in front of the engines. (Figure 13 and Figure 15).

Last but not least, a three-wheel landing gear system is simulated to offer a complete picture (Figure 14).

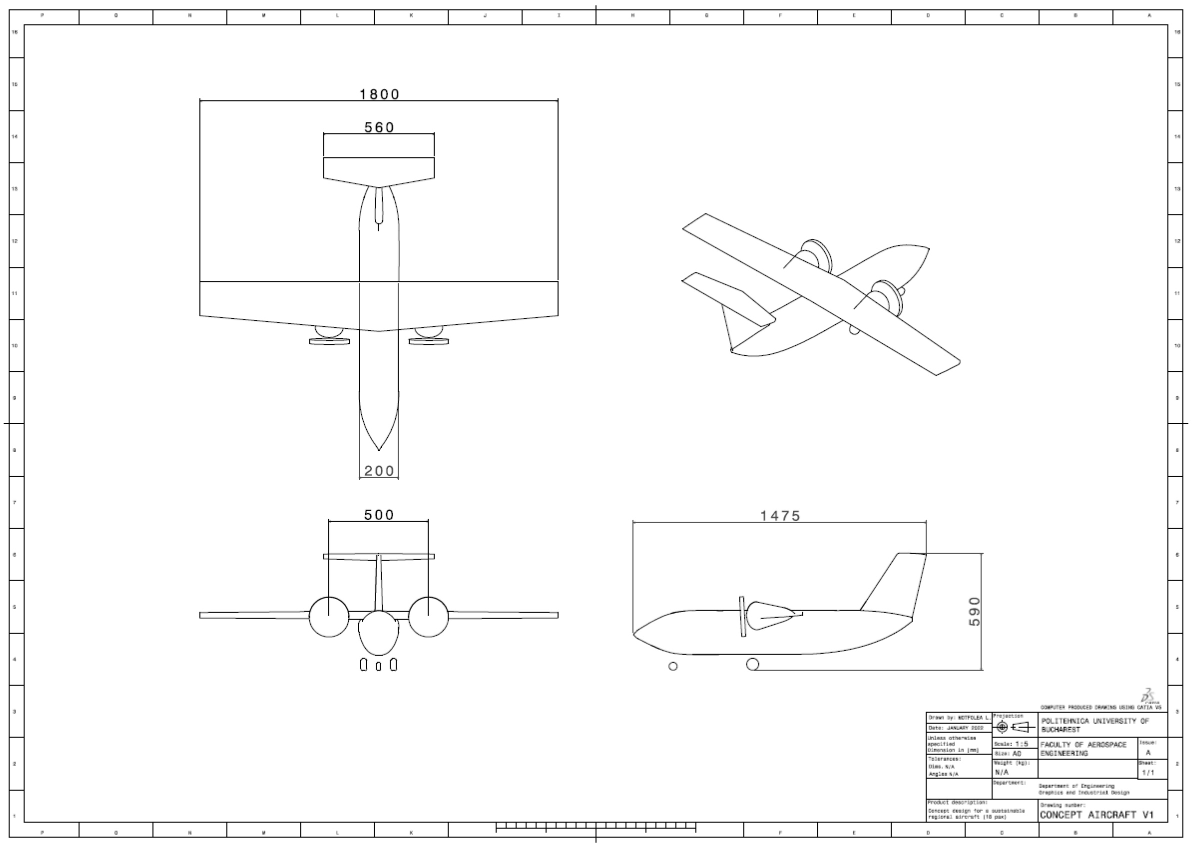

Figure 14 3-view drawing of the concept aircraft.

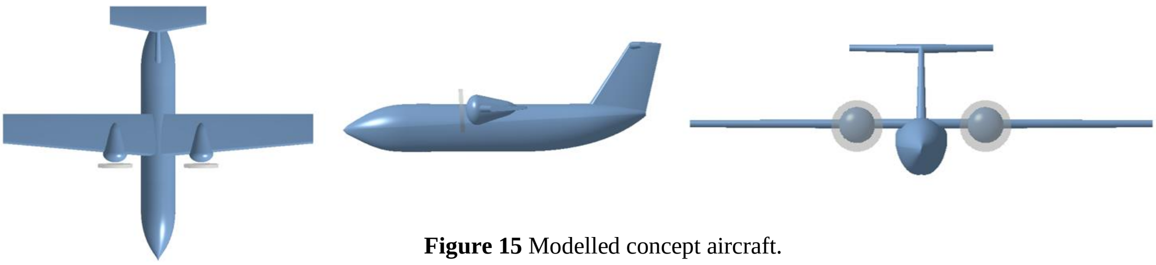

Figure 15 Modelled concept aircraft.

5. CONCLUSIONS

Aircraft design is a vast domain that offers unlimited options. Many things can be done in numerous ways and still meet their functionality criteria correctly. The concept presented in this paper is just one way of fulfilling the defined requirements, a version that after iterations may prove to be a functional design and be forwarded to the preliminary design phase.

The sustainability of this concept stands not only in the use of electric propulsion but also in the chosen configuration. Whilst it may seem like a classic design, its main advantage is the reduced cost of the structure. This offers the possibility to redirect part of the budget towards the acquisition of lighter materials or 3D printed parts. The possibility to optimize the structure and implement the use of new technology remains a topic to be analyzed.

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