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SOLAR-POWERED UAV: A NOVEL APPROACH TO CONCEPTUAL DESIGN

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Highlights

- A UAV system was designed to enhance the performance of a solar-powered UAV system by integrating the solar cells inside the wing
- Reduction of equipment weight used in solar-powered UAV to optimize performance and lead an increase in operational efficiency and flight ranges.
- Developing a conceptual design according to the duration of the UAV's stay in the air depending on the solar irradiation

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ABSTRACT: The increasing environmental impact of fossil fuel usage has propelled a sense of urgency to address depletion concerns and environmental consequences. This article explores the potential of solar-powered unmanned aerial vehicles (UAVs) as a sustainable alternative in the aviation sector. Originating from advancements in photovoltaic (PV) technology, the integration of solar cells onto aircraft structures has led to innovations in electric aircraft, with a focus on UAVs. The study searchs the conceptual design methodology, emphasizing the complex interplay of factors such as aerodynamics, structural analysis, and performance requirements in solar UAV design. The selection and analysis of solar cells, energy storage systems, and their integration into the UAV are detailed. The study further discusses the crucial aspects of solar irradiation, weight analysis, and aerodynamic parameters in the design process. The proposed UAV design incorporates monocrystalline silicon solar cells, lithium batteries, and Maximum Power Point Tracking (MPPT) technology. A constraint analysis aids in optimizing power-to-weight ratios, thrust-to-weight ratios, and wing loading. The article concludes with a detailed weight estimation, aerodynamic parameters, and a conceptual design that envisions a solar-powered UAV capable of sustained flight. The outlined approach provides insights for future enhancements in solar-powered UAV technology, addressing challenges and contributing to the evolution of eco-friendly aviation solutions.

Keywords: *Conceptual Design, Solar Energy, Solar Powered UAV*

1. INTRODUCTION

The undeniable environmental impact resulting from the utilization of fossil fuels underscores the urgency of addressing their depletion, given the alarming rate at which reserves are diminishing [1]. As a result, a considerable transition toward renewable energy sources is expected in the coming years.

The arrival of photovoltaic (PV) technology, pioneered by Bell Laboratories in the mid-twentieth century, marked a substantial leap in the development of electric aircraft, which had initially emerged alongside the Wright brothers' pioneering invention [2]. As PV technology advanced, it was used in both unmanned and manned aerial vehicles, as shown by Astro Flight Inc's Sunrise I. Over time, significant progress has been achieved in enhancing the efficiency of solar cells. While laboratory research into solar cell efficiency continues, this study looks into the best technique to use solar cells in unmanned aerial vehicles [2].

Renewable energy has gained a great deal of interest in the aviation sector, particularly in the twenty-first century, due to its potential to supply the energy needs of spacecraft. Furthermore, considering the adverse environmental effects of fossil fuels, solar cells have emerged as a viable option for meeting energy requirements in this industry [3].

The sun's limitless energy supply, combined with the ability to store such energy in batteries, enables the building of aircraft capable of sustained flight. Additionally, solar energy production is emissions-free, supporting ongoing ecological initiatives [4] and is expected to reduce maintenance and repair costs [5]. Nevertheless, solar-powered aircraft face challenges due to the inherent fluctuations of weather conditions, leading to fluctuating solar availability throughout the year, which affects aircraft performance [6].

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The integration of Unmanned Aerial Vehicles (UAVs) into the aviation sector occurred shortly after the flight experiments conducted by the Wright Brothers. Consequently, the timeline of UAVs aligns with the year 1916, which is close to that period [7]. The emergence of UAVs has led to their significant utilization across various sectors, particularly in agriculture, defense, and reconnaissance. As the frequency of UAV deployment continues to rise, there is a growing emphasis on addressing current climate issues and adopting energy transformation strategies. Consequently, numerous configurations have been developed for powering these aircraft, with solar energy serving as a prominent option among them [8].

The solar-powered UAV employs a technologically innovative approach, integrating solar panels onto the aircraft structure [9]. This integration functions as a basis for the generation of electricity through photovoltaic processes, thereby enabling propulsion. The underlying principle involves utilizing solar panels as energy converters, harnessing solar radiation, and converting it into electrical energy.

During daylight hours, the solar panels directly absorb sunlight, converting it into usable electrical energy. This energy powers various UAV components, including the propulsion system, avionics, and communication systems. Excess energy generated during this phase is stored in onboard batteries or capacitors, ensuring continuous power supply for UAV operations even in the absence of sunlight.

This research aims to conceptualize a solar-powered UAV and explore potential enhancements to maximize its efficiency. The initial phase involves detailing the fundamental processes in the conceptual design of the solar-powered UAV. Subsequently, an assessment and selection process will identify the materials needed to meet the required power parameters based on sizing factors.

2. DESIGN METHODOLOGY

The planning of an aircraft is a highly complex and diverse task that demands a methodical strategy, utilizing extensive expertise and experience acquired over time. The process involves the integration of numerous factors, such as aerodynamics, structural analysis, performance requirements, and operational constraints. By combining these elements, engineers strive to create an aircraft that meets the desired objectives and specifications while ensuring safety, efficiency, and reliability [10].

Throughout the development of aviation, various design philosophies and methodologies have emerged, influenced by historical avhievements, technological advancements, and insights gained from previous aircraft designs. These varied approaches, along with the continual advancements in aeronautical industry, have shaped the contemporary practices of aircraft design [11, 12].

The assumptions made during the presizing phase are pivotal in the initial phases of aircraft design. These assumptions encompass preliminary estimations of the aircraft's dimensions, weights, and performance characteristics, relying on initial requirements and a predefined set of assumptionsassumptions [11]. Presizing allows designers to establish a starting point and evaluate the feasibility of the design concept before delving into more detailed analyses and refinements. To capture and share the knowledge and methodologies integral to aircraft design, extensive documentation has been created, serving as a valuable reference for engineers and designers [10].

The UAV design process shares similarities with that of traditional aircraft. However, in the case of solar-powered UAV systems, there are distinctions from conventional systems. The integration of energy derived from sustainable sources into the aviation industry is a relatively recent concept, and the limited number of experimental applications constrains the design possibilities of such systems, particularly in the pre-sizing phase of solar-powered aircraft.

Despite these limitations and challenges, there have been numerous studies on this topic. Solar energy, being a sustainable and boundless source, is regarded as a promising technology for UAV systems in aviation [13, 14, 15]. These studies include calculations of the required solar panel area to provide the requisite power along with a general solar-powered UAV design.

Variable factors such as weather conditions, the amount of solar intake depending on duration and latitude all have an impact on how a solar-powered UAV is designed [10]. This is due to the fluctuations in energy intake, the number of solar cells to be used, the battery, and other equipment to be utilized all vary depending on the amount of energy to be stored. Consequently, these studies involve assessments of the required solar panel area to meet the specified power output, alongside a comprehensive design framework for solar-powered UAVs.

Due to a lack of extensive studies on solar-powered UAVs in the literature, the initial data of the UAV, whose mission profile was developed, was derived from a survey of the literature [13]. The design of the UAV will be conducted independently, utilizing calculations performed at various stages of the ongoing procedure. As the design process is incremental, each stage must be individually planned and executed.

2.1. Solar Cells and Energy Storage Systems

In the subsequent stage of the design process, the most crucial decision revolves around the selection of solar cells to be utilized. During this selection process, market research was conducted with a focus on the fact that spacecraft and satellites meet their energy requirements using solar panels as a standard. Upon reviewing the existing solar cell types available in the market and considering the findings from NCEL's studies [16], monocrystalline silicon (monoSi) solar cells emerged as the most efficient option, achieving efficiencies of up to 23% [17]. These monocrystalline solar cells are considered a viable alternative due to their lightweight nature, excellent structural properties, and high reliability, as evidenced by their usage in similar studies.

It is worth noting that solar cells generate heat; however, the planned UAV is expected to operate at altitudes of up to 5 km, where the prevailing weather conditions (-17.5 °C at 5 km) will aid in natural cooling [18]. Despite this, a more comprehensive investigation into the temperature distribution of the solar cells is necessary to ensure accurate calculations.

The selection of solar cells is an important part of solar aircraft design. Solar cell technologies are continuously evolving, witnessing ongoing advancements in efficiency. Consequently, each component used inevitably impacts the overall efficiency of the system. A crucial component in this regard is the battery, necessary for storing and utilizing the collected energy for the aircraft. Considering battery performance, the decision was made for Lithium due to their superior charging capabilities and minimal impact on system efficiency. Lithium batteries are widely preferred in various sectors, including electric vehicles, UAVs, and electric aircraft, owing to their extended service life and low volumetric energy densities [19]

In this specific case, similar studies were explored, and after evaluating various options, a Li-ion battery with an energy density of 300 Wh/kg was chosen as the most suitable option for the calculations. This choice ensures an efficient energy storage solution for solar-powered aircraft [20].

MPPT (Maximum Power Point Tracking) technology is essential for efficiently harvesting and reliably transferring solar energy to the battery [21]. However, due to the limited availability of lightweight MPPT systems, especially tailored for solar-powered aircraft, selecting suitable options becomes challenging. Weight plays a critical role in aircraft, making it advantageous to **opt for** choices that minimize the overall weight.

Considering these factors, it was found that in the context of using MPPT in studies, designs for systems to be integrated into compact structures, such as UAVs, had to be custom-made from the ground up. This approach ensured that the MPPT systems met the specific size constraints and weight limitations of solar-powered aircraft, allowing for optimal performance in the given applications. [13].

Another critical factor to consider is the Electronic Speed Control (ESC). This component must be selected in alignment with the chosen battery, and several factors need to be considered during the selection process. These criteria encompass the specifications provided by the battery, along with weight-related considerations.

2.2. Solar Irradiation

For this study, a comprehensive analysis of available solar irradiation was conducted, taking into account factors such as flight altitude, latitude, day of the year, and time of day. It's worth noting that altitude plays a crucial role in optimizing solar energy absorption [10]. Additionally, an examination of Turkey's annual solar consumption map, depicted in Figure 2.1, indicates that a significant portion of the region experiences solar potential exceeding 1600 kWh/m². Utilizing the data from Figure 1, considering that the majority of Turkey's average solar radiation falls within the range of 1600-1700 kWh/m², a value within this range was used as a reference in the relevant portion of the study.

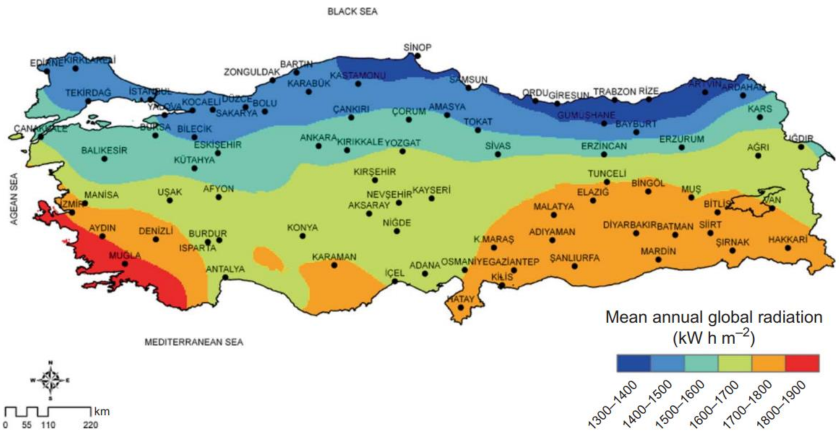

Figure 1. Geographical annual solar irradiation map of Türkiye [22]

2.3. Conceptual Design

Before proceeding with the conceptual design, it is essential to establish specific design criteria for the aircraft under consideration, a step common to nearly all aircraft design projects. While the construction of solar-powered aircraft may vary slightly, the design phase employs methods similar to those outlined in [11], which provide insights into the properties of solar-powered aircraft developed up to this point.

Designing a solar-powered UAV presents unique challenges distinct from other types of aircraft, particularly in the process of generating thrust to meet power requirements. Until reaching this iteration stage, the design follows the conventional steps employed in traditional aircraft design, which are widely preferred in the field [11]. Despite the limited research on solar-powered UAV design, key studies in this area are encompassed in [13].

2.3.1 Weight analysis

The weight of an aircraft is an important factor to consider. Given that the necessary power will be derived from solar radiation and considering the relatively low efficiency of solar cells, minimizing the weight of the unmanned aerial vehicle is essential. A lighter aircraft is paramount to conserving power for the solar-powered UAV under design. With an increase in the system's weight, the corresponding power consumption also rises.

$$P_{level} = Tv \quad (1)$$

When examining the P_{level} equation provided in Eq. (1), the required power value dependent on velocity and thrust is derived. By making this equation under the necessary assumptions and extending it accordingly, Eq. (2) is obtained according to [11].

$$P_{level} = \left(\frac{C_D}{C_L}\right)^{\frac{3}{2}} \cdot \sqrt{\frac{(mg)^2}{S}\sqrt{\frac{2}{\rho}}} \tag{2}$$

This formula requires the total weight of the aircraft. Solar-powered aircraft do not have varying weights based on flight phases, as do liquid-fueled aircraft. As a result, the total weight of the system is early constant, and the system's power consumption is calculated accordingly.

The weight value after design is determined by the weight of the chosen equipment and the materials utilized after production. Since these weight values were not precisely specified initially, the reference weight of the planned aircraft was calculated using the weight calculations detailed in [13]. On the basis of this value, MATLAB computes the average weight range for each component.

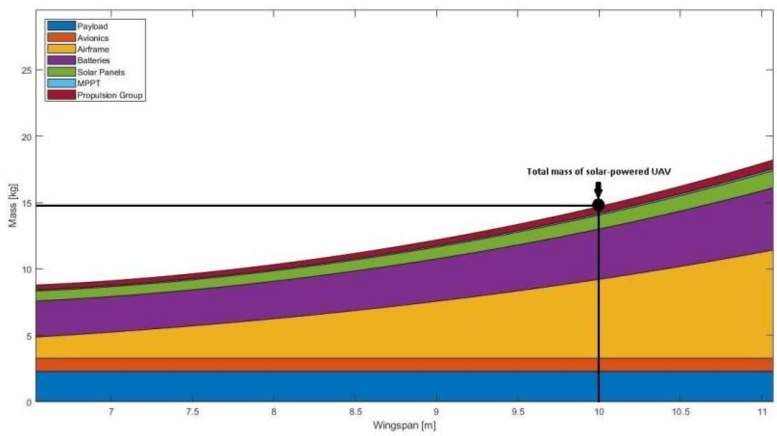

Figure 2. Total mass distribution of the designed solar-powered UAV

2.3.2 Design phase

A constraint analysis is a graph illustrating the variations in power-to-weight (P/W) or thrust-to-weight (T/W) ratios, as well as wing loading (W/S) values during the preliminary design phase [23]. This graph provides insights into the aircraft's capabilities and identifies areas where enhancements can be implemented.

In Figure 3, the constraint analysis in this study is represented by a graph generated using MATLAB Code, a method uncommon in most research studies. The estimated wing sizing parameters are computed utilizing other code outputs with an R-value of 0.65.

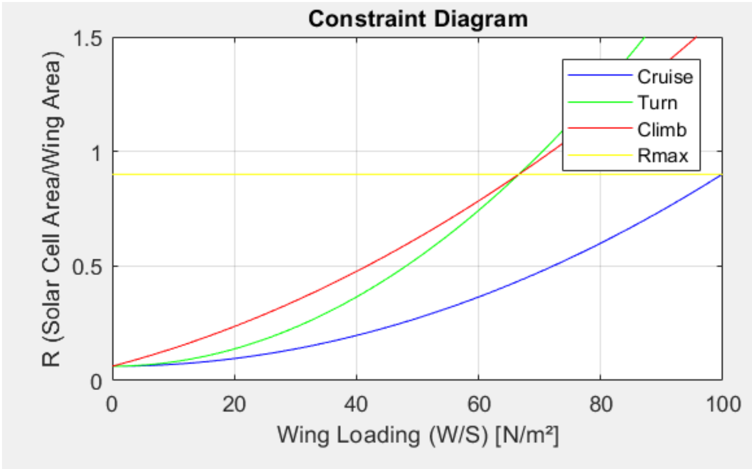

Figure 3. Constraint diagram for solar-powered UAV

In the consideration of other aspects of wing construction, no taper was applied to facilitate cell placement, and it was kept at a value of 1 for this purpose. The wing incidence angle, which is usually predetermined based on the type of aircraft being designed, was set to 0 in this case. This decision aimed to eliminate shadow effects and optimize cell usage. As for the dihedral angle, it was agreed upon to be zero. This choice was made because the weight, which increased with the number of pins used in the fuselage assembly, held greater significance for the solar-powered UAV.

The R-value, determined by selecting a point on the graph as depicted in Figure 3, represents the ratio of the solar cell area to the wing area. Utilizing the calculated wing dimensions, the area covered by the cells on the wing is computed to be 2,86 m^2.

At this point, to determine the power produced by the solar cells, it is imperative to conduct a power assessment for each individual solar cell. Subsequently, the total power provided by the number of cells that can be accommodated within the calculated wing area must be calculated.
To calculate the electrical power output, an analysis of solar cells available in the market and those used in comparable studies was conducted to select the solar cells suitable for mounting on the wings. The calculation was performed using Eq. (3). During this calculation, data from the manufacturer of the QJ Solar Cell 4G32C series was utilized. It was determined that 894 cells could fit within the calculated wing area. The power output for a single cell was calculated and extrapolated to the entire system, resulting in a total power output of 1172.3 W.

$$P_{mp} = V_{mp} \times I_{mp} \tag{3}$$

This value represents the maximum power output and was determined without factoring in efficiency. When calculating the power output from the solar cells, it is essential to consider their efficiency. The selected solar cell falls within an efficiency class of approximately 32%. Additionally, a 10% risk factor is incorporated in the calculations to account for other potential losses, resulting in an assumed efficiency of 28%. Consequently, the recalculated power output is represented in Eq. (4). "The efficiency values, or in other words the potential losses taken into account, result in a calculated new power value of 328.24W from solar cells.

$$P_{sc} = P_{mp} \times \eta_{sc} \tag{4}$$

The next step involves calculating the power needed for the intended aircraft to achieve flight and evaluating whether this power matches the power generated by the solar cells. If there is surplus power, it should be directed to the batteries. Conversely, if there is a shortfall in power, adjustments should be made to the design or alternative methods should be devised to compensate for the power deficiency from different systems.

When Figure 3 is re-evaluated, the power required can be calculated from the intersection point of the curves. In this determined value, the efficiency losses of the electric motor, propeller, and other components will be analyzed, leading to the determination of the power needed for the system. Evaluating the power required from Figure 3 as 65 W and factoring in the efficiency of the electric motor and propeller, the required power value is calculated to be 95.6 W.

There exists a power surplus of up to 232.64 W when comparing the power output generated by the solar system, computed using Eq. (4), and the power requirements determined from Figure 3. This surplus power will be stored in the batteries and utilized in situations where power cannot be supplied by solar cells or during high-power consumption phases, such as take-off and climb. During a cruise, the energy stored in the batteries will not be consumed as long as the aircraft can gain energy from the sun.

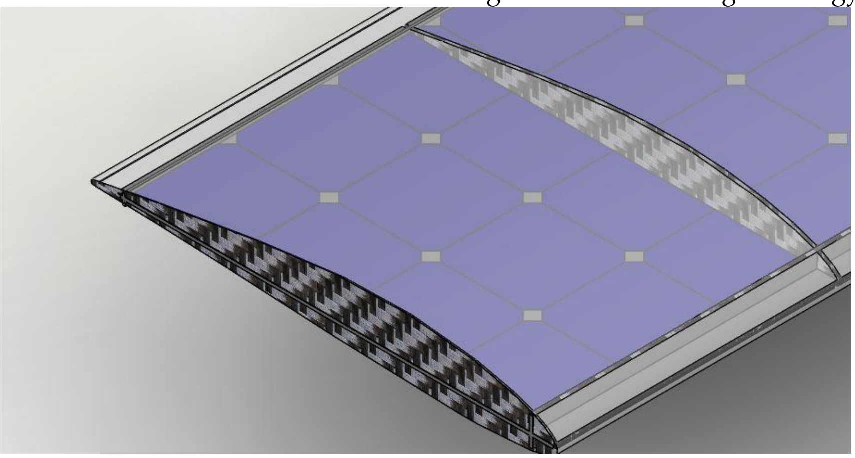

Figure 4. Detailed view of the designed wing for the solar-powered UAV

2.3.3 Detailed weight estimation

Up to this point, the computed weight has included weight estimates for designing and determining the required power. It is now requested that a final weight study be conducted, referencing the weight of all the equipment to be utilized in the system, as part of the ultimate weight calculation process.

After determining the weight generated by the required number of solar cells in the previous section, along with the weight of the battery to be used, other systems, and the UAV's empty weight, the fuselage design and sizing are calculated based on the total weight. Therefore, it is crucial to finalize the weight calculation once the conceptual design has been clarified to a certain extent.

In the context of weight analysis, there will be no variation in weight during flight phases, as observed in liquid-fueled systems. The weight change resulting from the chemical reactions occurring during the usage of energy stored in the battery is negligible. Consequently, Table 1 presents a comprehensive value table, including the total weight and the weights of all components contributing to this extent.

Table 1. Total Weight Estimation

Component	Weight in kilogram
Batteries	3.196
Solar cells	2.579
MPPT	0.22
Motor controller	0.020
Motor	0.34
Propeller	0.034
Other	1.5
TOTAL	7.889

2.3.4 Aerodynamic and performance parameters

Afterward, the fundamental aerodynamic properties of the aerial vehicle, including the airfoil characteristics and geometric parameters of the wing, are specified. These selections were made taking into account the trends and limitations pertinent to the design of solar aircraft.

When evaluating the design requirements, selecting the appropriate airfoil for integrating the solar cells into the wing is essential. The choice of airfoil holds significant importance as it directly influences the aerodynamic characteristics. When picking an airfoil, careful consideration must be given to features such as camber and thickness. Given that the solar cells will be housed within the airfoil, it was decided to opt for airfoils with minimal camber, striving to design wings that are as symmetrical and thick as possible. The selected thickness is crucial when accounting for the surface area covered by solar panels and other equipment placed on the wing. A balance must be struck, as greater thickness leads to increased weight and reduced aerodynamic efficiency due to higher air resistance.

As a result, analyses have been conducted on these airfoils. To assess the aerodynamic performance of the airfoils under low altitude and low-velocity conditions, the plan involves utilizing XFLR5 software [24]. This software will be used to analyze the airfoils, allowing for the selection of the most suitable one under the desired conditions. The wing will then be designed around the chosen airfoil. In the study, after evaluating the required performance, installation procedure E197 was chosen. This choice was made due to the projection of a thicker wing profile to accommodate equipment and solar cell positioning. Table 2 displays the aerodynamic parameters determined at an altitude of 2000 meters, utilizing the outputs from the batch analysis conducted on XFLR5.

Table 2. Analysis results obtained for 2000 m.

Parameter	Value
$C_{L,\,max}$	1.2
$C_{D,\,min}$	0.02
C_m	-0.062
α_{stall}	10°

2.3.4 Configuration layout

After establishing the fundamental aerodynamic performance parameters, the factors necessary for configuration creation can be determined. The design of the UAV's fuselage structure and other layouts should be executed in a manner that does not disturb the overall design, avoids incurring aerodynamic penalties, and minimizes additional weight. Consequently, the fuselage structure is shaped to mirror the airfoil profile, aiming to minimize fuselage-induced drag. This approach not only reduces drag but also enhances lift, aiding the aircraft in maintaining its stability.

If the winglet structure is used, it is used as a structure that prevents lift loss due to fuel use, reduction of sound emission, and vortex formation [12]. However, since there is no high altitude or high speed for the solar-powered UAV designed and since there will not be much of a situation such as sound emission due to the use of an electric motor and this structure will create unnecessary weight, it was decided not to add winglets. However, in hybrid designs, it will be useful to have this add-on.

2.3.4 Fuselage configuration

The design and dimensioning of the fuselage for aircraft using solar energy is one of the simplest steps in the design phase as there is no need to add fuel to the body and no positioning is required. If there is a need to study the equipment that will be attached to the body; The two most important elements are the battery and the motor.

The fuselage configurations of solar-powered aircraft vary. To disperse wing load, some utilize two fuselages and tail booms, while others use a single fuselage and tail boom for structural continuity. A single-engine application example in this study implies that a single fuselage and tail boom combination might be more appropriate, providing a lighter construction and less surface friction drag.

The dimensions of the diameter of the body must be in the smallest dimensions, and the maximum value of this size must be determined so that the maximum size of the equipment used in it will fit. Hence, it was decided that it would be more accurate to show the measurements of the detailed sizing as a final CAD drawing after the full aircraft design was completed. At this stage, this length is given as a dependent function of the weight in [11], since the length of the body must be used as a parameter for the size of the tail.

$$L_{fuselage} = AW_0^c \tag{5}$$

The calulcation can be performed using the equation above for the fuselage length accordingto Eq (5) from [11]. In the Eq. (5), A and c are constant and, based on experimental studies, have been given a certain standard for different types of aircraft. The values of these constants are given in [11] and for this study, these values are chosen 1.48 and 0.23, respectively.

In solar-powered aircraft, fuselage design and sizing are critical considerations in determining the optimum dimensions and positioning of the empennage (tail section). When sizing and situating the empennage, proportional consideration of body size is vital, with special care paid to moment arm length, a critical element in tail sizing. The fuselage length is used as a criterion, by the guideline provided in reference [11], which indicates that the moment arm length is 60% of the fuselage length. Following that, the dimensions of the empennage are computed using the equations (Eq (6) and Eq (7)) stated in [11]'s relevant section.

$$S_{VT} = \frac{c_{VT} bS}{L_{VT}} \tag{6}$$

$$S_{HT} = \frac{c_{HT} bS}{L_{HT}} \tag{7}$$

Examining Eq. (6) and Eq. (7) reveal that tail volume coefficients are necessary for both equations. These coefficients are calculated using specific assumptions and aircraft types, which is a standard approach in the entire aircraft design process. However, because solar-powered UAV design is a unique method, no standard parameters for this specific aircraft type are supplied in reference [11]. As a result, the essential data for these calculations can be obtained by using an aircraft with similar characteristics or by conducting experimental trials with various sizes to determine the appropriate empennage type.

Since the V-tail will be developed as the tail type in this study, the angle between the V-tail must be determined in addition to the measurements. [11] states that the formula in Eq. (8) can be used to compute this angle and the CAD drawing of the V-tail design created based on the values obtained from the calculations is shown in Figure 5.

$$\theta_T = arctan\left(\sqrt{\frac{S_{VT}}{S_{HT}}}\right) \quad (8)$$

Figure 5. CAD drawing of the computed V-tail

3. RESULTS AND DISCUSSION

The design approach results in a solar-powered UAV concept capable of completing its intended missions and achieving the initial requirements by utilizing both solar and stored energy sources. Figure 6 represents a 3D Computer-Aided Design (CAD) model of the envisioned UAV, whereas Table 3 displays the primary geometric, performance, and aerodynamic properties of the intended solar-powered UAV. It should be noted that the solar-powered UAV is far from an optimum concept since only the conceptual design phase has been completed. There is still a tremendous possibility for improvement in the latter design phases, including extensive structural analysis.

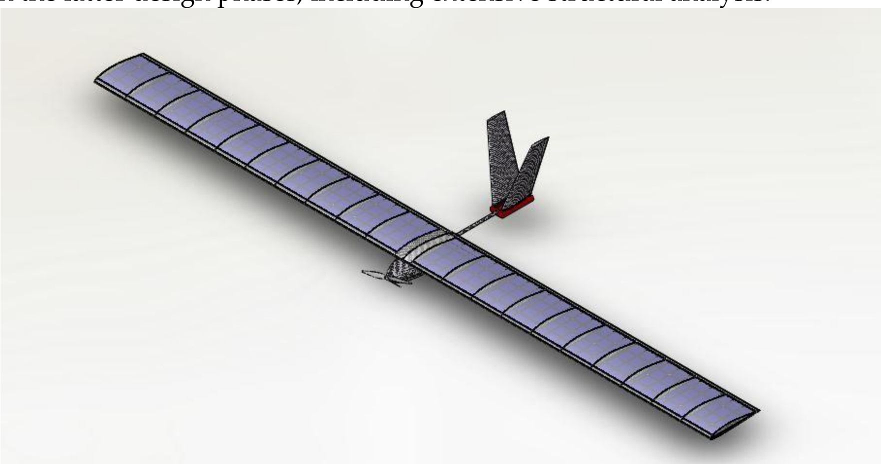

Figure 6. The final 3D CAD model of the completed solar-powered UAV design

Table 3 includes a comparison between this concept and various solar-powered UAVs to provide information about the concept's validity. Specifically, the Sunrise 2 and the The Solar Challenger, are two separate solar-powered UAVs powered only with solar energy and energy storage technology that supply electrical power to the UAV.

Table 3. Technical characteristics and comparison of the conceptual designed solar UAV and other solar UAVS

	Solar-powered UAV concept	Sunrise 2	The Solar Challenger
Gross Weight	7.889 kg	10.21 kg	153.77 kg
Wing Span	7.162 m	9.75 m	14.26 m
Wing Area	5.9283 m^2	8.36 m^2	21.83 m^2
Aspect Ratio	8,65	11,4	9
Wing Loading	1.33 kg/m^2	1.22 kg/m^2	7.03 kg/m^2
Length	2.38 m	14.4 m	9.27 m
Solar Array	894 cells	4480 cells	16128 cells
Airfoil	Eppler 197	Eppler 387	Lissaman
Cruise Speed	10 m/s	24.9 m/s	20.56 ml/h
Maximum Altitude	5000 m	22000 m	9100 m

Batch analysis with XFLR5 was used to determine aerodynamic performance parameters influencing the flight performance of the planned solar-powered UAV at 2000 meters altitude. The UAV had the wing properties and cruise speed listed in Table 1 at the time of analysis. Table 2 displays the acquired results, which include aerodynamic performance metrics.

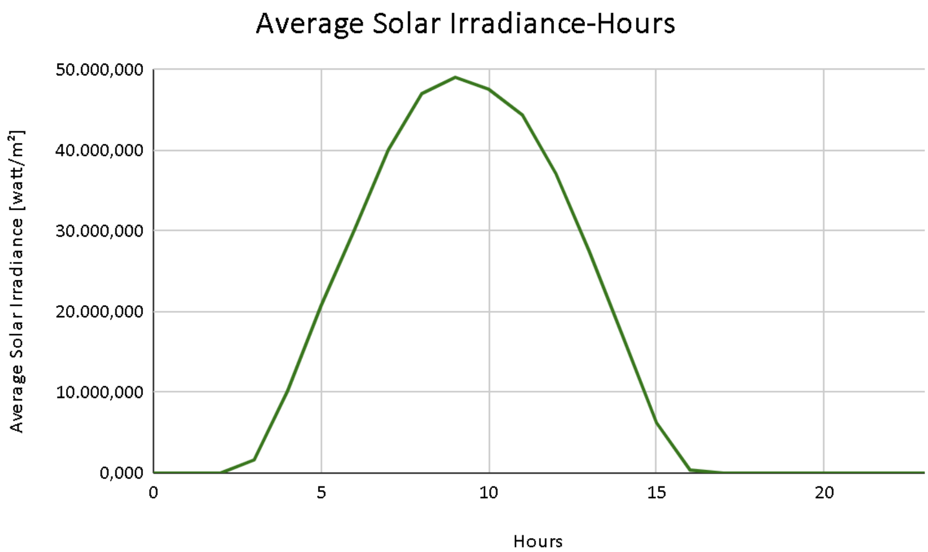

Figure 7. Solar irradiance for each hour in April 2018

As can be seen from Figure 7, it is almost impossible to benefit directly from the sun after 5 pm. Solar irradiance reaches its maximum value at 9 am. In this scenario, the designed UAV should initiate its flight before the specified hour to capitalize on sunlight optimally, storing surplus energy in the battery to extend the total flight duration. The irradiance model exhibits regional variations; hence, flight predictions for the selected region should be made to achieve maximum efficiency. Efficiency extends beyond such factors and is closely associated with system performance, including the characteristics of the utilized equipment and considerations such as weight. Particularly, the efficiency of the solar cells employed must be maximized, and the system weight should be reduced through ongoing studies.

4. CONCLUSIONS

In conclusion, the exploration of solar-powered unmanned aerial vehicles (UAVs) through the lens of a conceptual design methodology has unveiled promising prospects for the integration of renewable energy in aviation. The comprehensive analysis presented in this article highlights the feasibility and potential benefits of utilizing photovoltaic technology to power UAVs. As a result of this study, it was recognized that solar-powered manned/unmanned aerial vehicle design is a very complex area due to the lack of studies on the subject and the limited number of studies in this area.

The classic design approach relies heavily on statistics and assumptions. This design approach does not have enough information on the design methodology for battery-powered and electric aircraft, as the design applies primarily to fueled manned aircraft. Therefore, as in the classical aircraft design approach, the maximum number of solar cells that can be placed was calculated after determining the required power of the aircraft with the help of the constraint diagram, according to the design criteria determined by first proceeding from the wing design. As a result of this calculation, it was calculated that the integration of 894 cells was possible.

Depending on the number of 894 cells integrated and considering the efficiency coefficient, it was concluded that there is an excess power of 232.64 W, based on the ratio between the amount of power that can be transmitted to the aircraft by the cells and the amount of power required by the engine. In order to prevent the waste of this excess energy and increase the flight time, it is planned to use a Li-ion battery and store the excess energy there.

In addition to the fact that analyses and calculations are made considering the altitude as 5000 meters within the scope of the design, the value of $C_{l,max}$ of 1.2 indicates that the aircraft's ability to hold in the air is good and that the stall angle is 10 degrees, which is not a serious obstacle to performing a controlled flight.

The detailed results obtained as a result of the calculations and analyses made within the scope of this study can be found in Table 3.

When economic issues are examined, the composite materials used in the airframe, including solar cells, the high cost depending on the amount of battery, the cost of production and equipment, and the cost of an aircraft that runs on renewable energy can be examined. It can cost high prices, and with technological progress, this situation will no longer be a problem in the next few years, this assumption arises from the result when the costs of solar cells when they are launched on the market are compared with their current values.

Considering the aspects for improvement, most of the parameters that affect the aerodynamic properties of the wing geometry have not been assessed in order to increase the maximum number of cells that can be used. Because the UAV is designed to be a non-aerodynamic performance UAV that flies at low speeds, however, these properties were not a problem in the context of this project, as the preference for solar energy in aircraft with different properties can lead to changes in the properties of the wing design can be discussed in more detail.

The body size has been designed so that only the necessary equipment can be mounted to keep drag and weight as low as possible, and to use in the fuselage geometry, it is necessary to change types of equipment and geometry to add other equipment to the body geometry. In this context, a new design of the fuselage size can be created through flow analysis and an evaluation of the weight, which is influenced by the material to be used.

Finally, the collaborative efforts of researchers, engineers, and environmental advocates will play a pivotal role in realizing the full potential of solar-powered UAVs. For instance, advancements such as the development of higher-efficiency cells for integration into UAVs, the improvement of energy storage equipment with high energy density, and studies aimed at reducing the weight of equipment used in solar-powered UAVs and aircraft will make progress easier in this field. Hence, these endeavours will open up avenues for research, enabling the use of solar energy as the main energy source across all types of aircraft, thereby fostering the evolution of the entire aviation sector.

Declaration of Ethical Standards

Authors declare to comply with all ethical guidelines including authorship, citation, data reporting, and original research publication.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability

Not applicable.

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