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Energy efficient Solar Powered Unmanned Aerial Vehicles (UAVs)

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Abstract—**This paper delves into the integration of solar power in Unmanned Aerial Vehicles, or UAVs, highlighting its potential to revolutionize the field of aerial robotics. The main objective is to study the application of solar technology in UAV design for enhanced flight endurance and enabling sustainable long-duration operations. The paper discusses the basics of solar energy harvesting, the difficulties of integrating photovoltaic systems into UAVs, and the benefits of reducing reliance on conventional battery power. Some of the key topics discussed are the types of solar cells used, the optimization of energy storage systems, and the impact of environmental factors on performance. In addition, the paper discusses current advancements in solar-powered UAVs and their practical applications in environmental monitoring, agriculture, and search-and-rescue missions. The paper further discusses challenges such as weight limitations, energy efficiency, and operational constraints and future trends for improving solar energy integration. The study concludes with prognostications on the possibility for solar-powered UAVs of greater autonomy and efficiency and promise toward sustainable, eco-friendly aerial technologies.**

***Keywords*— Renewable Energy; Solar Power; Unmanned Aerial Vehicle (UAVs);**

I. INTRODUCTION

Fossil fuel use at the cost of environment prompted the need to shift to alternative renewable energy sources, the depletion of fossil fuel reserves at an alarming rate further exacerbates the need for innovative and sustainable alternatives in numerous sectors, such as the aviation sector. PV Technology Breaking Grou nd Since the mid-20th century, when Bell Laboratories first developed the PV, this technology has been a cornerstone in this shift. PV technology was first applied to manned and unmanned electric aircraft and was notably used in the historic Sunrise I by Astro Flight Inc. With the rise in solar cell efficiencies that have realized in recent years, there have been increasing opportunities to develop solar-powered aerial vehicles as an entirely clean and renewable energy source for aviation. Renewable energy, therefore, gained significant interest in the aviation industry over the past few decades, since it has possibilities of satisfying energy demand without the worsened negative effects that are detrimental to the environment through fossil fuels. Solar cells have become a viable option because they can provide emissions-free energy and enable long-term energy and enable long-term flight by storing energy in energy storage systems. The virtually limitless sun energy supply ensures reduced maintenance and repair costs for aircraft while offering their appeal. In any case, flight performance of solar-powered aircraft depends upon weather-dependent fluctuations in solar energy availability, posing a challenge to consistent energy production and flight performance.

The history of UAVs in aviation dates back to the early 20th century, and they are widespread in sectors such as agriculture, defense, and environmental.

The increased deployment of UAVs and increased focus on climate friendly solutions have mase solar energy one of the most sought-after sources of power. Solar-powered UAVs use photovoltaic cells integrated within the structure, converting solar radiation into electrical power that can power the propulsion, avionics, and communication equipment. This extra energy is stored in batteries, ensuring continuous operation when sunl ight is weak. This research aims to conceptualize an efficient solar-powered UAV by detailing the design processes, identifying the optimal materials, and proposing improvements to maximize energy efficiency. Through the resolution of challenges presented by solar-powered UAVs, this study hopes to contribute to sustainable and

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innovative solutions for the future needs of aviation. Fig.1. depicts the model of a solar powered UAV.

Fig. 1. Solar Powered UAV model

II. METHODOLOGY

An aircraft is so complicatedly designed, and it cannot be designed without a method; there are so many requirements of the aerodynamics analysis of structure along with its performance and operational constraints. This engineering makes possible aircraft which meet specified objectives to maintain safety, efficiency, and reliability. Over time, this process has been shaped and refined through technological advancements and lessons learned from historical achievements.

The first presizing phase is of utmost importance in the design process, wherein preliminary estimations of dimensions, weights, and performance take into consideration the initial requirements. It thus forms a basis for checking feasibility before advancing into detailed design and analysis. Exhaustive documentation of such methodologies is an excellent guide for engineers.

Whereas design UAV is a traditional aircraft, solar UAVs pose new challenges. Renewable energy application to aviation is a very new concept; only some experiments can form possibilities at the presizing stage. Design consideration for solar UAVs varies greatly with latitude, weather conditions, and variations in solar intake, thus influencing factors such as the size of solar panels, battery capacity, and overall energy management.

III. SOLAR IRRADIATION

For this research, an in-depth analysis of the available solar irradiation was carried out, taking into account factors such as flight altitude, latitude, time of year, and time of day. Altitude is a major factor in maximizing the absorption of solar energy. Likewise, from the annual solar irradiation map of India, it can be determined that a large part of the country has high potential for solar energy, with several regions receiving solar radiation more than 1600 kWh/m² per year.

According to data from India's National Institute of Solar Energy (NISE), the average solar radiation in most places, especially in Rajasthan, Gujarat, Madhya Pradesh, and some parts of Maharashtra and Telangana, is 1600-2000 kWh/m². For this work, a value within this range was chosen as a reference, fitting most of India's potential for solar energy to ensure optimal performance of solar-powered UAVs.

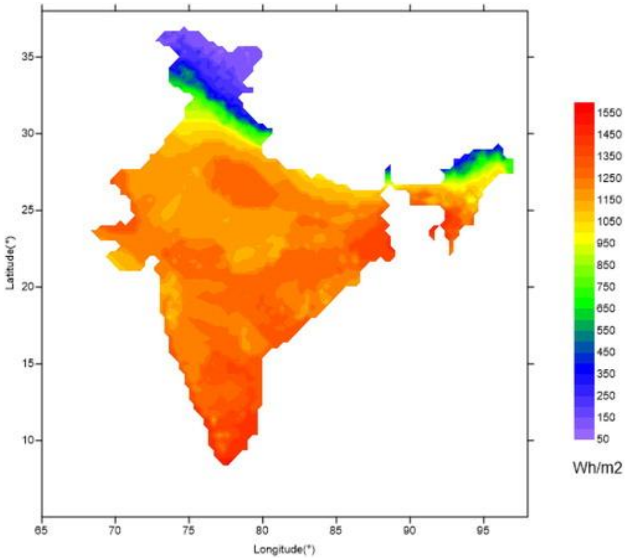

Fig. 2. Solar Irradiation map of India

A. Weight Analysis

The weight of an aircraft is a critical factor in its design and performance. For solar-powered UAVs, where the required power is obtained from solar radiation and the efficiency of solar cells is relatively low, minimizing the weight is essential. A lighter aircraft not only enhances energy efficiency but also ensures optimal performance, as increased weight directly translates to higher power consumption. The power needed in relation to the aircraft's velocity and thrust can be represented as:

$$P_{level} = T_v \tag{1}$$

Here P_{level} is the required power, T is thrust, and v is velocity. Expanding this relationship with some necessary assumptions, a more specific formula is derived:

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

C_d and C_l are the drag and lift coefficients, respectively
m is the mass of the aircraft
g is gravitational acceleration
S is the wing area
ρ is the air density

Total weight again is central to calculating system power use. With solar aircraft, total weight is almost constant along a trajectory; for liquid fuel, of course, weight will increase due to fuel being used up along the way. The complexity of the power estimate, therefore, depends only slightly on these variables. This determines the total weight of the UAV since its weight depends upon the selected components and materials. Because initial designs usually don't provide accurate values of weight, a reference estimate is first made as a starting point. From this, using MATLAB-based computational tools, one refines these estimates so that there are average values within the given range for every component such that the final design fulfills all the specified weight and performance criteria. This makes for an organized procedure for optimal efficiency and functionality of the UAV.

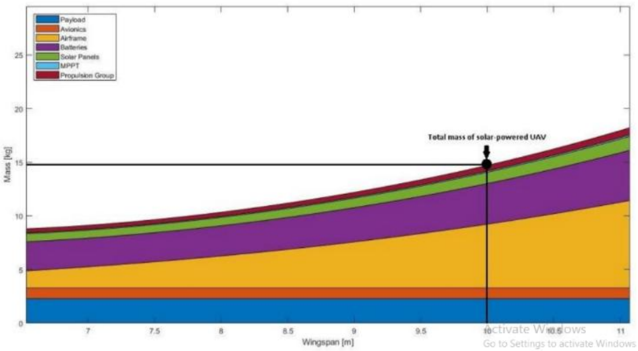

Fig. 3. Mass distribution

IV. DESIGN PHASE

A constraint analysis graph is a visual representation of the variations in power-to-weight (P/W) or thrust-to-weight (T/W) ratios and wing loading (W/S) values in the preliminary design phase of an aircraft. It is an analytical tool that is very important for evaluating the potential performance of the aircraft and pinpointing areas where improvements can be made.

In this study, the constraint analysis is represented using a graph generated using MATLAB code, which gives an accurate and detailed visualization of critical parameters shown in Fig.4. The wing sizing parameters are estimated from the outputs of other code implementations and yield an R-value of 0.65. This approach ensures accurate parameter estimation and supports effective design optimization such that the aircraft meets the intended performance targets efficiently.

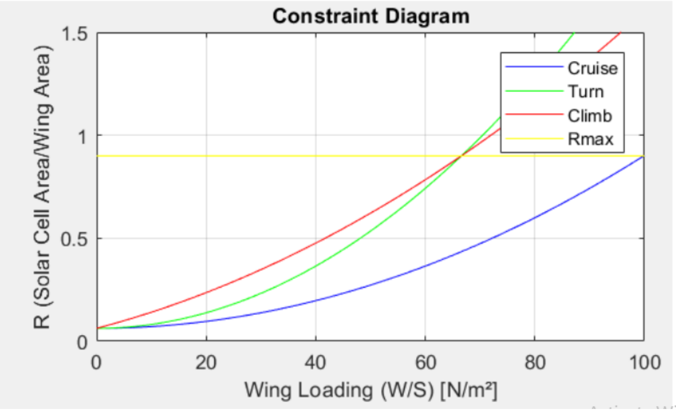

Fig. 4. Constraint Graph

For the wing structure design, some considerations were provided in order to optimize the number of solar cells and make it less complex. The taper ratio was kept at 1 to allow for easier distribution of cells on both surfaces of the wing. Also, the angle of wing incidence was kept at 0, which was a trade-off to avoid shadowing as well as to maximize cell utilization. Similarly, the dihedral angle was set to zero. The weight reduction was prioritized over the aerodynamic benefits, as the overall system weight was critical for the efficiency of the solar-powered UAV. From a given point in the constraint analysis graph, the R-value that signifies the ratio of solar cell area to wing area was found. With the calculated wing dimensions, the total area available for solar cells on the wing was found to be 2.86 m². To estimate the power output of the solar cells, an analysis was conducted to determine the best available solar cells in the market and from previous studies. This included an evaluation of the specifications of the solar cells for optimal efficiency and compatibility. The total electrical power output was calculated using Eq. (3) considering the selected type of solar cell. Using these measurements, it was calculated that 894 solar cells would fit inside the calculated wing area. Utilizing the single solar cell's power output to extrapolate the total system power, calculated a total output of the system to be 1172.3 W. This output does show that the system can meet the power requirements necessary for the UAV while attempting to maximize the energy that is harvested in the process.

$$P_{sc} = V_{mp} * I_{mp} \tag{3}$$

The calculated value of 1172.3 W is the theoretical maximum power output of the solar cells, considering no real-world efficiency losses are considered. To estimate the actual power output, one must consider the efficiency of the selected solar cells. For the chosen solar cells, the efficiency rating is roughly 32%. To account for possible energy losses due to a variety of factors, such as temperature fluctuations, dust accumulation, and system inefficiencies, a 10% risk factor is added. This adjustment brings effective efficiency to 28%. Using this adjusted efficiency, the actual power output is recalculated, as shown in Equation 4. The inclusion of these efficiency considerations reduces the theoretical power output, which gives a new calculated power value of 328.24 W from the solar cells. This adjusted power output is a more realistic estimate of the energy available for the UAV's operation, ensuring that the design aligns with practical performance expectations.

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

The second stage is to calculate the amount of power that will allow the airplane to fly and see if it is produced by the solar cells. If more than is needed, then this power will be channeled into the batteries. However, if it's short of what is needed, adjustments need to be made in design or other alternatives to help fill the gap. Looking at the same figure, 3, power requirement can be calculated from the point of intersection of curves. The value obtained here will then be adjusted to account for losses in the efficiency of electric motors, propellers, and all other components of the system. From Figure 3, it is calculated that the power requirement is 65 W. After adjustment to account for motor and propeller efficiency, the required power becomes 95.6 W. The surplus power output of the solar system, calculated using the adjusted efficiency (Eq. 4), compared to the power requirements is 232.64 W. This excess power will be stored in the batteries and can be used when solar energy is not sufficient, such as during high power consumption phases like takeoff and climb. During cruise flight, as long as the aircraft could continue to absorb sunlight, the stored power in the battery would not be expended.

V. FUSELAGE CONFIGURATION

In many cases, the design and sizing of the fuselage is one of the less challenging steps in the whole process of aircraft design due to the lack of fuel tanks in solar aircraft and simple mounting of solar cells. This differs from a conventional aircraft because it lacks the necessary designs for the fuel tank and fuel lines, as its main objectives are to focus on the structural integrity and aerodynamics, together with the proper integration of the solar panels, batteries, and propulsion system. The most important components inside the fuselage are either the battery or the motor. The motor and the related systems in the fuselage are significant for storing, converting solar energy into electric power that drives the aircraft in flight. Hence, the light of the aircraft needs to be maintained along with aerodynamic stability while using the design. The configuration would depend upon the design objectives pursued by the UAV. Some of the solar-powered aircraft choose dual fuselages and tail booms in order to ensure an even load distribution over the wing for improved stability. Some others prefer to make use of a single fuselage and tail boom together to have structural continuity and thereby avoid complexity and possible drag. In the context of this study, a single fuselage and tail boom design would be more suitable for a lightweight and efficient structure because it reduces surface friction drag and simplifies construction. The diameter of the fuselage should be minimally necessary to house the equipment needed. Although minimizing diameter decreases weight and drag, a minimum diameter is also crucial such that the fuselage houses all the necessary systems that could include the battery, the motor, and the wiring. Thus, this diameter must be calculated considering all the dimensions of equipment necessary to be housed in. At this stage, the precise fuselage dimensions are treated as a function of the overall aircraft weight, which plays a critical role in determining the fuselage length. The length of the fuselage impacts on the design and size of the tail section, as the tail must be appropriately sized to maintain stability and control during flight. Thus, instead of having to define fixed dimensions at this point, it is better determined at the final design phase, when the complete aircraft configuration is established and can have detailed sizing finalized through CAD modeling. The dimensions and configuration of the fuselage are, in fact, directly related to the overall performance goals of the solar-powered UAV, which include weight, aerodynamics, and energy efficiency. When these factors are carefully balanced, the fuselage will be optimized to support efficient operation of the solar-powered aircraft.

Fig. 5. CAD Drawing of V Tail

VI. CONCLUSION

The study emphasizes the viability of solar-powered UAVs in aerobic aviation by extracting renewable energy. Even though photovoltaic technology shows promise, its applicability in aircraft systems pose more challenges than solutions.

894 solar cells could be mounted on the UAV in place of its existing structures based on the power requirements for this project. The solar cells coupled with system efficiency generate a net power of 232.64 W, conserving the energy in Li-ion batteries to prolong the flight duration. The UAV can maneuver at 5000 meters while clutching a Cl, max of 1.2. It showcases exceptional flight control and stability with a stalling angle of 10 degrees.

Despite batteries and composite materials leading to initial budget limitations, the recent advancements in battery and solar technology sharpen the hope of making solar powered UAVs a reality. Aerodynamic optimization, such as wing geometry, is an area where improvements can be made because the existing design was aimed at lifting the nose during low speed flights. The length of the fuselage was curtailed to decrease weight and drag. However, more research should be done to augment the modified dimensions or extra equipment. The advancement of lightweight materials, energy storage and more powerful solar cells infused with collaboration among environmentalists, engineers and researchers will take us a step closer to affordable and sustainable solar powered UAV.

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Abbreviations and Acronyms

1. UAV - Unmanned Aerial Vehicle
2. PV- Photovoltaic
3. MPPT- Maximum Power Point Tracking
4. NISE- National Institute of Solar Energy
5. CAD- Computer-Aided Design

REFERENCES

[1] Chu, Y., Ho, C., Lee, Y., & Li, B. (2021). Development of a solar-powered unmanned aerial vehicle for extended flight endurance. *Drones*, 5(2), 44.

[2] Sri, K. R. B., Aneesh, P., Bhanu, K., & Natarajan, M. (2016). Design analysis of solar-powered unmanned aerial vehicle. *Journal of Aerospace Technology and Management*, *8*, 397-407.

[3] Valencia, E., Cruzatty, C., Amaguaña, E., & Cando, E. (2024). Paving the Way for Sustainable UAVs Using Distributed Propulsion and Solar-Powered Systems. *Drones*, *8*(10), 604.

[4] Hariharan, R., Saxena, A., Dhote, V., Srisathirapathy, S., Almusawi, M., & Kumar, J. R. R. (2024). Advancements in Solar-Powered UAV Design Leveraging Machine Learning: A Comprehensive Review. In *E3S Web of Conferences* (Vol. 540, p. 02024). EDP Sciences.

[5] Kumar, G., Sepat, S., & Bansal, S. (2015). Review paper of solar-powered UAV. *International Journal of Scientific & Engineering Research*, *6*(2), 41-44.

[6] Salazar, F., Martinez-Garcia, M. S., de Castro, A., Logroño, N., Cazorla-Logroño, M. F., Guamán-Molina, J., & Gómez, C. (2024). Optimization of the solar energy storage capacity for a monitoring UAV. *Sustainable Futures*, *7*, 100146.

[7] Sharma, P., & Goyal, P. (2020). Evolution of PV technology from conventional to nano-materials. *Materials Today: Proceedings*, *28*, 1593-1597.