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Evolution of Solar Powered Unmanned Aerial Vehicles with a simple economic study of solar cells

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A B S T R A C T

Solar energy is the most abundant form of clean energy, which will possibly provide the solution to the ongoing climate change challenge. Hence the research on the applications of solar energy in different areas is essential. Starting from the first solar powered Unmanned Aerial Vehicle (UAV) in the 1974 'Sunrise 1', this article provides a short study on the evolution of UAVs, solar cells and solar powered UAVs. Including a brief introduction on the effect of solar cell efficiency and solar cell cost on the economic aspect of the development of solar UAVs. The most common commercial applications of solar UAVs are High Altitude Long Endurance (HALE) and eternal UAVs, which are mostly used in surveillance and communication.

Key words :UAV, Solar powered UAV, Solar cell cost, HALE, Eternal UAVs
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1. Introduction

Climate change is one of the most crucial challenges in the 21st century, though whether enough actions are taken to ease the environmental and economic effects is an ongoing debate. A few of the main causes are the emission of greenhouse gases from burning coal, oil and gas, deforestation, growing population, overconsumption, poor infrastructure. The effects of climate change are triggering not only environmental effects but also economic disturbance as well. One of the considered solutions is moving towards renewable energy sources.

Solar energy has been used as an energy source since the earliest human history. Considering the abundance of clean solar power, the efficiency of harnessing this energy is low yet evolving. Applications of solar power are growing with the rising efficiency and declining cost of solar cells.

This paper focuses on the evolution of unmanned aircrafts powered by solar energy and the effect of the economical aspect of solar cells and their efficiency on the development of solar powered UAVs.

2. Unmanned Aerial Vehicles (UAVs)

An aircraft that can fly (controlled remotely) without a pilot or passengers onboard is classified as an Unmanned Aerial Vehicle (UAV) or sometimes called a drone.

The record of the first unmanned aircraft can be traced back to the hot air balloon launched in 1783 by Joseph-Michel and Jacques-Étienne Montgolfier, which was the first aircraft to not require a human pilot (Britannica n.d.). Starting from there, the UAVs were developed to have a camera on board (1896), radio-controlled (1898) and more advanced in coming years (Tesla Radio, no date; Ingemar Skoog, 2010). In 1935, the first modern drone was developed by the Royal Air Force, named 'Queen Bee′ (de Havilland Aircraft Museum n.d.). In 1957, Colonel H. J. Taplin of the United Kingdom made the first officially recorded electric powered radio-controlled flight, 'Radio Queen' (Pearson, Chapin and Noth, 2008). Followed by the first solar-powered UAV in 1974, named 'Sunrise 1', in California. After 2013 major companies such as FedEx, UPS, Amazon, Google, Uber, and countless other companies invest in tests and regulations (Consortiq n.d.). Throughout the history of the evolution of UAVs from 1783, the military applications have caused its rapid development, including the Austrian balloon attack on Venice, World War 1, Vietnam war and Israeli-gulf wars.

3. Solar Cells

2.1. Solar Energy

Solar energy is the cleanest and most abundantly available renewable energy source. And humans have been harnessing solar energy since ancient times using diverse methods. Solar energy is widely used in space applications as it allows a clean and long-duration source of energy source that requires almost no maintenance (Noth 2008).

2.2. Solar cells (Photovoltaic Cells)

Photovoltaic (PV) Cells are composed of semiconductive materials, which when exposed to light, absorb their energy and transfer it to the electrons. These charged electrons flow through the material as an electric current, which can be extracted. The amount of electricity produced from PV cells depends on the cell performance characteristics as well as characteristics of the light (Intensity and wavelength..) (Office of Energy Efficiency & Renewable Energy n.d.). Silicon is very often used as the semiconductive material in solar cells and provides high efficiency, low cost and long lifetime. The rate of converting receiving sunlight into electric power is considered as the efficiency of the PV cells

2.3. Evolution of solar cells and their efficiency

The studies on the sun as an energy source started in the 18^{th} century. After the discovery of the PV effect in certain materials by Alexandre Becquerel in 1839, the first considered solar cell was built in 1833 by Charles Fritts. Charles' design was a gold-selenium junction with an efficiency of 1%.

Einstein's paper on the photoelectric effect in 1904 was a breakthrough in solar cell technology. In 1954 Bell Laboratories produced the modern PV cell, which achieved an efficiency of 4% but was not still cost-effective compared with the other energy sources available. Solar cells with an efficiency of 10% were successfully created by Hoffman electronics in 1959 and in 1960 they beat their own record with 14% efficiency. Over the next few decades after the 1970s, more efficient solar cells were manufactured with reduced cost (Electronics360 n.d.; Clearway Community Solar n.d.).

2.4. Influence of solar cell cost

At the time of the Charles Fritts' solar cell with an efficiency of 1%, the cost was 300$ per watt compared with the cost to generate electricity with coal, which was 2-3 at the time. In 1960 with upgrading the efficiency and the increased production due to space applications, the cost was reduced to around 100$ per watt. Dr Elliot Berman's research in the 1970s to produce less expensive solar cells brought the cell price to about 20$ per watt. Currently, it is possible to produce solar cells with the price of around 0.50$ per watt with around 15% of efficiency. Since the 1980s due to the more focused attention on clean and renewable energy, the cost of solar cells has dropped by 10% a year. This solar cell cost reduction influences the commercial application of solar cells as well as research in the area.

4. Solar-Powered UAVs

After the first electric-powered UAV (in 1957), which used a permanent-magnet motor and a silver-zinc battery, the focus was on improving the performance of electric motors and batteries. From the limited energy stored in the battery, the airtime of the UAV is limited until the batteries are recharged.

The first known solar-powered aircraft called 'Sunrise I', had its maiden flight in 1974 by the dry lake at Camp Irwin, California, successfully completing 20 minutes of airtime at an altitude of around 100m. With a wingspan of 9.76 m and weighed 12.25 kg. The power output of 450W was acquired using 4096 monocrystalline solar cells with an efficiency of 11%. 'Sunrise II' improved version of 'Sunrise I' was manufactured in 1975. 'Sunrise II' had the same wingspan as 'Sunrise I' with a 10.21 kg weight. Due to the 14% efficiency of the solar cells, an improved 600W was able to harness from 4480 solar cells (Boucher 2012).

And many more solar-powered UAVs in the following years. 'Solaris' in 1976, 'Solar Solitude' in 1996 which flew for 38.84 km at 1283m altitude, 'Solar Excel' in 1999 which made the record of 11h 34m 18s flight at 2065m altitude. In the next coming years, the improvement of the long endurance UAVs was more focused, such as High-Altitude Long Endurance (HALE) and eternal UAVs.

Solar-powered aircraft provides a balance between energy collection and consumption, having the advantage of maintaining long endurance flights that might solely depend on solar energy. Though it should also consider that the amount of energy available and stored on a solar-powered UAV also depends on external factors such as,

- Geometric parameters
- Time of the year and time of the day
- Weather - humidity, clouds, temperature …
- Flying altitude
- Flight orientation (Solar panel inclination)

4.1. High Altitude Long Endurance (HALE) and eternal UAVs

High Altitude Long Endurance (HALE) and eternal UAVs are two of the most common commercial applications of solar-powered UAVs. Which are mainly used in surveillance, communication, and military applications.

'Pathfinder Plus' is a HALE which was the first propeller-powered aircraft to achieve 80210 ft altitude. 'Pathfinder Plus' is used for telecommunication missions and aerial surveillance of coffee corps in 2002 and atmospheric turbulence measurements in 2005.

'Helios' is another HALE solar UAV, designed to fly for full 24 hours by storing energy for the nighttime, developed by NASA in 2001. with 247 ft wingspan. Which achieved the 96863 ft altitude, reaching a new altitude record for the sustained level flight for both propeller and jet-powered aircraft in 2001 (AeroVironment n.d.).

'Prasha-35' is a new HALE solar UAV with 35m of wingspan and a possible maximum altitude of 70 000 ft developed by BAE Systems in collaboration with Prismatic. Who offers economical surveillance and communication services for defence, security and civilian missions.

'Solitair', in 1994, was constructed with adjustable solar panels for optimum solar radiation absorption, intended to year-around operations in northern European latitude with entirely solar-powered energy. The first successful eternal UAV record was in 2005, 'SoLong', which flew for 24 hours and 11 minutes on the first try and 48 hours and 16 minutes at a later stage solely by solar power. 'SoLong' was also powered by monocrystalline solar cells that generated 225W and had a wingspan of 4.75m and weighed 11.5 kg.

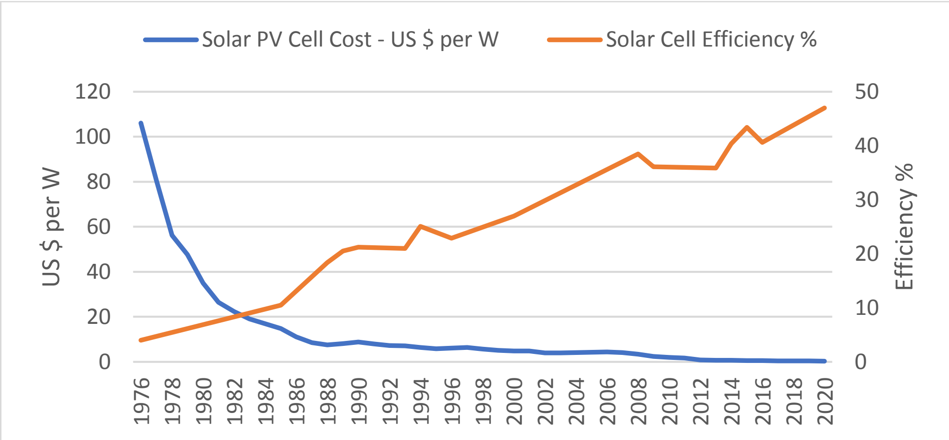
Up to date the record for the longest duration and highest altitude achieved by a solar UAV is owned by the 'Zephyr' Eternal UAV developed by Airbus Defense and Space (Guinness World Records n.d.). In 2010, 'Zephyr' was developed with a wingspan of 25m, 75kg of weight and amorphous silicon with an efficiency of 19%. In 2018, it was able to keep hovering for 25 days during its maiden flight. Equipped with two solar-powered electric motors, the 'Zephyr' UAV can reach up to 70,000ft of altitude (Safyanu, Abdullah, and Omar 2019).

Currently on the market solar-powered UAV designed for surveillance can be bought from 10000$ to 100000$ and more with different specifications.

5. Discussion

From the first solar-powered UAV to the currently developed models, the evolution of solar-powered UAVs depends mostly on the efficiency and the cost of solar cells. Figure 1 provides a graphical representation of the evolution of solar cell efficiency and the cost per watt over the years. Which cause the evolution of the solar-powered UAVs in parallel.

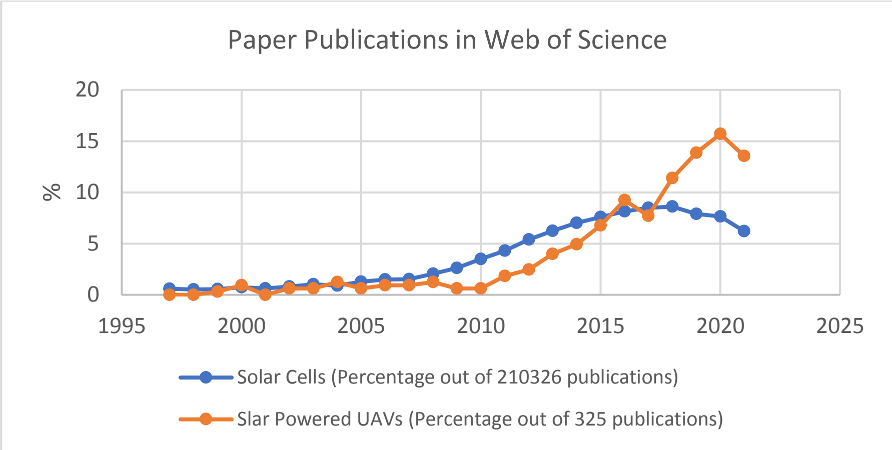
Figure 1: Evolution of solar cell efficiency and cost per watt.



Source: Data from International Energy Agency, https://ourworldindata.org/ and National Renewable Energy Laboratory

As seen in figure 1, even though during the last decade, the efficiency of the solar cells increased with reducing cost, there hasn't been a considerable amount of research dedicated to solar-powered UAVs. As seen in figure 2, only after 2013, there had been an increase in the published work on solar-powered UAVs. Only 22 articles were published in 2015 to 51 articles in 2021. (Only considering the article published in the web of science).

Figure 2: Number of papers published on Web of Science over the years in research areas 'Solar-powered UAVs' and 'Solar cells'



Source: Data from Web of Science

In the coming decades, the commercial UAV industry is expected to rise exponentially, according to the Business Insider Intelligence, the UAV market will reach up to 6.3bn dollars by 2025. The commercially available modern solar UAVs with enhanced specifications such as 'Zephyr' developed by Airbus, already provides cost-effective solutions to core markets such as security and protection, agricultural monitoring, high-resolution typography, disaster asses and monitoring (wildfire monitoring), environmental monitoring, border protection, broadband services and lot more.

Solar cells used in UAVs are demanded to have not only better efficiency but also be lightweight, thinner, and flexible. Future research to improve those aspects should be investigated. Currently available solar cell encapsulation methods such as Ethylene Vinyl Acetate (EVA) film based and glass fibre lamination methods have limitations when used in UAVs. Encapsulations should provide enough support to the solar cells and while being considerably thinner, flexible, lightweight and smoother surfaces (for aerodynamic efficiency). Some used encapsulation methods decrease the efficiency of the cells by reflecting sunlight. In future research, optimal solar cell encapsulation methods for UAV applications will be investigated.

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