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PV System Design on Hybrid Airships: a Literature Review

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Hybrid airship, Solar-powered airship, systematic literature review.

Abstract

The integration of solar panel technology in airships presents a promising solution to reducing reliance on fossil fuels and minimizing greenhouse gas emissions in the aviation sector. However, the application of photovoltaic (PV) technology on hybrid airships still faces various technical and operational challenges. This study aims to evaluate the current knowledge regarding the use of solar panels on airships by conducting a systematic literature review of peer-reviewed journal articles published between 2015 and 2024. The review focuses on the technologies used to generate solar energy, the conditions and contexts of PV technology application, and its impacts on hybrid airships. The findings indicate that PV systems have significant potential to support hybrid airships by providing sustainable energy sources, reducing operational costs, and enhancing environmental sustainability. However, challenges such as energy conversion efficiency, additional weight, and airship design optimization remain critical factors that need to be addressed. The implications of this study highlight the necessity for further research to explore more efficient design strategies, improve energy absorption capabilities, and enhance the overall feasibility of PV integration in airships. Future studies should focus on innovative solutions to maximize the effectiveness of solar energy utilization, contributing to the transition toward more sustainable aviation technology.

1 Introduction

The global aviation industry is currently in the spotlight in the development of renewable energy. In 2022, the aviation sector accounted for 2% of the total global CO2 emissions related to energy, with faster growth in recent decades compared to the rail, road, or shipping sectors. As international travel demand recovers post-Covid-19 pandemic, aviation emissions in 2022 reached nearly 800 million tons of CO2, approximately 80% of pre-pandemic levels. Various technical measures related to low-emission fuels, aircraft and engine design improvements, operational optimization, and demand control solutions are needed to curb emissions growth and eventually reduce it this decade, in line with the Net Zero Emissions (NZE) scenario by 2050. Strategic steps to support this transition have gained momentum through international cooperation and domestic policies in various countries.

The International Civil Aviation Organization (ICAO) set an ambitious net-zero target for international aviation by 2050, adopted by 184 countries in 2022. In the United States, policies like the Inflation Reduction Act provide fiscal incentives of USD 3.3 billion to accelerate SAF production, targeting 3 billion gallons by 2030. The European Union, through ReFuelEU Aviation, has established regulations on the minimum SAF blend, which must be gradually met until 2050. The United Kingdom has also demonstrated its commitment by allocating GBP 165 million for SAF projects and targeting the construction of five commercial SAF plants by 2025 (IEA, 2023).

These global efforts indicate that although the challenge of decarbonizing the aviation sector is significant, international collaboration and technological innovation are key to accelerating the transition to sustainable fuels. With policies encouraging investment in SAF and low-carbon technologies, aviation emissions are expected to be progressively controlled, paving the way for a greener and more sustainable aviation industry.

One of the innovations currently attracting attention is the development of hybrid airships that combine conventional aviation technology with renewable energy systems such as Solar Power Plants. Hybrid airships have great potential for use in various applications, ranging from logistics delivery in remote areas, environmental monitoring, to humanitarian missions in hard-to-reach locations. However, the operation of hybrid airships still faces various challenges, particularly related to energy efficiency and the durability of electrical systems during long-distance flights. One potential solution to overcome these challenges is the integration of solar power systems as an additional, environmentally friendly, and sustainable energy source (Green, et al., 2021).

Since the mid-1990s, the development of airship design and technology has advanced rapidly to improve aerodynamic efficiency, performance, and payload capacity. To enhance the efficiency of airships in terms of payload capacity and aerodynamics, NASA conducted feasibility studies on modern airships in collaboration with Boeing-Vertol and Goodyear Aerospace Corporation. The outcome of this study was the creation of a new airship configuration known as the Hybrid Airship (Manikandan & Pant, 2021).

Research conducted by Zhang et al. in 2017 focused on the conceptual design and optimization of solar-powered hybrid airships. This research aimed to develop hybrid airships that utilize aerodynamic lift and buoyancy to operate at high altitudes. During the design simulation and optimization process, MATLAB software was used with the application of genetic algorithms (GA) combined with gradient-based search methods. Based on the optimization results, a hybrid airship with a surface area of 8,829 m^2 and a buoyancy ratio of 0.615 was capable of achieving an optimal cruising speed of 19.7 m/s. The study also revealed that seasonal factors and geographical conditions, significantly influenced by local winds and solar irradiation intensity, have a substantial impact on the ideal total weight of the airship (Zhang, Lv, Meng, & Du, 2017).

Furthermore, research conducted by Pflaum et al. in 2023 examined the design and route optimization of airships that utilize solar energy as their primary power source. The objective of this study was to develop airships equipped with solar panels and lithium-ion batteries for long-distance flights. Using specialized software developed for this research, flight route optimization and battery management were carried out to minimize travel time. The results showed that solar-powered airships could reduce carbon dioxide emissions by up to 95% compared to conventional aircraft, while operational costs ranged from only 0.5% to 2.5% of jet-fueled aircraft costs (Pflaum, Riffelmacher, & Jocher, 2023).

Lastly, the research conducted by Zhang et al. in 2019 focused on mission optimization using a multidisciplinary design approach for solar-powered hybrid airships. This study aimed to minimize the total mass of the airship by considering various mission phases, including the climb phase, daytime cruise, glide, and nighttime cruise. The Enhanced Collaborative Optimization (ECO) method was used in this study, successfully reducing the total mass of the airship from 13,894.6 kg to 8,432.3 kg. Multi-objective optimization was carried out through the Non-dominated Sort Genetic Algorithm-II (NSGA-II), resulting in a trade-off between nighttime flight altitude and total airship mass. The results indicated that the higher the nighttime flight altitude, the greater the total mass of the airship due to increased energy requirements. The optimal buoyancy ratio for high-altitude flights ranges between 0.7 and 0.9, with the recommended nighttime cruising altitude between 15 and 18 km (Zhang et al., 2019).

This literature review study aims to identify various research related to hybrid airships by considering the generator technology used, PV application methods, and the effects of solar panel installation on airships.

2 Materials and Methods

A. Literature Review Method

To achieve the objectives of this review, academic publications on the application of PV systems on hybrid airships were collected from various journal portals. Given the broad scope of the research, a systematic approach was employed to establish clear boundaries. This study utilized bibliometric analysis through the science mapping method. The process of identifying keywords began with fundamental terms such as "PV System" and "hybrid airship design," followed by iterative reviews to analyze keyword relationships and thematic relevance. The final step involved validating the keywords to ensure the studies encompassed various aspects of PV system design on airships, including research objectives, scope, impact, findings, and recommendations (Kassem, M. A. et al., 2024). A comprehensive Literature Review covering the last ten years was also conducted to provide an in-depth evaluation of methods, techniques, technologies, and their associated limitations. Here are some processes carried out in the literature review method :

1) Search Strategy
   To select the articles to be included in the review, a two-step screening process was conducted, consisting of an initial stage and a more in-depth final stage. In the initial stage, the title, abstract, and keywords were evaluated to assess the relevance of the article. Afterward, a more detailed analysis was carried out on the selected articles to determine the final articles to be included in the review (Yaser, B., Alberto. et al., 2024).
2) Research Questions
   The research questions addressed in this paper have been formulated based on the CIMO scheme : Context, Intervention, Mechanisms, Outcomes (Denyer, D. et al., 2008) . Based on the research objective, the primary research question is presented as follows: In the context of PV system design in hybrid airships (Context), what methods or technologies are implemented (Intervention) to generate and convert energy to be used on hybrid airships (Mechanism) in order to achieve a sustainable and environmentally friendly energy supply (Outcome), which is then broken down into the following research questions:

a. Research question 1 : What methods or technologies are implemented to generate solar energy to supply power to hybrid airships ?
b. Research question 2 : What are the conditions and contexts in which PV methods and technologies have been applied to supply power to hybrid airships ?
c. Research question 3 : What are the documented outcomes, recommendations, or impacts of implementing PV methods and technologies to provide sustainable and environmentally friendly energy to hybrid airships ?

1) Eligibility criteria
The chosen works must be in English, have passed peer review, contain all relevant keywords or their synonyms in the title and/or abstract, be sourced exclusively from journals, and focus on hybrid airships concerning the design and application of solar energy to power the electrical systems of these airships. These types of studies were selected as criteria to ensure a thorough synthesis of all terms and themes related to this review.
2) Selection of the scientific Sources
The Web of Science and Scopus databases were used to find research related to the design and application of PV technology on hybrid airships. The use of these two databases was chosen to provide access to a wide range of studies and literature from various fields, in accordance with the guidelines from previous studies.

B. PV System Design on Hybrid Airships

1. Hybrid propulsion system

A hybrid system refers to the combination of two or more elements working together to form a more efficient system. For example, the research conducted by Manikandan et al. (2021) explains that the hybrid system developed is a combination of fossil fuel-based and renewable energy systems. Hydrocarbon fuels, used in engines, have the highest known specific energy values to date. Therefore, there is no renewable fuel that can replace fossil fuels with similar energy capacity. The main components of the proposed hybrid system include solar panels, regenerative fuel cells (H_2-O_2), a conventional hydrocarbon fuel-powered engine, and an electric motor. To minimize energy loss during the power transfer process, a parallel powertrain configuration was chosen. Each subcomponent and its mechanism of operation is explained in the following sections. Solar panels generate the required electrical energy to split the electrolyte in the fuel cell system into its two main components, hydrogen and oxygen. These gases are stored in separate high-pressure tanks. In hybrid mode, these gases react in the fuel cell, generating electricity that is then supplied to the electric motor as needed (Manikandan. et al., 2021).

2. Photovoltaic array model

In general, the PV system design on hybrid airships has several configurations, models, and forms that are quite diverse. These differences and variations occur because the PV system designs that are attempted to be utilized are usually adjusted to the research objectives to be achieved, the desired outputs, and the experimental tests that are intended to be analyzed. For the conventional design, a double ellipsoid and a cylindrical structure in the middle section of the body are used to position the solar array. The multi-lobe configuration, on the other hand, can be seen as several conventional bodies arranged in parallel with the photovoltaic array placed on the upper surface, as depicted in Figure 1. Similar to the conventional arrangement, the solar array is installed symmetrically on the upper surfaces of the lobes. Assuming the lobe takes an ellipsoidal shape, the curved surface and solar panel can be described as a rotating surface (Zhang, L. et al., 2017).

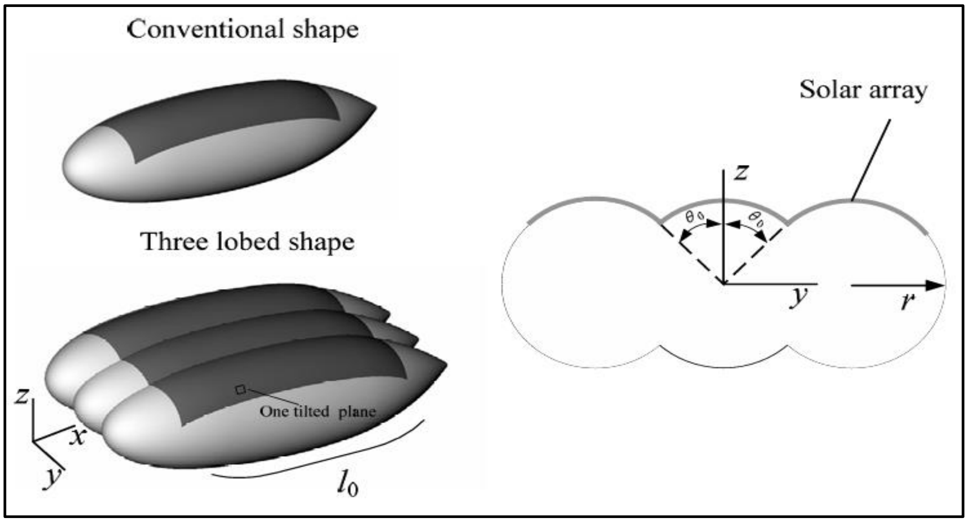

Figure 1. Envelope and solar array configuration in hybrid airship
Source : (Zhang, L. et al., 2017)

3. Energy management system hybrid airship

In hybrid systems, propulsive power is derived from two or more energy sources. Placing the components in an optimal configuration is crucial to ensure efficient performance. Generally, there are two types of powertrain configurations used: series and parallel configurations. In the series configuration, the electric motor is directly connected to the propeller. This connection allows for noise reduction and greater flexibility in component arrangement. However, it can also lead to significant energy losses during transfer, which is undesirable.

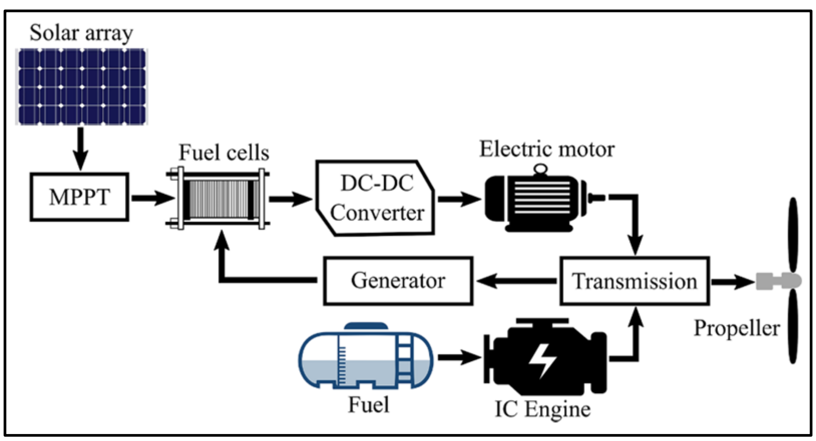

Figure 2. Energy management system hybrid airship
Source : (Manikanda,. et al., 2022)

In Figure 2, the parallel configuration, as stated in Manikandan's research, is significantly more complex but offers the additional advantage of a fail-safe mechanism. Furthermore, the powertrain can be configured in such a way that the battery or fuel cell can be recharged when there is excess power. The parallel configuration allows for multiple energy sources and paths, facilitating the transfer of excess power between components through direct connections. This configuration is more compact, efficient, and enables energy to be directly delivered to the propeller.

Photovoltaic (PV) cells do not produce constant energy due to fluctuations in wind and irradiance, causing variations in voltage or current that reduce efficiency. This issue is also commonly encountered in ground-based solar panel installations. To address this, a maximum power point tracker (MPPT) is used to capture the maximum power point on the I-V curve, ensuring the PV cells generate optimal energy by locking the operating point at the highest power point.

3 Results and Discussions

The implementation of hybrid systems in airships has shown significant improvements, as evidenced by the growing number of studies on this topic. In recent years, innovation in this field, particularly in military and cargo transport development, has seen considerable progress. This review focuses on exploring the methods and technologies used to generate solar energy as the primary power source for hybrid airships. The research highlights various photovoltaic (PV) technologies applied, such as flat and curved solar panels, as well as the integration of lithium-ion batteries for energy storage. Additionally, the review analyzes the conditions and contexts in which PV technology is applied, considering geographical factors, solar irradiance, and weather conditions that influence airship performance. The study also evaluates documented outcomes and impacts, indicating that PV applications can significantly reduce carbon emissions and lower operational costs, while providing recommendations for design optimization and energy efficiency to support the sustainability of hybrid airships in the future. The table below presents the results of a review of several studies conducted on hybrid airships.

Table 1. Result of a review studies

References	Objective	Scope	Result and recommendation
M. Manikandan, Eshan Vaidya, Rajkumar S. Pant (2021)	Develop a feasible model for the operation of a hybrid airship utilizing hybrid propulsion technology, and present the conceptualization of a hybrid propulsion management system comprising conventional fuel-powered engines, electric motors, photovoltaic panels, and fuel cells for energy storage. Provide a detailed methodology using previously accepted formulations for the conceptual design of hybrid airships.	hybrid airship model that combines conventional fossil fuel engines with electric motors powered by solar energy through solar panels installed on the upper part of the airship.	Reducing the use of fossil fuels, Improving the efficiency of solar panels and electric propulsion systems, Optimizing the aerodynamic design of the airship, Regulating the thermal management system for electric motors, Conducting further research on the impact of location and seasons on energy efficiency
Liu, Y., Sun, K., Xu, Z., & Mingyun Lv. (2022)	Provide a valuable reference for deciding the connection configuration of PV array on the airship, and make significant corrections to the empirical	Photovoltaic array on the stratospheric airship under partial shading conditions	The effects of partial shading on PV arrays in stratospheric airships, proposing a CSM for performance evaluation.

References	Objective	Scope	Result and recommendation
	estimates of output efficiency of airborne PV array		Key findings show power losses under shading, better performance with the TCT connection, and CSM predictions that are more accurate but lower than empirical methods.
Lanchuan, Z., Mingyun, Lv., Junhui, M., & Huafei Du. (2017)	Develop a high-altitude solar-powered hybrid airship that combines aerodynamic lift and buoyancy force for continuous cruising.	Conceptual design of a high-altitude hybrid airship with solar-powered propulsion, geographical variations (latitude) and seasonal effects on solar irradiance, and integration of solar arrays and fuel cells for energy storage and propulsion.	The optimal design demonstrated significant sensitivity to latitude and seasonal solar irradiance variations. At higher latitudes, lower solar irradiance and varying wind speeds impacted the optimization result. Winter condition resulted in higher optimal total weight due to reduced solar energy.
Sownya, G., Chinmay, R., Siddhartha, P.D.,& Mira, M. (2021)	Implementing a zero-energy deficit design by integrating solar photovoltaic systems, batteries, and diesel generators as auxiliary power sources. Developing a hybrid energy scheme to ensure uninterrupted power supply, and mitigating impact of wind induced platform instabilities, dynamic cloud footprints, and platform contour effects on solar power generation.	Designing a hybrid energy system for Lighter Than Air systems, integrating solar PV panels, lithium-ion batteries, and a diesel generator as an auxiliary power source.	During clear-sky conditions, the PV array met most of the power requirements, and excess energy was stored in the batteries. The hybrid energy design successfully compensated for power deficits, ensuring continuous power delivery throughout both operating conditions.
Chuan, S,, Kangwen, S., Xinzhe, J., & Dongji, C. (2023)	Reduce mismatch losses in photovoltaic (PV) arrays installed on stratospheric airships to enhance energy output and system efficiency	Design, implementation, and evaluation of a reconfiguration method for photovoltaic (PV) arrays on stratospheric airships, specifically targeting improvements in energy efficiency and power stability	The use of the Smart Choice Algorithm (SCA) for initial optimization, followed by the Greedy Algorithm (GA) and Munkres' Assignment Algorithm (MAA) for refinement, ensured optimal energy distribution across the PV array.

References	Objective	Scope	Result and recommendation
Junhui, M., Moning, L., Lanchuan, Z., & Mingyun, L. (2020)	Analyze the thermal performance of a hybrid air vehicle (HAV) during long-distance cargo transportation. The research investigates how flight time, geographical location, flight attitude, and relative wind speed influence the temperature distribution and output power of the HAV's photovoltaic (PV) system	evaluating the thermal performance and energy output of solar arrays on HAVs used for cargo transportation across long distances and varying environmental conditions. The scope includes analyzing the temperature distribution on different HAV components (solar array, helium gas, and envelope material) under dynamic flight conditions	The study found that excessive temperatures on the solar array during peak radiation hours reduce photoelectric conversion efficiency, causing lower power output compared to spring equinox conditions. Geographical factors, such as latitude and longitude, showed strong correlations with temperature and power output, reflecting the Earth's rotational and seasonal effects
M. Manikandan, Eshan, V., & Rajkumar, S. P. (2022)	Design and analyze a hybrid electric multi-lobed airship specifically tailored for cargo transportation while emphasizing sustainability, fuel efficiency, and reduced carbon emissions. The research aims to develop an energy management system integrating conventional fuel-powered engines, electric motors, solar photovoltaic panels, and regenerative fuel cells.	Conceptual design, aerodynamic analysis, and hybrid propulsion optimization of a multi-lobed hybrid airship for long-range cargo transportation missions.	The results show significant improvements in energy efficiency and fuel savings due to the integration of solar panels, regenerative fuel cells, and electric motors. The solar photovoltaic panels generated up to 1980 kWh of energy, with efficiency enhanced by a Maximum Power Point Tracker (MPPT) system.
Murugaiah, M., Theng, D.F., Khan, T., Sebaey T.A., & Singh, B. (2022)	explore the potential of hybrid electric propulsion systems for multi-lobed airships in achieving sustainable aviation goals. The research aims to address the increasing concerns related to fossil fuel depletion, greenhouse gas (GHG) emissions, and environmental sustainability in air transportation.	design an optimal hybrid propulsion system integrating conventional fuel engines, batteries, and solar photovoltaic (PV) arrays to minimize carbon emissions while maintaining operational efficiency	The integration of solar PV panels contributed to generating up to 1980 kWh of energy, supported by an efficient Maximum Power Point Tracker (MPPT) system.
Lanchuan, Z., Mingun, Lv., Junhui, M., & Huafei, D. (2017)	Develop a conceptual design and analysis methodology for hybrid airships that integrate renewable energy systems to improve performance,	The structural design, aerodynamic properties, and power management systems of hybrid airships, highlighting	For solar-powered airships, the integration of photovoltaic panels and regenerative fuel cells enabled sustained

References	Objective	Scope	Result and recommendation
	sustainability, and operational efficiency	their feasibility in addressing modern aviation challenges	energy output, with efficiency influenced by solar irradiance, altitude, and flight velocity

4 Conclusion

The literature review on the development of PV systems for hybrid airships shows significant potential in providing renewable energy and reducing carbon emissions in the air transportation sector. The application of this technology can enhance energy efficiency and reduce reliance on fossil fuels. However, several challenges need to be addressed, such as energy conversion efficiency, additional weight, and aerodynamic design optimization to maximize solar energy absorption. Research on this topic in Indonesia is still limited, highlighting the need for further studies to support technological development. The implications of these findings emphasize the importance of continued research and innovation in improving PV system integration for hybrid airships, particularly in enhancing energy efficiency, lightweight materials, and advanced aerodynamic structures. Furthermore, a multidisciplinary approach involving experts in renewable energy, aerodynamics, and materials engineering is crucial for overcoming technical limitations. It is recommended that future research focus on the development of high-efficiency solar panels with lower weight, advanced energy storage solutions, and intelligent power management systems to optimize PV utilization on hybrid airships. Collaboration between academia, industry, and the government is expected to accelerate the implementation of PV systems on hybrid airships and drive the transition towards more environmentally friendly transportation. Additionally, government policies and incentives for sustainable aviation technology should be strengthened to encourage investment and large-scale adoption of renewable energy solutions in air transport.

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