Exploring Applications for Solar Electric Aircraft

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Solar powered aircraft are typically only used in low wing loading applications, such as atmospheric monitoring, communications, and reconnaissance. They are limited by the fact that as weight increases, more power is required to keep the aircraft aloft than can be generated by the solar array. Solar aircraft are therefore unable to carry heavy payloads for sufficient range or achieve high speeds, rendering them impractical outside of these niche applications. However, solar power remains a favorable clean energy option in today's warming climate and the ever-growing concern of carbon emissions, which the aviation industry in particular has been pressured to mitigate. This paper aims to explore and facilitate expansion of solar aircraft into more spaces by investigating several mission profiles in which solar aircraft could be viable, including pipeline inspections and Antarctic inter-station delivery, and assessing the advantages and limitations of each. Pipeline right-of-way inspections are currently done mainly with helicopters, but a solar aircraft could be cheaper and more efficient. Antarctic inter-research station cargo delivery is a case which takes advantage of the region's extended periods of daylight, as well as a solar plane's ability to land, recharge, and takeoff again with no additional fuel. Development of a subscale model aircraft for the latter design mission is underway to demonstrate feasibility of this concept.

I. Introduction

A. Background on Electric Aircraft

Air travel is rapidly growing and is expected to continue to grow as demand steadily increases. The electric aircraft sector in particular has seen significant growth in the past decade. This is due to many factors; the concern for climate change being a big one. The main cause of global warming is CO_2 emissions. The aviation sector was responsible for 2.5% of global CO_2 emissions in 2023 [1]. Aviation is the second largest source of emissions in the transportation sector, after road, at 14% [2] and has been growing at a faster rate than road, rail or shipping. Therefore it is important that an environmentally-friendly solution is found. The United States and other member countries of the International Civil Aviation Organization (ICAO) have adopted the goal of achieving net-zero CO_2 emissions from commercial aviation by 2050 [1]. Electric aircraft are a potential way to cut aviation emissions, while also reducing noise and providing lower cost air transportation [3].

The big disadvantage of electric vehicles is the limited energy density of batteries. Gasoline fuel has about 100 times the energy density of a lithium-ion battery, and while an electric motor is much more efficient at converting battery energy to kinetic energy than an internal combustion engine is at converting gasoline energy [4], a gas-powered vehicle still has about 30 times the energy and therefore range capability of a battery-powered vehicle at the same weight. Because of these battery limitations, all-electric vehicles are limited to relatively short-range applications, but this market is looking promising. Companies like Joby Aviation, Archer Aviation, and Wisk Aero are developing electric vertical take-off and landing (eVTOL) aircraft for regional air mobility, meant to serve as commercial air taxis in urban locations.

B. Background on Solar Powered Aircraft

Solar power is an energy source of significant interest as it produces no carbon emissions and is a renewable source of energy. For the application of aircraft, solar panel's power output are limited by sun intensity, time of day, weather, and surface area of the upper surface of the aircraft's wings and fuselage on which panels can be mounted. Because the power collected from the solar panels is relatively low compared to the power needs of a typical aircraft of equal size,

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solar powered aircraft must be designed similar to sailplanes, which are glider airplanes characterized by extremely low weight, high aspect ratio wings, and large wingspans. A particular metric of interest is wing loading:

$$WingLoading = \frac{W}{S} \tag{1}$$

- W is the weight of the aircraft
- S is the wing area

The wing loading of a solar-powered aircraft should be as low as possible [5] because the heavier the aircraft is, the more power is required to power its flight. This way, the power required can be low enough that the solar panel array is enough to provide it, and wing area is maximized allowing for maximum space to mount solar panels. Therefore, solar powered aircraft are limited to applications that require little to no payload weight. This design also means that flight speeds will be slow, also limiting the potential applications. However, solar planes do have the advantages of being able to fly at high altitudes, cover large areas, and have extremely long endurance. Table 1 summarizes this information.

Advantages	**Disadvantages**
Long endurance	Must be light; limited payload capacity
Cover large areas	Long wingspan
Capable of high altitude flight	Slow maximum airspeed
Zero-emission flight	Dependent on weather and daylight hours for power

Table 1 Advantages and Disadvantages of Solar-Powered Aircraft.

The world's first solar-powered airplane, Astro Flight's Sunrise I, flew in 1974 as a demonstration that an aircraft can fly on solar power alone [6]. Today, solar-powered aircraft exist as high altitude long endurance (HALE) unmanned aerial vehicles (UAV) with endurance capabilities of up to months-long continuous flight. This is possible because these planes are capable of storing excess power from daytime to power flight at nighttime, and therefore have access to an "unlimited" supply of power [6]. These aircraft are used for atmospheric monitoring, communication relay systems, and surveillance/reconnaissance. BAE System's PHASA-35 solar-electric UAV, for instance, is able to operate over an area of interest for several months without refueling, providing surveillance and communications [7]. Airbus's Zephyr High Altitude Platform Station has demonstrated day and night endurance in the stratosphere, and is capable of high resolution imagery and video, which enables things like maritime surveillance, border monitoring, mapping, forest fires and emergency response [8].

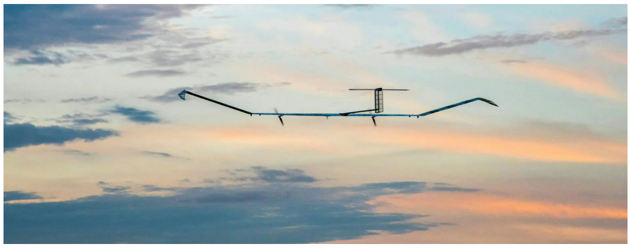


Fig. 1 Zephyr High Altitude Platform Station. Image courtesy of Airbus AALTO [8].

The U.S. Navy, with Skydweller Aero, has developed a solar-powered plane to do maritime surveillance of military ships, capable of flights lasting several weeks. It replaces the MQ-4C Triton, a traditional fuel-based aircraft with only a 30 hour endurance, and in doing so saves a lot of money, maintenance time, and emissions [9].

II. Other Potential Applications for Solar Aircraft

The aircraft discussed above are fairly niche, and apart from these high-altitude applications, solar-powered aircraft are not used. This section will investigate other applications for which solar aircraft may have potential, and discuss how they avoid the limitations associated with solar aircraft, while leveraging their advantages.

A. Pipeline Inspection

One such application is pipeline right-of-way inspection. The U.S. has over 190,000 miles of oil pipelines and over 2.4 million miles of natural gas pipelines [10]. With oil and natural gas being the world's primary energy source and demand only set to increase, these pipelines are here to stay, and more will continue to be built. These pipeline networks move these combustible fuels under high-temperature, high-pressure conditions, so it is extremely important that the pipelines are monitored and maintained to avoid environment-damaging incidents. The strip of land that contains the pipeline is the right-of-way (ROW). The U.S. Code of Federal Regulations (CFR), Title 49 section 195.412, requires operators to conduct inspection of the surface conditions on or adjacent to each pipeline ROW, at least 26 times each calendar year, at intervals no larger than 3 weeks [11]. Both inspection of the pipelines themselves and checking for any encroachment on the ROW is necessary.

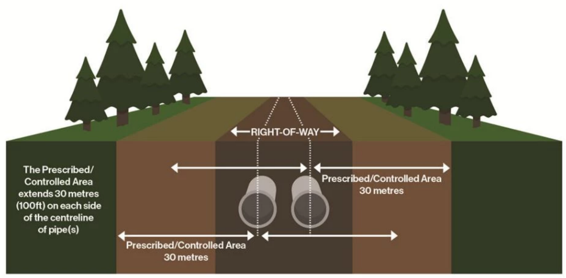


Fig. 2 Pipeline Right-of-Way defined. Image courtesy of JOUAV[12].

Currently, most energy companies use helicopters to conduct these inspections, as aerial inspections are the safest and time-wise the most efficient way to do so. However, using helicopters is expensive; each trip costs around $150,000 [10]. Some drone companies offer pipeline ROW inspection services via remotely-operated drones capturing video [13], but traditional multi-rotor commercial drones have limited range and endurance, about 12 miles and a 1 hour endurance at best [14].

Fig. 3 Pipeline Inspection. Image courtesy of Flytbase[10].

Solar-powered aircraft have the potential to be effective for pipeline inspection because of their ability to fly continuously for long flights, enabling them to inspect miles and miles of pipeline at a time. One of the main drawbacks of using solar power, which is its dependence on solar availability and weather, can be avoided since the inspector is able to choose the day and time to conduct the inspections, as long as it adheres to the CFR requirements described above. Therefore, the inspector can select a day and time of good weather conditions and peak solar intensity to maximize the effectiveness of the solar aircraft. A solar aircraft's low airspeed is also acceptable as inspections would require slow travel regardless. Compared with a helicopter, the operating cost of a smaller solar aircraft would be significantly lower, and it wouldn't require a manned aircraft, as the solar aircraft could be remotely piloted or made to fly autonomously. Therefore this application has strong potential to adopt solar powered aircraft.

B. Antarctic Circle Operations

The Antarctic is home to over 70 research stations, operated by over 40 countries [15]. A map of the stations is shown below in Figure 4. Most of them are located along the coast of the continent but several are further inland. Some operate year-round, while most are staffed only in the summer. About 4-5,000 people live in these stations during the summer, and about 1,000 people live there during the winter[15]. These stations exist to conduct scientific research.

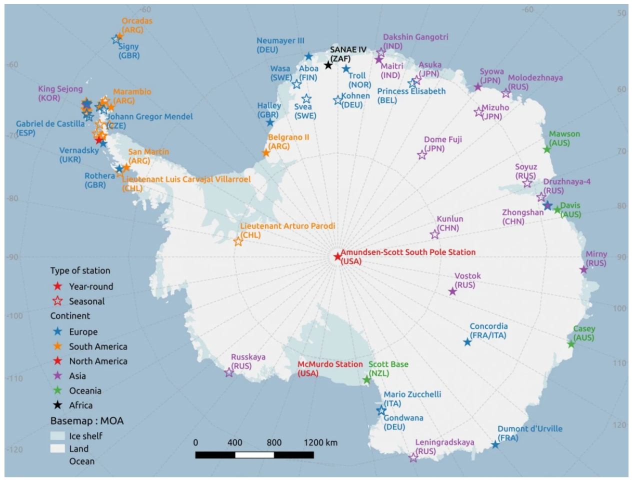
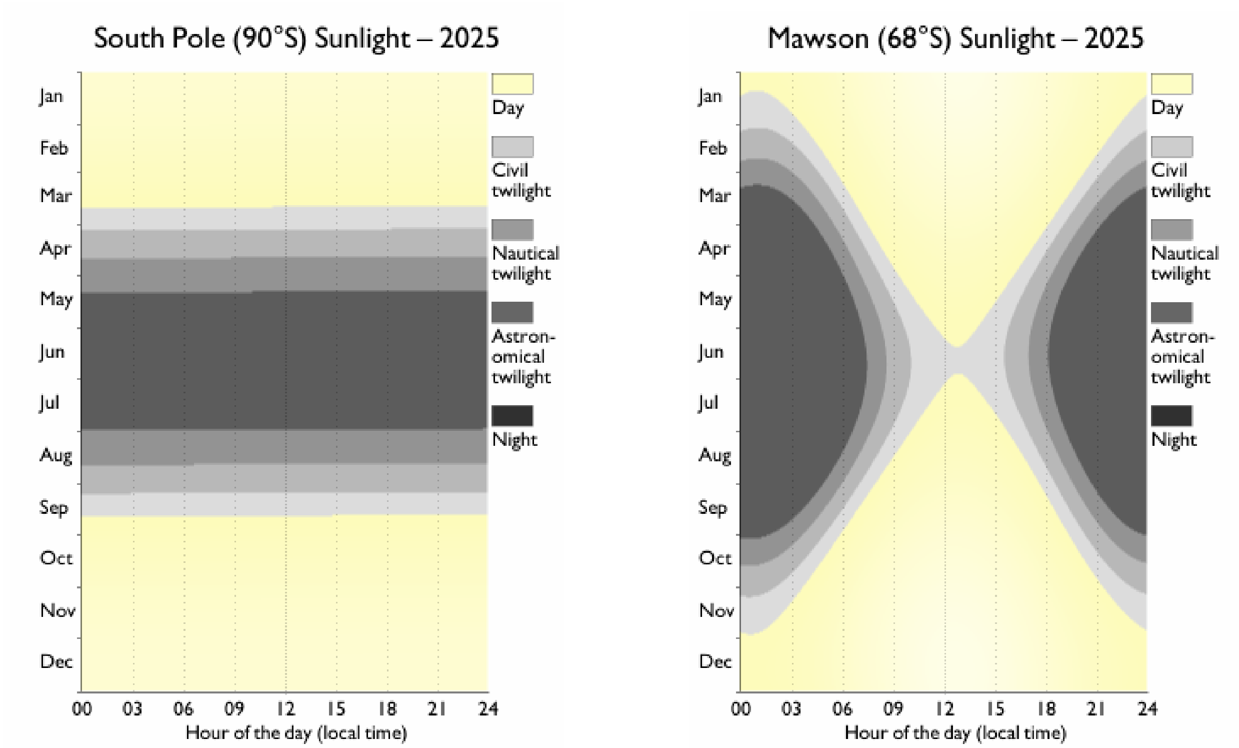


Fig. 4 Map of Antarctic Research Bases. Image courtesy of Antarctica Cruises [15].

This is an area of interest for this paper's topic because of the daylight hours in this region. Within the Antarctic Circle (66°) in the southern hemisphere's summertime, the sun remains completely above the horizon for at least a day at the Circle's border, and lasts longer the further South you travel, lasting for several months at the South Pole [16]. This is a phenomenon known as "midnight sun", observable also in the Arctic Circle. Figure 5 is a great visual of the seasonal daylight, comparing the south pole with Australia's Mawson station off the northeast coast of Antarctica. It can be seen that even on the coastline, month-long periods of continuous sun occur.



(a) South Pole **(b) Mawson Station**

Fig. 5 Daylight Hours Across the Year. Images courtesy of Australian Antarctic Program[16].

A solar-powered vehicle could take advantage of this long duration of continuous sunlight. Currently, Antarctica's population of researchers use various modes of transportation to move cargo to and across the continent, including ships, aircraft, trucks and tractors. Regarding aircraft, big transport jets haul cargo in and out of the continent, and smaller, ski-equipped aircraft like Twin Otters, LC-130s, and helicopters are used to ferry people and cargo between stations [17].

The main need for an aircraft in Antarctica would be for transportation between its research stations, which are up to over 1,000 NM apart. For a solar aircraft to be able to carry a payload of actual useful weight, it itself would have to be much heavier than the lightweight aircraft for the other applications discussed thus far. This extra weight comes from the necessary increase in structural stability of the aircraft to accommodate the heavier payload. A heavier solar aircraft will have drastically shorter endurance and range capabilities than the high altitude aircraft, but it would make up for it with its ability to land anywhere, recharge its battery under the Antarctic sun, and takeoff again once reaching full battery. It could repeat this process for a "grasshopper"-like flight profile until the destination is reached. Of course, this would make for much slower delivery. But for smaller sized payloads for which quick delivery time is not necessary, such as resupplying seasonally-occupied research camps which can be prepared and sent at a time far in advance of when it is needed, potential for a solar aircraft can be seen.

III. Conclusion

The applications of solar-powered aircraft for pipeline inspection and Antarctic cargo delivery capitalize on the strengths of solar aircraft, and have potential to help reduce carbon emissions into the atmosphere by replacing traditional fuel-based aircraft in these cases. As the authors of [6] conclude, "solar-powered airplanes are potential alternatives to some present technologies and they complement current satellites, traditional airplanes, airships and balloons. However, these planes require further development and enormous technical obstacles must be addressed". Overall this paper aimed to facilitate interest, discussion, and expansion of solar aircraft for more uses. More research will need to be conducted for an aircraft designed specifically for the grasshopper mission, but that is worth looking further into, as it can be modified for dessert and ocean variants as well.

Acknowledgments

The findings presented in this paper are part of a larger research effort looking at solar electric cargo aircraft feasibility. This research group is based out of the Georgia Institute of Technology in Atlanta, Georgia and is led by faculty advisor Dr. Brian German and graduate student Jeff Perry. I would like to thank both Dr. German and Jeff for providing me with the platform to conduct research on this topic and write this paper.

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