WHITEPAPER

Selecting Solar Technology for Fixed Wing UAVs

Contents

Executive Summary

This white paper discusses the key characteristics, tradeoffs and relevant metrics of the various solar photovoltaic technologies available today in the context of fixed wing unmanned aerial vehicles (UAVs). We identify the inadequacy of current solar metrics in this context and calculate a new performance index (P_{UAV}) that prioritizes power-to-mass and power-to-area ratios. P_{UAV} is more relevant to UAVs than efficiency alone, and takes into account critical UAV constraints such as available surface area and weight. Of all the technologies in the market today, thin gallium-arsenide solar has the highest performance in situations where space is limited and weight must be minimized.

Introduction

Fixed wing unmanned aerial vehicles (UAVs) are poised to revolutionize aerial observation, commercial communication and military reach. From game wardens in Africa to insurance companies surveying industrial sites, military, government and civil users worldwide are increasingly appreciating the utility of this technology. Large companies like Facebook and Google are developing high altitude long-endurance UAVs to provide internet connectivity. Others plan to use UAVs for multi-month missions focused on land management, resource mapping and topographical surveys. Although rotary wing UAVs allow precise maneuvering, fixed wing UAVs are more efficient in flight, can carry greater payloads such as sensors for longer on less power and are better suited for high-altitude and long endurance (HALE) missions. Fixed wing UAVs can benefit immensely from thin, lightweight and highly efficient solar cell technologies available today.

Fig. 1. Solar cells can help quadruple the range of battery powered UAVs.

The Sun as the Power Source

The large horizontal surfaces on fixed wing UAVs can accommodate a significant quantity of solar cells. Aircraft such as the NASA/AeroVironment Helios demonstrated, in the 1980s, the potential for solar cells to transform the wing from a passive mechanical component into a primary power source or to provide payload power, with minimal impact on aerodynamics. Recent improvements in electric propulsion technology and wireless connectivity are now driving strong commercial interest in solar power for UAVs of all sizes, such as the AeroVironment Puma (Figure 1).

What to Consider When Selecting Solar

The photovoltaic industry is dominated by large players manufacturing near-commodity product for the large scale utility, commercial and residential power generation markets. The dominant performance metric is efficiency. However, there are other metrics and solar technologies that are more relevant to UAV applications. We discuss these below.

Power to Weight Ratio

$$P_m = \frac{power}{mass_{cell} + mass_{encapsulation}}$$

The objective of the UAV is to carry a payload; any excess weight detracts from this ability. Since the solar panels are usually integrated into cantilevered wings, the weight of the solar can lead to a further increase in the weight of the aircraft due to increased structural requirements. Therefore, the power to weight ratio (Pm) of the solar technology being evaluated is a primary consideration in a UAV application.

The total weight of the solar is the sum of the weight of the cells themselves, plus the weight of the protective packaging needed for that cell to survive the expected operating environment. Certain cell technologies need special thick or multilayer packaging for acceptable lifetimes. This packaging can be heavy.

Therefore, it is important to consider the total weight of the solar submodule (i.e. cell weight including interconnections, plus weight of encapsulation) when comparing technologies using power to weight ratios.

Power to Area Ratio

$$P_A = \eta * F * 1000 \ (W/m^2)$$

Surface area is limited even on fixed wing UAVs, so an important metric is efficiency (η, quoted in %), or power per unit area (PA). As discussed below, there are solar technologies that can have high power-to-weight ratios but suffer from low conversion efficiencies. This can be a handicap in UAV applications since the available area is limited. Increasing wing area for the sole reason of accommodating additional solar power may not pay off, due to increased structural weight and drag. The relative size of the individual solar cells compared to the wing size also becomes a consideration, with smaller cells enabling higher packing densities (F). The ability and willingness of the vendor to provide customized sizes and shapes of solar cells and cell assemblies to ensure maximum utilization of available area are also important here.

Ease of Integration

Ideally the chosen solar technology must not impose additional constraints on the aircraft design or the manufacturing process. Solar cell technologies can vary greatly in this regard. Thickness, mechanical flexibility and ability to withstand common manufacturing processes, such as vacuum forming, are major factors to be considered. Thinner solar cells are typically easier to integrate because they are more flexible and more resistant to breakage. Cells can be encapsulated with a variety of plastic films and even spray-on clear-coats. Other factors include the ability to provide a smooth surface for optimal aerodynamics while maintaining a high power to weight ratio.

Durability and Reliability

UAVs operate in harsh environments. Extreme temperature swings, vibration and flexing are normal. In addition, impact and abrasion are possible during takeoff, landing and low altitude operations. Many UAV designs (especially larger UAVs) will seek to employ higher bus voltages in order to reduce the weight of wiring and use more efficient propulsion. Higher voltages can result in specific failure modes in the solar panels which may not appear during low voltage bench testing. Finally, if the solar sub-modules are to be adhered to the UAV surfaces, it is extremely important that the adhesion system be thoroughly qualified. The encapsulation system used to protect the cells must be similarly qualified. It is important to select a technology vendor that is willing to invest in needed testing and to provide relevant data on an ongoing basis as the UAV design evolves.

It is important to select a technology vendor that is willing to invest in needed testing and provide relevant data on an on-going basis as the UAV design evolves.

Technology Landscape

There are over twenty photovoltaic technologies being actively pursued by various manufacturers and research groups. Broadly, they can be divided into wafer-based and thin-film types. Here we discuss only those technologies which can readily be produced in a form suitable for UAV integration. Relevant wafer-based technologies are crystalline silicon (c-Si) and gallium-arsenide (GaAs). Relevant thin-film technologies are amorphous silicon, copper-indium-gallium-selenide and thin gallium-arsenide based photovoltaics.

Crystalline Silicon Solar Cells

The chief advantage of crystalline silicon is technology maturity and good efficiency under standard conditions. However, integration can be problematic, particularly for smaller UAVs.

The vast majority of existing solar cells and manufacturing capacity is of crystalline silicon, typically made from 6-inch size wafers. The typical efficiency of this technology is approximately 17% (up to 20% for some newer technologies) as measured under standard test conditions, but the efficiency can drop off under real world operating conditions of elevated temperatures and reduced illumination. These wafer-based cells are generally about 0.2 mm thick, are brittle and must be encapsulated in relatively thick laminates for adequate environmental protection which can increase weight by a factor of 3 or more. Production of these cells is dominated by large manufacturers who may be reluctant to support the relatively low volumes of the UAV industry. The chief advantages of crystalline silicon are its technology maturity and good efficiencies under standard conditions.

Lightweight Thin Film Solar Cells

Thin-film solar cells utilize much thinner layers of semiconductor material a hundred times thinner than the wafers discussed above. Potentially, these cells can be made into very thin and lightweight panels. We discuss these next.

Copper Indium Gallium Selenide (CIGS)

A popular thin-film technology is copper-indium-gallium arsenide (CIGS). Flexible CIGS cells can be fabricated on thin metal foils and offer large area efficiencies of up to 13% (under standard conditions). They are extremely sensitive to moisture and air, however, and must be encapsulated in a hermetically sealed package in order to provide a satisfactory lifetime. This package increases product weight and reduces options for integration. CIGS also has relatively low energy yield in high temperature and low light conditions.

Amorphous Silicon (a-Si)

Lightweight amorphous silicon (a-Si) solar cells are technologically mature, inexpensive, relatively insensitive to moisture and air, easy to integrate and can provide good energy yields in real world conditions. However, their conversion efficiency is relatively low (about 8%) and it can be difficult to find sufficient surface area on an UAV to mount enough of these cells to meet power needs.

Thin Gallium Arsenide (Thin GaAs)

Thin GaAs is a relatively new technology that offers the high conversion efficiencies (25%-35%) and high energy yield of traditional GaAs solar cells, but in a lightweight and flexible format. This technology offers power to weight ratios over 1 kW/kg as well as the high conversion efficiencies needed in situations where available real estate is limited. Not as sensitive to air or moisture, these cells are also easier to integrate than CIGS cells. Thin GaAs cells are available in smaller sizes than traditional GaAs solar, which can result in superior packing density especially in smaller aircraft.

Thin GaAs offers very high power to weight ratios as well as the high conversion efficiencies needed in situations where available real estate is limited.

The Need for a New Metric

High efficiency is not sufficient for a technology to be suitable for UAVs, if it comes at the expense of increased weight. A high power to weight ratio may not be sufficient in the absence of high conversion efficiency, if the available wing area is not enough to provide a meaningful amount of power. The commonly used metric of efficiency does not take into account these simultaneous constraints of surface area and weight inherent to UAV design.

In the next section, we present a new metric that underscores the importance of power per unit area and power per unit mass and permits the reader to rank solar technologies with these key factors in mind. We present rankings for solar panels based on standard and advanced crystalline silicon, amorphous silicon, CIGS, and traditional and thin gallium arsenide, but the metric may be calculated for any solar technology.

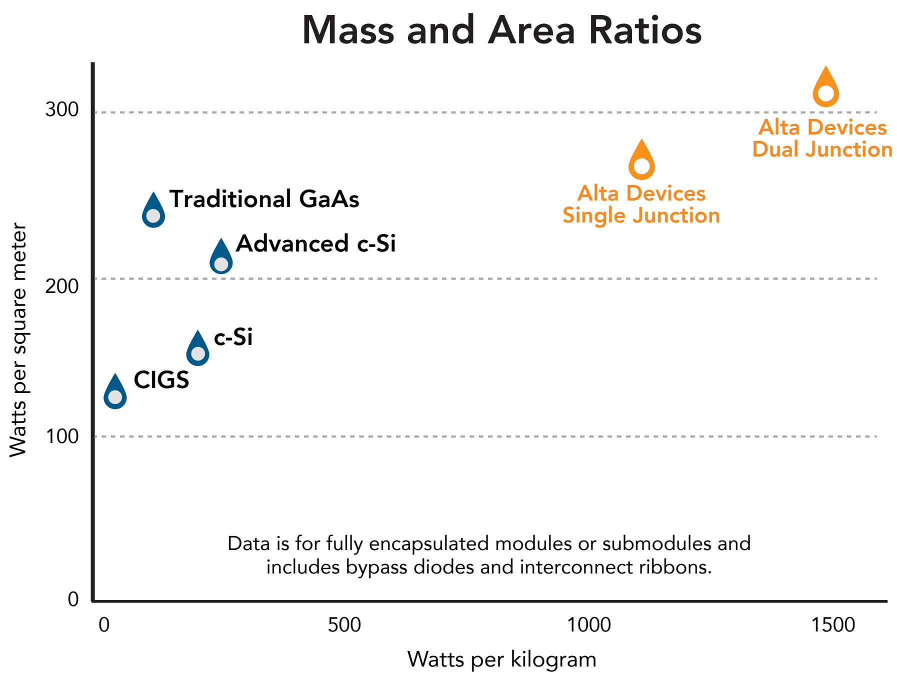

Fig 2a Power-to-weight and power-to-area ratios for four different solar technologies.

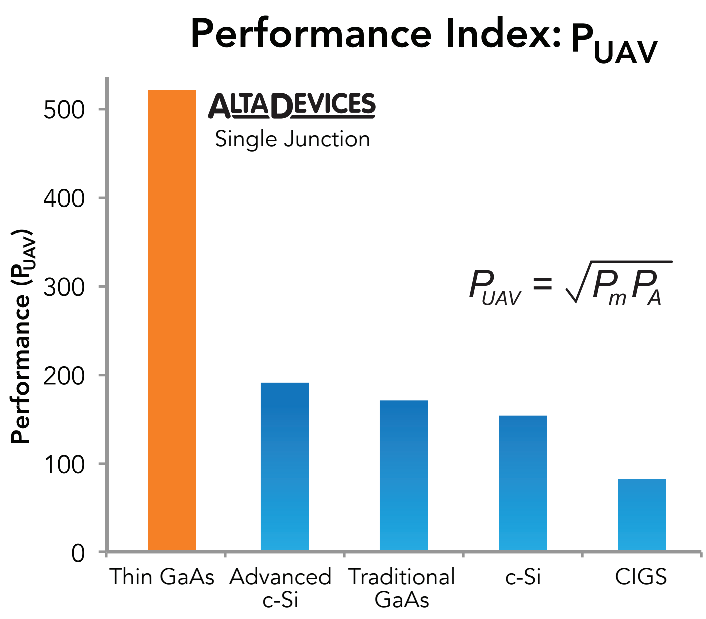

Fig 2b The corresponding performance indices.

A Solar Performance Index for UAVs

Of the various technology parameters that designers must consider, power to area (PA) and power to mass (Pm) ratios are clearly very important due to limited mass budgets and surface areas. These are charted for six relevant technologies in figure 2a (see notes 1-5 for data sources). There is no simple relationship between the two, because the type and weight of the necessary encapsulation is influenced by chemical and mechanical stability of the cells. Since the UAV application demands high values for both ratios at once, we multiply the two ratios and take the square root of the product to convert the numerator to the dimension of power (watts). The resulting performance index (P_{UAV}) is shown in figure 2b.

Conclusion

Designers can choose from a wide range of available solar cells and must carefully evaluate the significant performance tradeoffs resulting from that choice. In this whitepaper we have presented a simplified performance index for comparing the power density of solar technologies. The index places a premium on simultaneous minimization of weight and surface area. With the effects of encapsulation taken into account, thin GaAs solar cells score over 2x better than the nearest alternative and are an excellent choice for designs seeking high performance while minimizing weight and surface area.

Data Sources and Assumptions

1. CIGS efficiency and weight from Miasole Flex-02W datasheet (Oct 2015).
2. Amorphous silicon efficiency and weight from Powerfilm Solar 0.72W RC Aircraft Module data (Oct 2015).
3. Crystalline silicon encapsulation assumed to be 1 mm ethyl-vinyl acetate and 0.025 mm polyester, on light-facing side only. Wafer thickness assumed to be 0.15 mm. See MXFlex 130W datasheet (Oct 2015) for comparable advanced crystalline product, but one that uses thicker encapsulation.
4. Alta Devices thin gallium arsenide encapsulation assumed to be 0.025 mm polyester and 0.050 mm adhesive, on light-facing side only. Cell data from Alta Devices Single Cell Technology Brief (Oct 2015).
5. Traditional GaAs data from Spectrolab single-junction datasheet (downloaded Oct 2015 from www.spectrolab.com).

ABOUT ALTA DEVICES

Alta Devices (*www.altadevices.com*) holds the world record for single-junction solar cell efficiency (28.8%). It manufactures ultra-lightweight gallium-arsenide based solar cells in its Sunnyvale, California factory and provides application engineering support to OEM customers worldwide. Alta Devices can be contacted at info@altadevices.com.

A Hanergy Company | 545 Oakmead Parkway, Sunnyvale, CA 94085 | www.altadevices.com