A SOLAR POWERED HALE-UAV FOR ARCTIC RESEARCH

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ABSTRACT

The paper reviews the current possibilities and difficulties for airborne earth observation as well as geophysical and atmospheric research flights in polar regions. The new concept of solar powered High Altitude Long Endurance (HALE) Unmanned Aerial Vehicles (UAVs) is introduced and explained why the research in the Arctic and Antarctic could tremendously profit from such aircraft. It is shown that just the icy poles are surprisingly the ideal operational areas for solar powered HALEs. The pros and cons for this new technology in comparison to traditional aircraft and satellites are discussed. Besides the scientific applications, such aircraft may also be of interest for surveying purposes in order to reduce navigational risks in polar areas. A major advantage is the low cost compared to satellite systems and the minimal ecological impact. First results of a Solar HALE study performed by the German Aerospace Center are provided.

1. INTRODUCTION

The idea behind the solar powered flight is that the aircraft or airship has not to land for a very long time span in order to get refuelled, because it generates the necessary energy with solar cells. Such an aircraft will be capable of a “permanent” or “eternal” flight, it will not produce any emission and will have less maintenance cost than conventional aircraft. Although there are attempts to have pilots in a solar aircraft, the concept of long flight endurance and the high flight altitude in the stratosphere (typically at 20km, which is necessary to avoid the jet streams) makes it necessary to fly the HALE (High Altitude Long Endurance) aircraft automatically and without a pilot (UAV – Unmanned Aerial Vehicle).

Especially applications which require a long term loitering of the UAV over a certain area are practically impossible with standard aircraft. Only geostationary satellites, which require an orbit height of 36.000 km, have this capability. They are used for TV broadcasting, communication and to take large scale meteorological images, but can´ t be used for remote sensing application, because the distance between the sensor and the ground is too large. Earth observation satellites like Landsat, Spot or Envisat are typically placed in orbits between 500km and 1.000km altitude. From such orbits their instruments can reach a certain area on the ground only within a revisit time between one and several days and can take furthermore only short snapshots of the scene. With an observation platform in the stratosphere the distance to the ground is much shorter than from the earth orbit, which permits the use of much lighter sensors. The focal length of the lenses of optical sensors can be shorter and for microwave sensors the transmitted power or the antenna can be smaller.

In summary HALE platforms have the following advantages over satellites:

- No complex and wasteful rocket launch is necessary.
- They can land for their own maintenance and for those of the payload, whenever required. They can even carry completely different payloads during their lifetime. (This is also possible with the Space Shuttle, but extremely expensive.)
- The platform and instrument electronics have not to be radiation hardened as for a satellite, which has the potential to make them cheaper, lighter and much more up to date. (For the electronics and computers of spacecrafts special semiconductor chips have to be used.)
- The distance between sensor and the observed object is much shorter. Some atmospheric sensing can be performed even in-situ.

On the other hand we will not keep secret that satellites have also some advantages over HALE platforms:

- A satellite can reach every part of the Earth within at least one day (depending on its orbit characteristics).
- Due to the high travel velocity of satellites of typically 7.000 m/s (25.200 km/h) they can cover very large areas rapidly. If the whole globe is of interest this is an unbeatable advantage.
- The third great advantage over any airborne platform is that satellites doesn’t penetrate the airspace of a country and can take pictures without violating the sovereign rights of a country (United Nations Open Sky Agreement).
- They can not crash and hurt people.

The advantages of Solar HALE platforms over standard aircraft are:

- They don’t need fuel.
- They are environmental friendly (“zero emission”).
- They can stay in the air for a long period of time.
- They can operate in high altitudes above the normal air traffic. (In principle this can be done with an aircraft, but mostly the pilot needs to carry a pressure suit.)
- They are much more weather independent, because they operate in the stratosphere with stable weather conditions.

The main disadvantage of solar HALEs is that the operation in high altitudes requires aircraft with large wings Due to the limited power available, speed and payload of a Solar HALE is limited. This is especially true when additional energy has to be stored for the operation at night hours in batteries or regenerative fuel cell systems. Therefore the summer seasons in polar areas may be especially suitable for the operation of solar HALE-UAVs because of the permanent availability of solar power. In this study we present examples for remote sensing applications in polar areas for which HALE UAVs might be considered as measurement platform together with a technical feasibility.

For long distance surveillance and research flights over the oceans and Polar Regions only a few aircraft types exist today, like the P-3 Orion and C-130 Hercules (Fig. 1). They are very expensive to maintain and with flight duration in the order of 12 hours they can just cross an ocean or the Antarctic continent, but not loiter in the area for a longer time frame. UAVs like the Global Hawk and the light-weight hydrogen powered aircraft Global Observer from the company AeroVironment are more effective, but they have to return to their base also after a couple of days. Furthermore, it has to be noted that these aircraft pollute the stratosphere with emissions which will stay there for a long time! However, these UAVs are already attractive for various scientific applications and NOAA and NASA have started the so called "Suborbital Science Program". A NASA report describes in detail possible applications and mission scenarios [1].

Fig. 1 C-130 Hercules in an Arctic mission

2. USAGE OF HALE-UAV IN POLAR AREAS

The high geographical latitudes are of special interest for the operation of solar powered HALEs, as during the polar summer solar energy is permanently available, which supersedes the necessity of bridging the dark night hours with battery or fuel power. Well above the troposphere, the direct sunlight can provide high energy if the solar cells are oriented towards the sun. In polar summer the sun stays at low incidence angles all around the clock without a sundown. In addition, the planetary albedo in polar areas is exceptionally high, which enables even the effective usage of reflected sun light from the ground. Installing solar cells practically on all parts of the aircraft, also beneath the wings, will yield a continuous high power supply during several months of the year. However, since an aircraft must be streamlined the available surface in the front and at the aft will always be very limited. Hence the flight planning has to take into account the position of the sun over a 24h day of operations.

In September 2004 more than 50 Antarctic researchers from the disciplines Geology, Geophysics, Glaciology, Oceanography, Atmospheric Science and Climate Interactions met in the United States to formulate the need for a **L**ong-Range **A**ircraft for **R**esearch in **A**ntarctica (LARA). The workshop report includes the scientific targets as well as the platform and instrumentation requirements [2].

At the time of the workshop only very few and early UAVs were commercially available and were considered to be insufficient. Furthermore the whish to carry whole suites of instruments led to high payload mass requirements and it was concluded that a heavy aircraft like the LC-130 Hercules would be the best choice. However, the permanent refueling problem in an Antarctic station and risks for the crew is in favor of a Solar HALE-UAV, even if its payload capacity is much smaller. Nevertheless the report provides a good summary of what can be achieved if long-range aircraft would be available for Antarctic research and we will cite here some significant passages:

„The Polar Regions are intimately linked to the global climate system, sea level, and marine, freshwater, and terrestrial ecosystems and they can amplify and drive changes elsewhere in the Earth system. To understand these links, it is imperative to study the current configuration and behavior of the Antarctic ice sheet and the surrounding ice shelves. Interdisciplinary research addressing the status, changes, processes, and connections of all major Antarctic systems (ocean, sea ice, atmosphere, solid Earth, and ice sheet) by coordinated measurement campaigns and by assimilating the data into complex models is needed to better understand past ice-sheet behavior and improve prediction of changes.

Currently, we have a physically based, conceptual understanding of many of the significant interactions that impact climate and the Antarctic environment. To transform this conceptual understanding into quantitative knowledge, it is necessary to acquire geographically diverse sets of fundamental observations at a range of spatial and temporal resolutions. Satellite data provide needed continent-wide coverage, but they often have limited spatial resolution and provide virtually no sub-surface information. They also require extensive calibration and validation, which can be difficult or impossible to obtain in the Antarctic.

Common to all mission profiles is the need for an aircraft capable of carrying an integrated payload of remote-sensing and in situ instrumentation over long distances. Almost all mission profiles require data acquisition in regions more than a thousand nautical miles from existing landing sites for wheeled aircraft in Antarctica. To get to the target area and be able to survey for several hours requires aircraft endurance of at least 10 hours or the ability to refuel in remote locations. Flights that maintain altitudes from a few hundred meters to at least 7 km are required. A large swath of East Antarctica remains virtually terra incognita because we are unable to reach it using available aircraft.

The availability of a long-range research aircraft would advance ocean research in the Antarctic in two ways. First, it would provide a new facility uniquely capable of gathering data over a very broad area, with a much higher resolution than available from satellites, and would allow deployment of air-dropped, remote instruments. Second, it would allow collection of data in a rapid response mode, permitting investigation of processes at work in event-driven phenomena such as polynyas or ice shelf break-up.

Most needs can be met using a long-range aircraft suitably equipped with surface-sensing instruments, shallow penetration systems such as active microwaves, and air-droppable buoys and probes. Such a platform can carry out, for example, rapid cross-basin traverses to obtain information on the sea-ice cover to a high level of detail impossible to obtain in any other way. Satellite-tracked drift buoys might be dropped at points along the flight track, allowing tracking of ice movement for as much as a year following the flight. Such transects could be continued annually, or even more frequently, for a decade, providing a wealth of information on pack-ice characteristics and movement. This information would be invaluable in assessing the interactions of the pack ice cover with other large scale systems in a climate-change context. " (end of citation from the LARA report)

A list of all suitable measurement sensors is provided in Table 4 of the LARA report [2].

Fig. 2 Ice Thickness Measurement with AWI EM-Bird

2.1. Sea Ice Thickness Measurements

Sea ice plays a critical role for the entire earth climate system, but is also of high economical interest, as e.g. potential shipping routes depend on its extent and thickness. Satellite systems exist which monitor the sea ice extent continuously. Because of the launch failure of ESA's Cryosat-1 in October 2005 still no dedicated system is available to assess sea ice thickness. This gap will be partly closed with Cryosat-2 in 2009. However, satellites like Cryosat depend on extensive validation work [3]. The only airborne system available at the moment for direct ice thickness measurements is the "EM Bird" which was designed by the German Alfred Wegener Institute for Polar and Marine Research (AWI) [4]. The "EM-Bird" is carried by a helicopter (Fig. 2) and emits a laser beam whose echo describes the surface of the sea ice, and a low frequency electromagnetic beam which analyses the total ice thickness. The height above sea level (freeboard height) and ice thickness yields information on the sea ice density. These measurements have to be performed at very low flight altitudes in the order of only 20m. However, helicopters can´ t be used due to the long distances and their high fuel consumption. Another convenient option is the usage of airships, which is planned during an Arctic expedition in 2008 [5]. However, a low flight altitude is only possible at low wind conditions. HALE-UAVs could be equipped with Laser or Radar altimeters to monitor continuously sea ice freeboard over smaller areas at high temporal and spatial resolution.

2.2. Monitoring of New Arctic Navigation Channels

Coming along with climatic warming, the Arctic Ocean coasts become more and more ice free. Navigation on the North-East Passage, which leads from Greenland to Alaska, and the North-West Passage, also called the "Northern Sea Route", which leads from the Atlantic Ocean to the Pacific Ocean along the Russian coasts, is currently possible 20 to 30 days per year. By 2030, this could increase to 90 to 100 days per year, even 150 for icebreakers. Routes from Europe to the Far East would save 4000 km through this passage, as compared to the current routes through the Panama Channel. HALE-UAVs may be a suitable platform for the monitoring of the new shipping routes and ice conditions in these remotest parts of the world.

This was confirmed by a study of the Canadian Department of National Defense which was concerned with the surveillance and reconnaissance of the Northern Territories. The study included satellites, aircraft and HALE UAVs. One of the conclusions was: "The low cost and risk of HALE UAVs compared to manned airborne alternatives make this platform a logical choice for routine patrols" [6, page 14].

2.3. Detection and Tracking of Icebergs

After icebergs calve from Greenland's glaciers, they drift into the Baffin Bay and Labrador Sea and eventually follow the Labrador Current. While icebergs are a constant hazard for shipping in the Arctic, the cold Labrador Current carries some of them south into the great circle shipping lanes between Europe and the major ports of the United States and Canada. In this area the Labrador Current meets the warm Gulf Stream and the temperature differences between the two water masses produces dense fog. The combination of icebergs, fog, severe storms and busy trans-Atlantic shipping lanes makes this area one of the most dangerous.

The International Ice Patrol performs daily ice reconnaissance flights using Hercules LC-130 aircraft and they publish an ice bulletin with the "limit of all known ice". In order to be save ships in the vicinity must pass just to the south of this boundary [7]. HALE-UAVs equipped with radar sensors have the potential to make this regular service more cost effective.

Figure 3 Icebergs can be a danger for ships and need to be monitored

Also for polar and climate research in general it is of interest to trace the icebergs, because of their freshwater flux into the ocean [8]. It would be of high interest to track the icebergs along their most prominent routes with a HALE-UAV. Due to the bad weather conditions in these areas a wide swath SAR would be the instrument of choice. With high-resolution across track interferometry the volume of the iceberg could be determined and tracked over time.

2.4. Observation of Polynyas

Another phenomenon in the artic and Antarctic sea ice are the Polynjas, which are ice free regions (see Fig. 4). Although they cover only a small percentage of the whole sea ice area, they are important for physical and biological processes. In a polynja comparable warm water is in direct contact to the winterly cold atmosphere. The transport of heat and moisture exceeds that of the ice covered neighboring areas by one to two order of magnitudes. Polynjas play an important role in climate models and their life cycle needs better understanding and observation. This could ideally be performed even by a small HALE UAVs because the digital cameras and lenses required for this task weigh only some kg.

Figure 4 Polynyas play an important role in climate models

2.5. Monitoring of Polar Land Ice in the Arctic and Antarctic

About 90% of the earth's fresh water resource is stored in polar ice sheets, and only a small change in their mass has significant impact on global sea level. The necessary observables to assess the mass balance of ice sheets by means of remote sensing are

- Ice velocity
- Surface height of land ice
- Bedrock topography and basal boundary conditions of ice sheets
- Snow properties, snow accumulation and melting

The ice discharge of most polar glaciers to the sea is only vaguely known. HALE UAVs could be used to regularly monitor the ice discharge at the margins of Greenland and Antarctica. In order to accomplish this techniques similar to them described in the ICEDANCE mission proposal [9] could be applied to measure the glacier ice velocity by SAR interferometry.

In order to model the future behavior of polar ice sheets in warming climate detailed information on bedrock topography and basal boundary conditions below thousands of meters of ice is required. Ice thickness sounders on HALE UAVs could provide the necessary information with the required spatial accuracy. In addition, such systems could be used to map the internal structures of ice sheets, an important requirement to extrapolate single measurements from cost intensive deep ice cores to larger areas.

For the measurement of surface topography, systems like ESA's Airborne SAR Interferometric Radar Altimeter System (ASIRAS) [10] can be used on HALE UAVs. Snow properties can be monitored by polarimetric P-, L- and C-band radar using systems like the German ESAR of the DLR Institute for Microwaves and Radar.

Regular data download for all above mentioned scenarios is not critical as the HALE-UAV can loiter for the necessary time over a convenient ground receiving station, like O´ Higgins in Antarctica and Svalbard in the Arctic.

2.6. Atmospheric Research

High resolution (vertical, horizontal, and temporal) measurements over long range are necessary to explain physical and chemical processes in the atmosphere. These fine scale observations are extendable to global scale observations with HALE UAV technology.

- Stratospheric ozone chemistry: profiling of source gases, water, aerosols, and temperature in the mid-latitudes and Polar Regions
- Trop pollutants: profiling of pollutants and particles and their source emissions on regional to hemispheric scales from near the surface to the tropopause region.
- Water vapor and total water: profiling of water from the mid-troposphere to the lower stratosphere from the tropics into the mid-latitudes.
- Clouds & aerosols: profiling of cloud and clear sky environments (optical, composition, and microphysical parameters) to examine chemical variability of aerosols and direct and indirect chemical effects of clouds and aerosols.

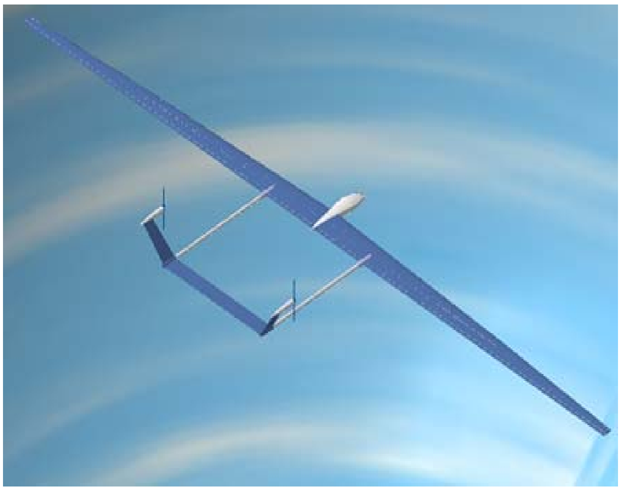
3. SOLAR HALE-UAV TECHNOLOGY

The roots for solar powered aircraft at DLR reach back to the year 1999 when the remotely controlled solar aircraft Solitair-1 (Fig. 4), which was designed and built by B. Keidel [11], flew over the Braunschweig airfield. In 2006 a DLR feasibility study for a solar powered HALE-UAV confirmed also the possibility of high altitude and long endurance flights with solar energy. One of the main findings of the study was that fixed wing as well as air ship HALEs have a great potential for application in the polar regions. While airships benefit from almost zero power required for static lift and almost any possible orientation of solar cells, they are hampered by large power requirements when higher flight speed is desired. Fixed wing aircraft are capable of higher flight speeds and thus can survey larger areas. On the other hand it is more difficult to integrate solar cells to exploit the low sun elevation angles prevailing in regions close to the poles. Current solar cell technology with its relatively low efficiency requires that a large area is covered by photo-voltaic cells. Due to the low air density at high altitudes fixed wing HALEs need large wing areas anyway, which provides a lot of space for solar cells. In polar region solar cells will especially be mounted below the wings in order to catch the reflected diffuse sunlight from the ground. In order to overcome cloudy days a HALE for polar region must have turn able solar cells (like the Solitair-1) or solar cells on the side of the fuselage.

Figure 4 Solitair-1 solar powered remotely controlled aircraft on the DLR Braunschweig airfield

All solar HALEs require a certain minimum size to carry a reasonable payload. For a typical payload of 100 kg, sizes range between 60 m wing span for fixed wing aircraft and about 80 m length for airships. A possible design is depicted in Fig. 5.

The feasibility of solar HALEs has also been proven in other studies and research projects, e.g. the ERAST program led by NASA, which culminated in the solar powered “Helios” aircraft [12]. A recent example of a manned solar powered aircraft project is the "Solar Impulse" initiated by B. Piccard in Switzerland [13]. The design shows the dimensions required to keep a payload of about 150 kg aloft by solar power. This Solar Impulse aircraft, eventually intended for perpetual flight, must have a wing span of 80 meters.



4.Figure 5 DLR design study of a SOLAR-HALE

For long endurance missions some of the power requirements for climbing to cruise altitude could be alleviated by applying unusual techniques, like towing the UAV behind an aircraft from a logistically suitable airport to an operational area like Antarctica.

4. CONCLUSIONS

During the polar summer solar powered HALEs have the potential to enable permanent and sustained scientific observations at remote areas and over long distances. Some sensor applications for such platforms could enable a revolutionary breakthrough for polar science, as e.g. for a continuous and complete mapping of ice dynamics, ice thickness, internal structure and basal boundary conditions of inaccessible ice sheets. During summer, the HALE-UAV could be used to observe important sea ice related processes and shipping routes. These aircraft will be completely emission free and therefore environmental friendly. In contrast to satellite technology new scientific instruments can come into operational use much quicker and in comparison to traditional aircraft the cost per flight hour will be reduced dramatically. The pilots will operate in save control centers and not longer endangered to get lost in extremely remote areas of the world. A study at DLR has confirmed that a solar powered flight is feasible, but to keep the aircraft in a reasonable size the first payloads must be light.

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