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# UNMANNED AERIAL COMMUNICATIONS PLATFORMS

ØSTBØ Morten

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Communications will be critical in a future defence concept that is based on rapid information gathering, dissemination and exploitation. All communications platforms will be considered high value targets. Unmanned aerial vehicles will be especially well suited for “dull, dirty and dangerous” communications missions. Service availability under all conditions is identified as the most important factor when considering different systems. Long endurance and high altitude are two commonly acknowledged ways to achieve this. The difficulties in developing platforms that can achieve both extreme altitude and extreme endurance within the timeframe of a few years are discussed. It is found that certain types of existing and emerging long endurance unmanned aerial vehicles are suitable for communications tasks, whereas current “tactical” and mini-UAVs are found to be unsuitable. It may prove costly to achieve system tolerance to losses with existing types of platforms. Other concepts aimed at achieving long single-platform endurance and system robustness to losses, using existing technology, are suggested and discussed.

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## CONTENTS

# UNMANNED AERIAL COMMUNICATIONS PLATFORMS

## 1 INTRODUCTION

Previous UAV- related work at the Norwegian Defence Research Establishment (NDRE) has focused mainly on UAVs as sensor platforms. The emerging view is that UAVs will become useful in a number of other applications as well. They may soon process, distribute and act on information and sensor data in addition to gather it. This poses new challenges and possibilities.

To achieve the level of connectivity between diverse and widely distributed ground, air and sea forces that is envisioned in future defence concepts, the information infrastructure needs substantial improvements. There are a number of different communications scenarios where aerial vehicles of some kind may be useful, be they manned or unmanned.

UAV systems that are well suited to perform these dull, dirty and dangerous, yet vital, tasks will need certain characteristics that UAV systems today largely lack. Some of these may be achieved using existing technology in a new way. New concepts are suggested and discussed. Among these is a new way of using atmospheric conditions to increase the endurance of existing and future UAVs.

Extreme altitude and endurance are considered desirable capabilities in relation to communications missions. Some important design aspects, challenges and ongoing research activities are discussed in this report. Communications payloads and concepts are also discussed.

## 2 ARGUMENTS FOR UNMANNED AIRBORNE COMMS PLATFORMS

Airborne communications platforms will in principle:

- provide a highly mobile and deployable infrastructure. The same infrastructure can support national and international operations alike. Parts of the infrastructure may be deployed abroad to take part in coalition operations with only partial degradation of capability at home.
- provide flexibility in functionality. Payloads may be exchanged quickly and inexpensively (as opposed to satellites).
- provide flexibility in coverage and bandwidth allocation when supporting mobile forces with varying communications needs (adaptive resource allocation)

  - not restrict the mobility of the forces they are supporting by requiring the users to set up and transport link equipment.
  - be able to provide a higher bit rate than geostationary satellites to users due to the much shorter distance (factor 1000).
  - increase look-angles compared to mountaintop relays and links, thus reducing the problem of obstructed line of sight.
  - reduce dependence on the satellite market, which will continue to be hard pressed the next decades to keep up with demands.
  - be harder to jam than satellites or stationary ground links, due to less predictability in location.
  - provide the possibility of introducing new technology in platforms and payload much more frequently than with satellites, due to lower cost.
  - be able to provide coverage to satellite "blind spots" and high latitudes.
  - be much lower cost than satellites (possibly factor 1:10).
  - enable a very high frequency reuse through cell division of coverage area. Thus available bandwidth is used more efficiently.
  - enable small ground/user terminals compared to SATCOM.

Arguments for unmanned systems in particular:

- Carrying pilots and life support systems reduces payload, manoeuvring, altitude and endurance potential for platforms.
- Communications infrastructure will be a high priority target for opposing forces. Thus, communications tasks will be high-risk, and should preferably be performed by unmanned systems.
- Communications tasks are potentially very dull.

## 3 MISSIONS

There are two main categories of communications tasks: point-to-point links and point-to-multipoint links. In most scenarios, communications services must be persistent and reliable. They should not restrict the operations that they are supporting. This means that they must be available over a sufficiently large area with as few "blind-spots" as possible, and whenever they are needed. Service availability must be a very heavy argument when it comes to UAVs as relays and nodes, especially in high intensity, high-threat scenarios for which the future communications infrastructure should be designed.

Platform(s) that supply communications services are not required to be at any accurately defined location. They may be "quasi-stationary", perhaps defined as staying within a cylinder several kilometers in diameter and height. This is a major difference between UAVs in communications missions and sensor missions. Sensor-carrying UAVs must often follow a very precise flight path. This extra degree of freedom presents new opportunities that are discussed in chapter 7.

The system must be configured to avoid terrain shadowing as far as possible. In mountainous areas there will always be communications shadows as seen from any given elevated point. The problem is greatest with high frequencies (which do not “bend around” hilltops or penetrate trees). The shadows become potentially larger the further away from the nadir (the point directly below the platform) we get and the lower the platform flies. Even a platform at 30km will leave shadows in most operations areas. Having more than one platform is the only way to get around this.

## 3.1 Point-to-point links

Limitations in line-of-sight (LOS) data links between UAVs and their ground control facilities have become obvious. In all but very flat operational areas (including open sea), system range is severely restricted by terrain obstructions ((26) and (17)). Point-to-point relay functions must be operational when Norway fields its first UAV system in 2008. Links that relay high data rate sensor data from one UAV to another or to a ground control station (GCS) are essential for mission flexibility and to secure real time data reception and near real time exploitation of these. Each UAV unit must have the option to deploy at least one platform to relay data during each mission. It is desirable to be able to deploy two during certain missions (9). To achieve 24/7 operations, this implies having at least three platforms available for relay functions for every sensor- or weapons platform that is deployed. The exact number will depend on desired link range and threat of loss etc.

Relaying data from the GCS to higher C4I echelons is another highly probable and important UAV application, as existing infrastructure has insufficient capacity and is not highly mobile (17).

Point-to-point links between moving platforms will require steerable high-gain antennas for receiving and retransmitting data. Data volumes will be high. Today, sensor data is on the order of 100Mbps, depending on sensor and platform. Data volumes will increase over the next few years due to increased demands from sensors and increased capability of data-links.

The operating conditions of air-to-ground links and air-to-air links will vary greatly. Atmospheric damping will be much stronger at lower altitudes than higher altitudes, and will vary with frequency.

## 3.2 Point-to-multipoint links

Flexible connectivity among many users may become an essential ingredient in future defence concepts. Availability and reliability may be more important qualities than data rate. It will be an important task to define information exchange requirements (IER) for a future (highly networked) defence structure. The amounts of data, number of users, quality of service etc are all still undefined parameters.

Improving tactical field radio communications coverage and mobility is one obvious near term application of UAVs. A single common node or an airborne network of nodes may connect thousands of users. The size of the desired coverage area depends on the operational scenario. “Hotspots” (areas with many users) may be connected via air-to-air “backbone” links (point-to-point). This type of “hotspot” application is the main focus of the current civilian HAPS (High Altitude Platform Systems) projects.

In an “airborne Internet” comprising many platforms, data will have many alternative routes between nodes, thus providing flexibility and robustness. Nodes may come and go in an ad hoc fashion. Data rates between nodes may be low compared to the dedicated sensor links. Still-images, voice and text are likely data forms, not live video. Such a multi-user ad hoc network may enable a common operating picture and rapid resource allocation.

It is important to emphasize the difference between this type of UAV application and the use of UAVs as dedicated relays for sensor-UAVs. Service must be available at all times dictated by the operations they are supporting. The UAVs will no longer be “accessories” to war fighters that we use when weather permits, but essential and integrated parts of operational doctrine. This means that UAV systems will have to be highly reliable and robust. It also implies that the “low cost” demand may be weakened, given that the value of information superiority and communications is emphasized more than it is today.

## 3.3 Combined communications-, sensor- and weapons missions

Combining the capabilities for communications-, sensor- and weapons-delivery missions in the same aircraft has obvious logistical advantages. Combining the three different tasks in one mission and one aircraft, on the other hand, may have some disadvantages.

Imaging sensors will many times require an exact flight path to obtain good imagery (due to e.g. sun angle, clouds, etc). In such cases there can be no compromises. If such a UAV were to have communications tasks as well, the sensor requirements will at times bring the UAV into a position that renders some communications users beyond line of sight. With few platforms in operation (a consequence of high cost which is again a natural consequence of multi-mission capability), there will thus sometimes be undesirable voids in the communications coverage. The alternative is less than optimal images, and loss of information value.

An aircraft’s capabilities are always a trade-off. If one expects a platform to perform other tasks as well as the communications task, then a larger payload capacity is needed as well as a sufficient power source. Increasing payload weight, power drain, and adding antennas will reduce endurance and altitude potential. Large payload capacity coupled with long endurance and high altitudes translates to an expensive and large platform. This again translates to few platforms being purchased. This results in little redundancy and less ability to avoid coverage blind spots.

The higher the platform flies, the less problematic it becomes to combine sensor and communications missions with respect to communications shadows (because the shadows become smaller with altitude). However, the higher a platform flies, the more critical light weight becomes to achieve good endurance.

An aircraft is usually very expensive, and so it has become common to desire “do-everything” aircaft. The result is often development programs that go on “forever” and produce less than optimal, yet very expensive, “super-platforms”. Given that airframes themselves are becoming potentially the least expensive part of a system, it may be time to explore other alternatives. Chapter 6 discusses an alternative concept.

# 4 PAYLOADS

Size, shape, weight and power requirements of payload components are major factors that decide which UAV platforms can accommodate a given communications capacity. Adapting suitable UAVs to specialized communications missions is routinely done today. The major questions are cost and interoperability.

Designing and selecting interoperable communications systems in a multi-nation alliance situation is expensive and time consuming. Designing airframes that can carry the given payload may be a small problem in comparison, provided extreme performance (e.g. very high or fast) or size (very large or very small) is not required. Extreme aircraft performance will lay restrictions on the communications payload that limit functionality and increase cost.

Any UAV system purchased should have a high degree of modularity, such that different payloads may be easily installed.  Communications capabilities should be implemented in small packages, rather than large boxes, for ease of installation and repair. Especially small UAVs lack large spaces inside, but there are often many small spaces that may be used.

## 4.1 Communications systems

The Norwegian MRR (Multi Role Radio) and the LFR (Light Field Radio) are highly probable payloads. Uniquely Norwegian communications solutions such as these will require a national initiative to specify and develop equipment for use on aircraft. Size-, weight- and power-wise they can be carried by small low cost UAVs.

Mobile GSM telephones and satellite telephones like the IRIDIUM are other candidates. The IRIDIUM is used in the Aerosonde during long flights at sea, transmitting low data rate messages and telemetry. Such systems will perhaps be more useful as UAVs employ higher levels of autonomy, and in small UAVs that produce small amounts of data. Base stations can easily be carried by medium sized UAVs, thus rapidly setting up a mobile network for voice and small data streams.

Such small relays may help to fill communications gaps left in the general coverage area of larger, high-flying communications nodes. They could also relay data from "over-the-hill" type sensor-UAVs.

The prospects of a UAV-carried TADKOM link are being studied (69). Such a capacity will strengthen the current infrastructure, and increase flexibility and mobility.

In order to be STANAG 4586 compliant, the first Norwegian UAV system must have STANAG 7085 compliant data links. In practice, this means one or several members of the CDL (Common Data Link) family of systems. These include the CDL, as used in the Global Hawk, the TCDL (Tactical CDL) which has been implemented in the Predator and Predator B, the MP-CDL (Multi Platform CDL) which will allow flexible connectivity between multiple airborne and surface components, the CDL-N, TCDL-N and the CDL-interoperable SUDL (Small UAV Data Link) which is used by the Shadow 200. Technical specifications for these systems are available on the manufacturers websites listed in the references section ((58) to (62)). Size, weight and power requirements and data rate differ substantially between a CDL and a TCDL/SUDL. Relay capability for these systems will be essential.

Other clear candidates are Link 16, Link 22 and IDM (Improved Data Modem, see (32) for details) for low volume data transmission capability. The two former have rigid message formats, and cannot handle images. The IDM has recently been demonstrated on a GA ASI Predator that transmitted still images to the cockpit of a fighter aircraft.

A SATCOM capability for higher volume sensor data will be an important "option". Availability of satcom is uncertain both due to terrain obstructions in high latitudes (low look-angle to geostationary satellites), limits in coverage and limited capacity. The very high cost of leasing civilian satcom resources makes it unlikely that this option will be used frequently in domestic operations. The capability will still probably be valued in international operations, where the ability to feed data to a joint exploitation system will be important.

## 4.2 Antennas

Antennas onboard most reasonably sized UAVs will be low-gain compared to the ones on the ground (Aerostats are an important exception in this respect, as they are very "unreasonably sized"). Receiver antennas at the GCS (Ground Control Station) are mostly on the order of one or two meters in diameter (parabolic). The diameter of an antenna on a typical MALE would be about 0,5m. An antenna with half as large diameter will give a link with half the range.

The lower antenna gain in the receiving airborne antenna will reduce range, but transmitting air-to-air above most of the troposphere gives less atmospheric damping. A specialized relay UAV may spend more power on retransmitting data than the sensor carrying UAV (e.g. a synthetic aperture radar is a large power drain). The total link performance must be studied more deeply when more system parameters are known.

Antennas may be mounted externally, internally or integrated in the airframe skin/structure of UAVs. Modern UAVs, sailplanes and some smaller commercial and sport aircraft are mostly made of composites. These materials will not shield radio signals substantially, depending on frequency. It is preferable to mount antennas internally, as the aerodynamic performance will not be affected directly (possibly indirectly if the centre of gravity is not corrected).

Antenna pods may be fitted straight onto the existing hard-points on available UAVs. The pods can be used for parabolic antennas that point in almost any direction. The antenna stabilizing and pointing mechanism and other aircraft structures will block certain pointing directions. This will set restrictions on relative positioning among nodes and individual airframe manoeuvring.

Any external antennas, pods and bulges will increase drag and therefore reduce endurance. The glide ratio of a Katana Extreme motor glider is for example reduced from 1:27 to 1:17 by the addition of a camera pod and a teardrop electronics pod (44). This means that the endurance is also potentially decreased by roughly the same factor ($17/27 \approx 0.6$). As a general rule, the larger the pod or bulge, the more drag. Careful design may reduce the problem. For very slow aircraft (i.e. on the order of 50-100km/h), this drag increase is not as important as for fast aircraft, as parasite/profile drag increases as the square of the velocity.

## 4.3 Frequencies

It is still unclear which frequency bands will be available to UAVs in Norway. No official steps have yet been taken to put this issue on the agenda in Norway (based on personal communication with frequency allocation officials). Decisions made by the ITU and NATO will set the premises for Norwegian spectrum allocation to UAVs.

Frequency spectrum availability, theoretical limits in information capacity for a given frequency and bandwidth, and atmospheric attenuation of higher frequencies will limit data rate growth much beyond 1 Gbps for point-to-point radio links. Frequency reuse through cell division of coverage area, highly directional point-to-point links, and DAMA (Demand Assigned Multiple Access) will be important methods to utilize the available spectrum efficiently. In a 15-year perspective, laser communications may become competitive and interesting alternatives to RF links (27).

Two 300Mhz wide bands around 47 GHz and 48GHz have apparently been allocated to HAPS by the ITU. There is a corresponding band around 28GHz in Asia. These very short wavelengths (about 6mm) permit smaller antennas with higher gain. Electronically phased arrays may be compact and flat. They may be structurally and aerodynamically integrated into the airframe (27). Arrays allow the coverage area to be divided into a large number of cells with a high level of frequency reuse (28). Such a concept is envisioned in civilian HAP projects like the Proteus HALOSTAR network and the European HELINET project. However there are some drawbacks to high frequencies. Shorter wavelengths are damped more strongly in the troposphere, high frequency electronic components (such as amplifiers) are more expensive, and antenna arrays for cell-divided coverage are hard to design without excessive inter-cell interference (28). Small cell size from antennas at very high altitude (20-30km) is more challenging and expensive than the same cell size from lower-flying nodes.

The migration towards higher frequencies and higher efficiencies in millimetre-wave amplifiers will make smaller UAVs candidates for more and more communications tasks. Lower weight and higher energy efficiency are also crucial to very high altitude and endurance flight.

## 5 PLATFORMS

Relays for sensor data on a dedicated single-mission basis are subject to the same requirements as the sensor platforms, with the possible exception of lower speed and range requirement. Platforms that provide vital connectivity in a networked defence concept are subject to much stricter requirements in terms of service availability. However it can be expected that tolerance to “weather-holds” will diminish for any type of UAV, as they become more integrated in military operations. Sensor, weapons and communications capabilities will all be relied upon whatever the flying conditions.

Such strong reliability of service may be achieved through extreme single-platform reliability and robustness, or by redundancy through numbers.

Wide coverage can be achieved by a few high altitude platforms (extreme case; satellites) or by many platforms at lower altitude (Figure 6.1). Persistence can be achieved by long endurance platforms or launching new platforms “all the time”.

In general, the choice stands between purchasing existing platforms “off the shelf” or specifying and developing new platforms (possibly domestically).  Platforms may be specialized communications platforms or multimission platforms. Each alternative has its advantages and drawbacks.

Multi-mission capability increases the cost of each platform and results in a compromised design. The platform will not be optimal for any single type of task, but its diverse abilities saves money and complexity overall.

It is very important that a communications platform does not become a restricting factor in operations that depend on it. Ideally, the means for communication should not be a concern to surface forces in combat. If a unit is in combat, it should get the required communications services regardless of weather. This is an argument against micro- or small mini-UAVs as communications carriers, unless they can be deployed by means that are weather-robust (e.g. rocket).

One way to get around the problem of weather with small or medium sized aircraft is to be able to postpone landings until weather permits. That means that the desired endurance is dictated by the statistical duration of “unacceptable weather”. It is suggested here that an endurance of about five days (120hours) is desirable to be able to exploit weather “windows”. In addition to weather delays on landing or take-off, possible delays in planned surface/user operations is included in the five-day specification. Shorter endurance is acceptable for aircraft with higher wind/weather tolerance, i.e. faster and heavier aircraft.

If platforms can relieve one another regularly without regard to weather, their individual endurance is less important. In a scenario where only one platform is available, long endurance is obviously important.

Solutions to certifications issues will without doubt influence the range of aircraft we may choose from, especially in the near term. Non-certification is a “show-stopper” for UAVs in most scenarios. It is partly a technological challenge, but just as much a cultural issue. The solutions that will emerge within the next few years will probably involve some hardware that requires a large platform. Large HALE or MALE (+) platforms will most likely be the first ones to be integrated in controlled airspace. The General Atomics Aeronautical Systems ALTAIR (Figure 5.1) is currently being used as a testbed.

*Figure 5.1 General Atomics Aeronautical Systems (GA ASI) Altair. The Altair is being used by NASA as a testbed for operations in controlled airspace. It is a modified version of the GA ASI Predator B (Photo: GA ASI).*

The ability to fly above all civilian traffic will also reduce possibilities for conflicts and accidents. In military applications, high altitude gives immunity to most or all existing anti aircraft missile systems. High altitude (and large size as a natural consequence) may be favoured for the above reasons. These are temporary advantages, though, as civilian air transport will no doubt occupy higher altitudes and sub-space within the next twenty years, and missile systems will emerge to challenge the new high-flying "Achilles heels" of the infrastructure. The only alternatives may be effective protection measures and redundancy through numbers. The first alternative weakens the argument that UAVs are "cheap and expendable".

HAPS (High Altitude Platform Systems) projects, as discussed in chapter 5.5, illustrate the current desire for extreme altitude and endurance in communications applications. The following section is a treatment of the challenges associated with achieving long endurance and high altitude flight. The discussion will lead to conclusions about the design of suitable and low cost military communications specialist platforms. Data on a number of selected platforms is included in APPENDIX B.

## 5.1 The challenges of increased endurance and altitude

Designing aircraft for one-week endurance is possible using today's technology. A good example is the Rutan Voyager (66) that flew around the world in a little over nine days. Universities and private projects are "almost routinely" constructing UAVs that can fly many days. This development has become possible with composite technology, computer tools and publicised research. A model aircraft was recently built by STAR (the Society for Technical Aeromodel Research) that crossed the Atlantic, from Newfoundland to Ireland. The 3000km flight took 36hours. This was achieved by a model weighing about 6 kg at take-off, half of which was fuel. The STAR TAM (Trans Atlantic Model) was built by amateur enthusiasts on a hobby budget. The previous Atlantic crossing made by an Aerosonde was backed with considerably more funds, yet with a platform that is itself very low cost.

Combining high altitude with long endurance, however, is more difficult (the Voyager flew most of the mission at around 5000m). The STAR TAM flew at about 200m. A good illustration of the effect on endurance of increasing altitude is found in the MAFV (Multi-Purpose Autonomous Flight Vehicle) Jabiru project at the RMIT Wackett Centre (Australia). Flying at 2600m gives 120 hours, or five days, endurance, while flying at 18000m gives only three hours. This is just one of many examples that illustrate the possibilities in building small, lightweight, modular and cheap aircraft that can stay airborne at low to medium altitude for up to one week.

The relevant equations for endurance are given in APPENDIX A. The ones given are valid for propeller driven aircraft. They will be different for jet-powered aircraft, but as jet power is not useful yet for very long endurance, this report will focus on propeller aircraft. From the equations, known as the Breguet equations, we may conclude that the following are desirable with respect to achieving long endurance:

1. A high lift-to-drag ratio. This can be achieved by careful airfoil design and by flying at the optimal velocity and angle of attack for the given airfoil and altitude. Low angle of

attack means low coefficient of lift, and requires a low wing loading, i.e. a light aircraft. The airframe needs to be very aerodynamically clean.

2. A small specific fuel-consumption (with respect to power).
3. A large propulsive efficiency factor. This is achieved with carefully designed, large diameter and slowly rotating propellers. The efficiency will vary with altitude and rpm.
4. A high fuel fraction. The Voyager had a fuel fraction at take-off of more than 70%. This means that the airframe itself has to be very light and strong. For the Voyager, the structural weight was only 9% of the total take-off weight.
5. Low altitude. This is linked to higher Reynolds number and propulsive efficiency. In contrast: long range favours high altitude flight at higher velocity (and therefore jet propulsion).

Low Reynolds number aerodynamics and efficient power systems are particularly challenging subject areas with regard to long endurance and high altitude flight, and to the combination of the two. These subjects will be discussed in the following sections.

### 5.1.1 Low Reynolds Number

LRN (Low Reynolds Number) is the central design driver for high altitude flight as well as for small and slow aircraft. The Reynolds number (Re) is defined in APPENDIX A. In qualitative terms, it expresses the ratio of the inertial forces to the viscous forces. The definition of a low Reynolds number is not absolute, but values below 500.000 are considered low. The root (or mean wing chord) length is the most common dimension used to compute the Re of an aircraft. Re varies over the entire airframe. Large aircraft operate in the range from $1x10^6$ to $1x10^8$. Model airplanes (and thus small UAVs) operate in the LRN range. Typical values lie around $1x10^4$- $1x10^5$. Most existing UAVs operate in, or close to, the LRN range, either due to small size, low speed or high altitude.

For high Re, the flow becomes turbulent easily. For low Re, the flow is more laminar – less prone to become turbulent. As a result, flow separation is a problem with LRN airfoils – so-called separation bubbles – which increase drag substantially.

Thus an aircraft that operates in the LRN-range is usually less aerodynamically efficient. This is well illustrated in model aircraft. If e.g. a sailplane is modelled exactly to scale (usually around 1:10 to 1:4), using the exact same airfoil shape, the scale model will perform much worse than the original. All commonly used HRN (High Reynolds Number) optimised airfoils have poorer efficiency factors at LRN. In the case of a model sailplane, the glide ratio may be less than one third that of the full size sailplane (example observed with a large sailplane model; 1:13 compared to 1:50). Small, slow or high-flying aircraft must therefore use different airfoils than large, fast and low flying ones. In addition, LRN aircraft must compensate for the low efficiency by having a much lower wing loading (W/S). The failure to do this is one of the reasons for the very poor endurance (around 4-8 hours) of so-called ”tactical UAVS”, or TUAVs.

LRN aerodynamics is still a field with many unknowns. New LRN airfoils are improving continually. This means that airfoils used today are inferior to those available five years from now. The opportunity to use state-of-the-art airfoils is important.

The operational range for good LRN airfoil performance is still narrow. Small changes in velocity, air density or angle of attack cause the lift-to-drag ratio to drop significantly (this seems to be the problem with the U-2, which must maintain its airspeed within a 5-knot range between stall and the transonic). LRN aircraft must therefore operate at, or very near to, the design point if good endurance is demanded. This means that LRN, long endurance aircraft will be less flexible in payload weight, airspeed and altitude than general aviation designs.

Analytical solutions for LRN flows are difficult to obtain (At higher Reynolds numbers, the Navier Stokes equations can be simplified to produce the Euler equations in potential flow theory). Practical tests are today the most important method for improvement. Wind tunnel data for LRN are still sparse. This is due to the difficulty in recreating a flow field without the small-scale turbulence that is common in wind tunnels. This small-scale turbulence is important in boundary layer (the region of viscous flow that has been retarded due to friction at a surface) dominated flows, which is the case with LRN. Flight-testing therefore becomes an important source of data. This is costly and time consuming, which is why there is not a large amount of data available yet. The NASA APEX project (52) studies airfoil performance at LRN using an adapted “American Spirit” sailplane. It has been equipped with especially designed wings with custom airfoils, and will be dropped from a balloon at 33 km altitude.

As a note – a high performance sailplane with a glide ratio of 1:50 (meaning that it drops one meter for every fifty it moves forward in the air-defined reference system) will glide more than 1000km from this altitude in still air. Deployment of cheap, non-motorized sailplanes from balloons could be an interesting alternative. Combined with techniques described in chapter 7, they may cover great distances and remain airborne for several days.

Boundary layer control techniques, such as vortex generators, turbulators, suction or blowing are the subject of research, and have already been implemented for some time. The “zigzag” tape is the most common, often used on sailplanes to trip turbulent flow in order to prevent separation bubbles on the upper surface. Changing the airfoil shape during flight is another interesting possibility.

### 5.1.2 Power

As airspeed increases, a greater portion of the total power budget is spent on propulsion. The power required to remain airborne increases as the cube of the velocity (8). Long endurance therefore favours slow flight. The power required to maintain level flight also increases with altitude (APPENDIX. FORMULAS).

It is important to note that the flight condition that gives the maximum endurance is not the same as the flight condition for maximum range. Maximum endurance aircraft will be slower than aircraft designed for range. This will influence choice of airfoil, structure and power plant.

For small and lightweight aircraft, the payload may be the greatest “power drain”. A study performed by the NRL (Naval Research Laboratory) (8), LAURA (Low altitude/Airspeed Unmanned Research Aircraft (1985-1990)), analysed several different configurations of small, piston-engine UAVs with respect to endurance. Several configurations in this study would have achieved more than 70hrs on one gallon of fuel (3.8 litres), and with a 4,5 kg payload. By replacing an inert payload with one that required twice the aerodynamic power (which is typically about 100 watts per kg for small aircraft), the endurance was reduced from 70 to 20hrs. The Aerovironment SeaScan can theoretically achieve about100hrs with a 1kg payload that requires 10 Watts. Replacing this payload with one that requires 70 Watts reduces the endurance to about 60 hours (Figure 5.2). This clearly illustrates the importance of low power consumption if long endurance is desired.

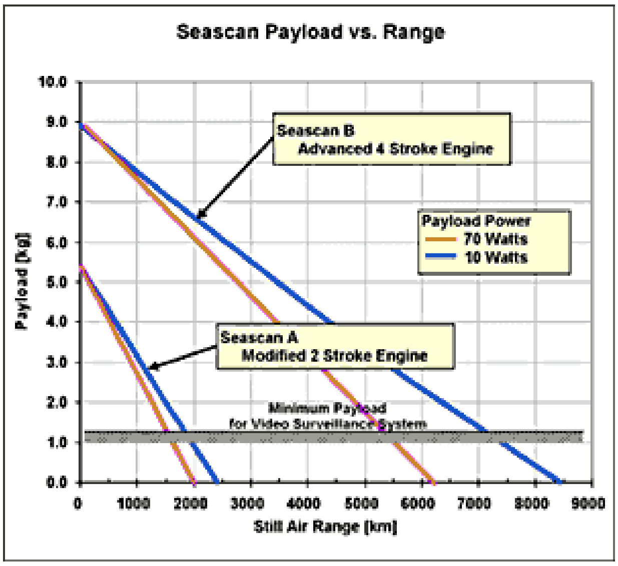

*Figure 5.2 Range vs payload for the Insitu Group SeaScan A and B.The figure illustrates the effect on range (and thus on endurance also) of increasing the payload power requirement (Reproduced with permission from The Insitu Group).*

Due to thinner air at high altitude, very high ratio turbo charging (which drains fuel and adds weight) is needed in ICEs (internal Combustion Engines). In addition to lower propeller blade efficiency (analogous to the wings lower lift-to-drag ratio), this results in high altitude flight being hard to combine with long endurance.

It is questionable whether purely solar powered aircraft will be operable over Norway due to our much lower solar irradiance, especially during winter (21). Solar cells will still be useful in providing power to charge batteries and drive payloads. Thin sheets of solar cells weigh less than 500g/m$^2$, and may be integrated in the aircraft structure. A small or medium sized aircraft will have a wing area from 10 to 20 m$^2$ (a sailplane has about 17m$^2$). Covering the entire wing will give a weight addition of up to 10 kg, and a power supply on the order of 1 kW (efficiency 20%, I=500W/m2). A new type of monochrystaline solar cell may produce as much as 3kW.

DARPA and Aerovironment have tested a very light and compact fuel cell system in a "Hornet" MAV of 38 cm span and 168 g takeoff weight. Even small UAVs may therefore soon benefit from employing fuel cells.

Triggered Isomer Heat Exchanger (TIHE) is a new propulsion concept that is being studied (4). By using X-rays to trigger transitions from higher to lower energy states in e.g. Hafnium 178 (one of several materials considered) a great energy gain is achievable (60:1). Radiated energy can be used to heat gases in a turbine, which may also use normal combustion in parts of the mission. This is not a nuclear reactor, and there is no particle radiation. High levels of gamma-radiation will however prohibit its use close to humans. To shield electronics onboard a TIHE-equipped aircraft, a heavy lead shield is required. The system, including the turbine engine, will initially be large and heavy, and thus not applicable to small aircraft. Even so, for an aircraft the size of the Global Hawk, it is estimated that mission durations of several weeks will be possible.

In the short term, small and efficient ICEs (Internal Combustion Engines) are preferable due to low cost and high reliability. In the next 10-20 years, fuel cells will increase their usefulness and efficiency, and become cheaper. A combination of fuel cells, structurally integrated solar cells, an efficient ICE and "smart flying" as described in chapter 7 may be a medium- to long-term solution to extreme endurance designs. A more in-depth study on the potential of solar and fuel cell power in UAVs in high latitudes is desirable.

## 5.2 Long endurance design conclusions – LALE / MALE

From the above discussion, we see that, for long endurance aircraft, the mantra is **"**low, light and slow**"**. A new designation may be introduced – LALE (Low Altitude Long Endurance. Low altitude is defined here as below 5000m). Enforcing a demand for high altitude and extensive payloads will decrease endurance potential and increase cost significantly. A "low MALE" or "High LALE" at between 5000m and 10000m may be the optimal solution to reduce vulnerability to SAMs (Surface to Air Missiles), reduce icing problems, and maintain the capability of extreme endurance.

The aircraft will be of medium size (from 10m to 20m span and 1m root chord) to avoid very low Reynolds numbers and thus inefficient wings. Some size also results from the desire to carry a useful payload, and still retain a low wing loading. Desire for higher altitude is more easily met with large chord lengths also. Too large an aircraft, however, will be difficult to handle, stow and transport and possibly too expensive. We end up with aircraft in the general size range between an Aerovironment SeaScan and a GA ASI Predator B. Final size will depend on the application.

A LALE UAV, and any other LRN aircraft, will fly within a narrow speed range. Small changes in airspeed or centre of gravity may have a significant effect on the aircraft endurance due to the need for trim adjustments and subsequent drag increase (an aircraft that flies along with e.g. the elevator in constant up or down will create more drag than a neutrally stable aircraft.).

The optimal designs will have high aspect ratio (the ratio of the square of the span to the wing area, $b^2/S$) wings (this means “long and narrow”) and slender, sleek fuselages (if not a flying wing). High aspect ratio, elliptical planform wings have the best lift-to-drag ratio. Smaller aircraft designed for LRN operation will have more rectangular wings to avoid low Re at the tips (low efficiency and tip stalling problems) and to simplify construction (thus saving weight and cost). They will have state-of-the-art LRN airfoils.

If the aircraft is fuel burning, as much as possible of the take-off weight should be fuel. The structure in general therefore has to be very light, and also stiff to avoid aeroelasticity problems (bending and twisting). Payloads will have to be a small percentage of the total weight (around 10 percent). Engines will be efficient piston engines for the coming decade still. Fuel cells and solar cells will gradually (10-20 year perspective) become competitive compared to combustion engines (ICEs). Structure and function will merge, for instance by having solar cells, energy storage and antennas be integral parts of the structure.

Modularity will be important, in order to be able to implement technological advancements, use COTS components, and for ease of repair.

The following section discusses some of the types of aircraft that can be adapted for communications missions, in light of the theoretical background from the above section.

## 5.3 “Traditional” UAVs

Advances in composite technology and aerodynamic design mean that unmanned aircraft are easily adaptable to many requirements. Completely new airframes can be developed very quickly given a set of requirements. Several projects have demonstrated that airframe development costs are a small portion of total system development costs (10% in the case of the Aerosonde).

Smaller UAVs naturally give less flexibility in payloads that can be carried. An advantage is that “backpack” or slightly larger “man-portable” systems can be quickly put together using mostly COTS equipment at low cost. Large numbers can thus be acquired, and platforms may be expendable – an advantage in many operational scenarios. An alternative is to deploy such small or micro-UAVs by means of rockets, cruise missiles, or from other aircraft on demand. The users themselves would not need to carry any equipment, but request relay, sensor or weapons “effect” from other units. The key is that the users can count on the services being delivered, and focus on the mission at hand.

Existing medium to large sized UAVs are suitable for a wide range of communications tasks. The combination of several-day endurance potential and relative tolerance to harsh weather makes them functionally adequate. Their large payload capacity will make them very flexible with respect to the range of different uses. Platforms may alternate between sensor-, weapons- and communications roles, and a single logistics system could be used. Purchasing “extra” platforms that are close to identical to the sensor-platforms is in this sense a practical alternative.

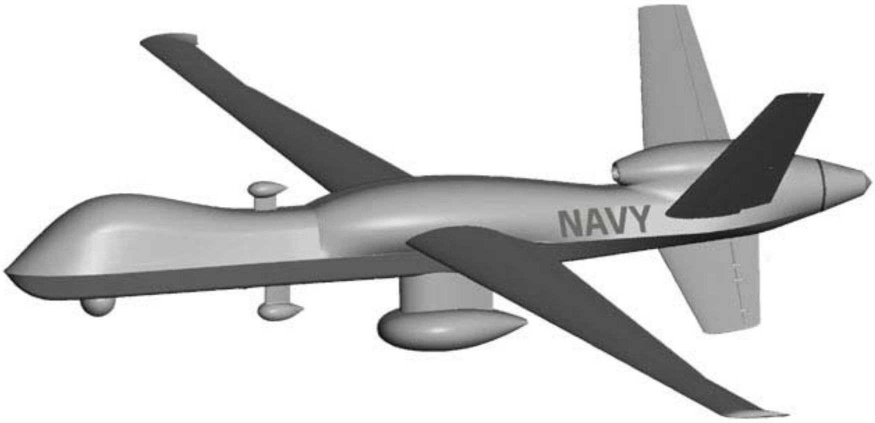

*Figure 5.3 General Atomics Aeronautical Systems (GA ASI) Predator B-ER (Extended Range) is a study for a NAVY BAMS (Broad Area Maritime Surveillance) platform. It would be well suited for heavy communications payloads. The pod below the fuselage houses a maritime synthetic aperture radar (SAR). The small pods contain line-of-sight links for communications relay. The large bulge above the nose houses the SATCOM antenna. The bulges above the wings are conformal fuel tanks. (Photo: GA ASI)*

*Figure 5.4 General Atomics Aeronautical Systems (GA ASI) I-GNAT has an exceptional endurance of 52 hours, which is possible due to a relatively light payload (90kg). It is suitable for a number of communications missions. The Predator is based on the I-GNAT, but sacrifices some endurance for a heavier payload and a large SATCOM bulge (Photo: GA ASI).*

The high cost of MALE and HALE platforms makes it questionable whether enough platforms can be acquired to guarantee service availability and robustness to the inevitable losses. After the initial losses have occurred in a conflict, the lack of individual platform endurance will be a serious drawback. This might not be a serious concern in international operations if the total participating number of platforms from many nations provides enough redundancy. However, if a single nation is expected to provide all UAV capability within an area, sufficient redundancy must be guaranteed. With existing "off-the-shelf" HALE and MALE platforms, this means perhaps multiplying the total cost of a UAV system by two or three.

Current HALE and MALE platforms are seriously over-dimensioned for some tasks with respect to powerplant and structure. They would therefore not be highly cost-effective in all communications mission types. The logistical savings achieved might however partly weigh up for the fact that the platforms themselves are "overkill" for the job.

Communications solutions will shortly be available for "off-the-shelf" platforms like the Global Hawk and the Predator. Thus, although expensive, these will represent a ready, interoperable solution that can be "plugged" directly into international/allied operations and be familiar to allied forces personnel.

Current "tactical" UAVs have some of the same drawbacks and strengths as the larger UAVs mentioned above, but lack payload capacity and altitude potential. They are severely hampered by weather, have very poor endurance, yet they are expensive enough to prevent the purchase of a large number. Currently existing TUAVs are probably the least efficient platforms to use in communications missions.

Given a design that is aimed at carrying a light load, a small to medium sized light aircraft will have a potential of staying airborne for more than one week. As outlined in chapter 7, their endurance can be extended to several weeks in some cases. Having a small to medium sized airframe specially designed or adapted to suit specific needs may be economically interesting. The cost lies mainly in other system elements, but platform cost will rise rapidly with size and complexity. Keeping each platform simple is therefore important.

The SeaScan (Figure 5.5) and the ScanEagle (a militarized version of the SeaScan) from The Insitu Group and the Aerosonde (Figure 5.6) from Aerosonde Ltd, Australia, are close to satisfying the requirements for LALE communications platforms. The ScanEagle is a militarised version of the SeaScan, developed in cooperation with Boeing. These are all low cost platforms with multi-day mission duration potential, and are available for purchase. ScanEagle will be able to fly for three days and 8000km. It is planned to cross the Pacific in 2003. It was used in the US NAVY exercise "Giant Shadow" as a communications relay. The Aerosonde was the first UAV to cross the Atlantic (1998). No runway is required, and wind is not a problem, making these LALE platforms suited for shipboard operations and field operations in wooded and mountainous areas. Currently, a great deal of experience with the

Aerosonde in arctic operations is being gathered in a science mission in Barrow, Alaska. The Aerosonde has also successfully flown as an EPLRS (Enhanced Position Location Radio System) communications platform in a multiuser network.

*Figure 5.5 The Insitu Group SeaScan is a good example of a LALE UAV, capable of multi-day missions with light payloads. (Photo: The Insitu Group)*

These small UAVs are limited to altitudes below 3000m (roughly) because of their small size (Low Reynolds Number). A single platform will therefore not provide a large coverage area, may be easier to bring down by enemy fire and may be more susceptible to icing. But their endurance and low cost will make them a very flexible alternative for some communications tasks. They are especially interesting in a multi-platform concept.

*Figure 5.6 The Aerosonde Ltd Aerosonde is another LALE UAV which has been used extensively in science mission in arctic conditions. It has also crossed the Atlantic. (Photo: Aerosonde ltd.)*

## 5.4 Sailplanes

Modern high-performance sailplanes may easily be modified for unmanned operation. These are the most aerodynamically efficient designs available, and they satisfy most of the design criteria outlined in chapter 5.2, with the exception of a high fuel fraction of course. Exchanging pilots and water ballast with avionics, payload and fuel, these platforms will achieve very good range and endurance. As an example, the Stemme S10-VT (39) achieves a range of 1700km in still air, and may cruise under constant power, thanks to the front-mounted prop. Claus Ohlmann used the S10-VT on the record distance flight of 2463km and 14 hours over the Andes. An unmanned surveillance version of the Stemme is under development – the Stemme S15-8 (Figure 5.7). The S15-8 has wing-pods for sensors and antennae, and will be certified for manned operation within two years (uncertain). The unmanned version will follow. This may be a low-risk platform with which to develop concepts of operations for communications- and sensor platforms in the near future.

*Figure 5.7 The Stemme Flugzeugbau S15-8 motorglider is currently under development for surveillance and communications relay missions. Stemme aims to have it certified for manned operation within two to three years, and for unmanned operation after that (Photo: Stemme).*

Motorized gliders are usually not designed for constant powered cruise (with the exception of the Stemme S10-VT). The propeller is deployed above and behind the cockpit (Figure 5.7) and produces a large amount of drag. The glide ratio of a DG1000-M will be reduced from about 1:50 with the propeller stowed to about 1:15 when the propeller is deployed. For these designs, a “saw-tooth” technique is recommended, using the engine in short bursts to gain altitude when needed. Using this technique, ranges of over 500km are achieved in still air and on 20 litres of fuel. Service ceiling is usually around 10000m under power. As discussed in chapter 7, considerably higher altitudes may be reached. This potential may be most safely and easily achieved with unmanned sailplanes.

*Figure 5.8 The Lange Flugzeugbau Antares is a very high performance electrically powered sailplane. The engine folds into the fuselage behind the cockpit when it is not in use. Sailplanes using this engine configuration must use the engine in "bursts" to gain altitude when needed. Flight with the engine deployed is very innefficient. When the engine is stowed, such sailplanes achieve extremely efficient flight (Photo: Lange Flugzeugbau).*

Carrying extra fuel instead of pilots will enable "engine-on" ranges beyond 2000km and endurance up to one day (24hrs) in still air. Airspeeds will be around 80-100km/h when maximizing endurance. Maximum airspeed is around 300km/h. Electrically powered versions are available. Examples are the DG808E and the Lange Flugzeugbau Antares (Figure 5.7). These have been developed mainly to satisfy requirements for low noise, but also have the added benefit of very low maintenance requirements. Unmanned versions could be serviced very quickly, perhaps only requiring a battery change, and then re-launched within minutes.

Modern sailplanes are built using mostly composites. Undercarriage, avionics and propulsion units are the only metal parts. Small antennas, with diameters up to 0.5 m may therefore be integrated inside the fuselage without aerodynamic penalty. Any external antenna pods will reduce the above outlined performance figures. For example, the S15-8 with pods has a glide ratio of 1:41, whereas most high performance sailplanes without pods have about 1:55.

The cockpit area will provide plenty of space for payloads, avionics, actuators and fuel once the seats and other control hardware are removed. Already many designs offer optional wing fuel tanks. The total weight of the payload and fuel will be on the order of 200-300kg. The payload could comprise a small power generator, communications electronics, antennas, solar cells, surveillance sensors etc. Modification is uncomplicated due to the open and accessible cockpit area, which is also very sturdily built for crash protection. All sailplanes can be easily dismantled, folded and stowed in containers.

Scale sailplanes are interesting low-cost alternatives that may be employed in large numbers. They are practical to experiment with, and easy to handle. They may be launched using towplanes, winches, small balloons or rockets, even from wooded or mountainous areas. They are cheap enough to accept a higher rate of loss, and thus realize one of the original arguments for unmanned aircraft.

Folded sailplanes in canisters carried by a “mothership”(e.g. balloons, airships or cargo planes) is another idea. The desired number and type could be deployed on demand and far from hostile area. Much like the Mars flyer concepts studied by NASA (50). Rockets could also rapidly deliver long-loiter sailplanes to areas of interest.

A 7m span sailplane may have a maximum take-off weight of about 30kg, and an empty weight of about 15 kg. It is thus capable of carrying 15 kg equipment and fuel. Altitude restrictions when remotely controlled are today based on visual range, but unmanned version should be able to fly at around 3000m. Such small sailplanes will be very hard to detect due to composite construction and low heat radiation. Even at very low altitudes (200m), they are virtually impossible to spot without knowing where to look. They may thus make low passes or fly on ridge lift without being noticed. A slight “whizzing” sound is the only thing that may betray them when they are straight above an observer.

Modern full size sailplanes cost from about NOK 1 million to 2 million. Used high performance aircraft can be obtained for about NOK 300.000 and upwards. Unmanned versions will probably at least double the cost. Scale sailplanes with high altitude potential may cost on the order of NOK 100.000. A Norwegian prototype demonstrator is under consideration by a private group, and may be completed within one to two years if funding is found.

Using the techniques outlined in chapter 7, sailplanes may indeed make flight of several weeks possible without dependence on solar irradiance. The techniques would also possibly make the use of solar powered aircraft, like the Aerovironment Helios, useable in high latitudes by maintaining altitude in times of solar energy deficit.

## 5.5 Developmental and research air vehicles

A new generation of aircraft will emerge within this decade (so-called HAPS - High Altitude Platform Systems) that will provide new possibilities. Stratospheric balloons and airships (both of the category aerostats), and a few aerodynes are promising. The vision is that these platforms will loiter high above cities and provide telecommunications services to thousands of users on the ground. The higher they fly, the greater the service area. The common definition of high altitude is from 18km to 30km. Compared to satellites, this concept will be much cheaper (factor 10. Source: various press releases on the Internet), and provide potentially about 1000 times the data rates to each user (given the same equipment and transmitting power). This is based on a shorter propagation path.

What is new is that these platforms are supposed to stay aloft in roughly the same spot for a very long time (preferably months. The optionally piloted Proteus (66) can only stay airborne for about 13 hours, but three aircraft will provide continuous coverage). This allows a few platforms to service a given area, and very modest ground infrastructure and handling needs. This concept breaks new ground in aviation. What is happening is a very significant increase of the flight envelope in terms of high altitude, low speed and long endurance.

Until today, military needs have been the strongest incentive for UAV development. This market will most likely continue to grow. The (civilian) science community has been calling for the development of research platforms for several decades already. Their needs have not yet been met. The combined effect of the increased military and civilian interest in UAVs and HAPS may be that development accelerates. HAPS systems will most likely be available for purchase by 2008, when the first Norwegian UAV system is to be operational. The cost is still an open question, but it will have to be competitive compared to terrestrial infrastructure and satellites. A cost of roughly one tenth of a satellite is likely for a national system comprising a handful of platforms.

The developmental aircraft can be roughly divided into two groups, the aerodynes and the aerostats. Aerodynes use aerodynamic forces to develop lift. They are thus dependent on the relative motion of airfoils in a fluid (air). Aerostats depend on buoyancy for their lift. Aerostats represent the area of HAP development with by far the most participants.

### 5.5.1 Aerodynes

The flights of the NASA ER-2 into the Antarctic Vortex resulted in the first set of data that speaks for a link between CFCs and the thinning of the Ozone layer (18). “The mission also showed the performance limits, high cost and risk to aircrew associated with using manned aircraft for this mission”(18). ERAST (Environmental Research Aircraft and Sensor Technology(53)) was established in 1993 partly as a result of the needs of the science community. The goal was to develop both sensors and platforms for use in atmospheric studies. Three platform types where to be developed:

- Ultra-high altitude, short duration
- Heavy-lift, long duration for medium altitudes
- Solar-powered aircraft for extremely long duration with small payload

The first was to result in the Perseus project, and the last the Helios. Over USD $100 million had been invested by the end of 2001 (18), and ERAST has resulted in a number of projects: the Perseus A&B, Pathfinder, Centurion, Helios, GNAT 750 (now offered by GA ASI in the I-GNAT version), Raptor (designed by Burt Rutan), APEX and Altus. These projects have increased the understanding of LRN aerodynamics and long endurance flight. More than USD $70 mill has been spent on the solar powered Helios (Figure 5.8). The Helios has demonstrated that the goal of sustained (more than 6 months) flight at 30km is attainable. The recent apparent midair breakup and subsequent crash does not mean the end for the concept, but does prove that there is some way to go before operational systems are available.

The HELINET ((51) and (35)), the QINETIC ZEPHYR (54) and the DARPA+Boeing ULTRA-LEAP (57) are groundbreaking HAP projects that aim to have prototypes flying within a couple of years. The HALOSTAR (42) is perhaps the most well known project, although it is not in the same “extreme endurance league” as the others mentioned. It is based on the optionally piloted Rutan-designed Proteus and is presently ready for commercial or military application.

*Figure 5.9 Left: The Boeing and DARPA ULTRA-LEAP. Right: The European Helinet Consortium Heliplat. These are examples of High Altitude Platform (HAP) projects that are exploring extreme altitude (30km) and extreme endurance (several weeks to several months).*

Despite the large sums of money that have been spent during the past ten years in the ERAST project, rivalry between differing interests has hampered progress (18). The tools to supplement satellite based, ground based and manned aircraft based sensors for atmospheric studies are still not available. Manned aircraft and existing UAVs do not fly high enough (with the possible exception of the ER-2 and the Russian M-55), and are far too expensive for the science community to charter. Only very limited data series may be obtained. What is needed is continuous, simultaneous and more widely distributed samples. Low cost platforms with high altitude capability and long endurance, irrespective of time of year or geographical location are essential. The Aerosonde and the RMIT Jabiru are examples of unmanned aircraft that have been developed (other than the ERAST platforms) especially with atmospheric science applications in mind. They are both low cost, long endurance platforms. They do not, however, offer the high altitude that is required. This is an illustration of the fact that the high altitude regime is still inaccessible to science communities and military forces on low budgets.

The National Science Foundation has recently bought a Gulfstream V for USD 70million. Still, the scientific market is probably very large.

The political and popular interest is not currently focused on environmental research. The much discussed climate changes have not shown themselves dramatically yet, and other matters seem more urgent. However, the need for knowledge is as great as ever. Providing the means for research will become a considerable market sooner or later. Knowledge of the Earth system is essential both with respect to resource management and military operations. Very small relative changes affect conditions for life significantly. Conflicts over recourses will most likely become more common in the decades and centuries that lie ahead. Defense and security issues will therefore be linked closely to scientific issues. This warrants further interest in the development of HALE UAV technology.

*Figure 5.10 The Aerovironment and NASA Helios is the first to demonstrate that 30km altitude flight for many months is within reach. (Photo: NASA)*

### 5.5.2 Aerostats

Driven by the prospects of competitive communications services, atmospheric research and planetary exploration (Mars), there are now a number of development projects underway to produce high altitude, long endurance airships and balloons. The performance envelopes of aerostats are being pushed towards significantly higher altitude and longer endurance.

The new generation of airships (e.g. the ATG StratSat (65)) will operate at around 20km altitude (to exploit the wind velocities minimum there), and remain airborne for several months or years. Balloons may fly even higher (30km) due to the lack of propulsion systems, and they have comparable endurances. The actual endurance will depend on the ability to provide power and on the rate of wear and degradation of materials.

A number of companies are involved in what has become a race to produce the first and least costly operational system, and thereby capture the awaiting market. Thanks to recent improvements in materials technology, solar power, fuel cell technology and more, aerostat HAPS are feasible within a few years. Prototypes will be flying this year. Prospective customers must specify their needs before concise cost estimates can be given. A cost of USD 2.5 billion is estimated for a worldwide system of 250 Sky Station platforms. One NASA ULDB (Ultra Long Duration Balloon) is said to cost USD 500.000 (uncertain Internet sources).

A major plus for large aerostats is their large payload capacity – on the order of 1000kg-4000kg for an airship about 150m long and 60m in diameter. Balloons have similar payload and size figures. The NASA ULDB (64) (Figure 5.11) is designed to stay airborne above 30km with a 2000kg payload for more than half a year. A network of several hundred such balloons (smaller versions with 250kg payloads) is envisioned to encompass the Globe (Figure 5.12). The Global Aerospace Corporation StratoSail TCS (Trajectory Control System, (63)) will provide a certain ability to control the trajectory. The TCS exploits the difference in windspeed at different altitudes by suspending an airfoil in a very long cable below the balloon. With a network of balloons, it will then be possible to control the distribution somewhat. A constellation of 400 StratoSat stratospheric balloons is estimated to cost USD 160 million.

*Figure 5.11 NASA ULDB (Ultra Long Duration Balloon). (Photo:NASA)*

The StratoSat concept may be especially interesting in a multi-national scenario, since the platforms will be following the general hemispheric circulation when deployed (and therefore overfly many nations). Such a network could provide e.g. the United Nations with a global communications and surveillance system with large capacity (due to large payload and power potential and high altitude, low damping environment). The potential for scientific use, e.g. in situ sampling, would be great.

Most of the aerostat designs employ large solar cell arrays for power supply, in different combinations with diesel generators, fuel cells and batteries. No known project has considered operation further north than 45$^{o}$N.

Aerostats are cumbersome on the ground, requiring calm wind conditions and large hangars. Given long enough endurance, this need not be a big problem. The aircraft would only have to be handled very seldom, and launching may take place far from the operational area.

The vulnerability of aerostats is another possible drawback. Their large size and fragile low-weight materials make them easy to bring down. However, damage apparently rarely ends with catastrophic failure, and the aircraft can most often be brought down safely.

Steerable directional antennas may be put inside aerostats for better aerodynamics. Very large antennas are possible in airships and balloons. Together with the high payload capacity and power supply, aerostats offer the greatest flexibility in types of communications payload, and they offer the greatest potential in data-throughput capability and long range.

HAPS or other long endurance and/or high altitude platforms will provide the opportunity to contribute to long-term scientific studies and resource management as well as provide civilian communications services in times of peace. A wartime capability may thus be partially financed in peacetime through selling services, at the same time generating a positive image through media coverage.

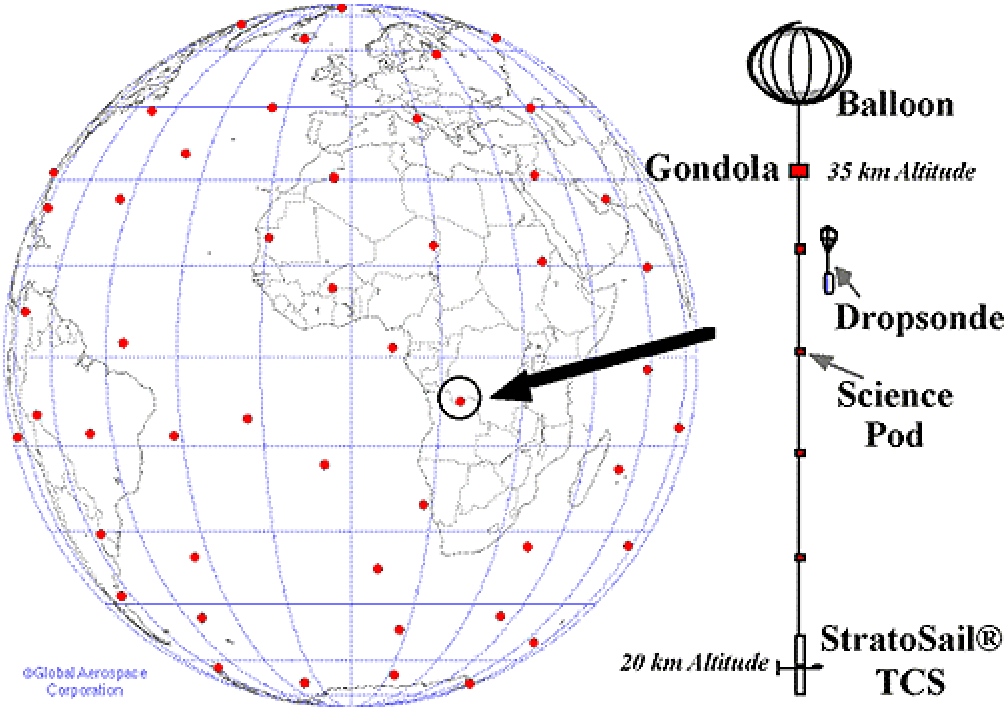

*Figure 5.12 A global constellation of statospheric balloons may be a multinational alternative. The Trajectory Control System (TCS) is suspended below the balloon, and will give a certain ability to influence flightpath. (Figure: GAC(42))*

## 6 MULTI-PLATFORM SYSTEMS

Having established that it is much easier to achieve good endurance with designs that follow a “low, light and slow” philosophy, it may be an alternative to replace single heavy platforms with several lighter ones. The effect would be a UAV-team with the same payload capabilities as the single platform has, but with much longer endurance.

Multiplatform networks would represent a step towards a new control paradigm chacterized by high levels of autonomy. A development away from operator “micromanagement” may be on the way. The concepts discussed in this section are illustrated in Figure 6.1.

## 6.1 Concepts

There are several different ways in which the job of a single platform may be divided among several cheaper ones. As an example, the job of one MALE may be performed by three platforms - one with a SAR, one with an EO/IR sensor ball, and one with SATCOM and other data links. Such a UAV team is illustrated in Figure 6.1 Multi-platform and UAV-team concepts as discussed in chapter 6. The three platforms may fly at the same altitude and achieve the same sensor/payload coverage but significantly better endurance. They may fly higher (HALE), giving up some of the endurance gain for better payload coverage, but may still be less costly than a single HALE. Or they may fly lower (MALE/LALE) to achieve much better endurance (on the order of one week) at the expense of payload coverage and with greater risk of being shot down.

They could communicate in a WLAN, and could fly very close to- or within a few kilometres of each other. Flying in a V-formation, fuel savings may be possible.

Stipulating a unit platform cost of less than one third of one Predator B is not unrealistic. A production sailplane costs about NOK 1 mill. A unit cost after modification for autonomous operation and multiple platform coordination of less than NOK 10 mill is not unlikely. A Predator B platform costs about NOK 45 mill (7). Three platforms doing the same job with possibly the same payloads carried collectively may thus cost NOK 15 mill less than a Predator B.

In addition to the cost savings, such a multi-platform system will fail “softly”. In case of technical malfunction or enemy fire, only part of the total capacity will be lost or degraded. This is of great military importance.

The coverage area of one HALE can be covered by about 25 LALE. Three to six HALEs are needed to maintain 24/7-coverage in addition to relays in between the service area and a GCS or another terrestrial node. Given a LALE endurance of five days, five platforms must be replaced each day on average. At least five must therefore be in readiness at the launch site(s). The addition of some spare aircraft gives a total of 35 LALE UAVs that would replace three to six HALEs. This means a ratio of between six to one and twelve to one in the number of platforms needed to service an area which is approximately 300km x 300km. The cost of three to six HALEs is between NOK 1000 million and NOK 2000 million, whereas 35 LALE would cost about NOK 350 million. A cost savings of between three to one and six to one could be achieved.

The above example assumes that all other aspects of operation are equal in cost, including total cost of payloads. In reality, development costs and additional system complexity will reduce the potential cost savings.

In terms of workload, will the multi-platform system be more demanding? Lets say we have thirty platforms airborne at any given time. Five of them are in transit to or from the service area. We stipulate that the platforms can stay airborne for five days on average. That means that 5 platforms must land and 5 must take off every 24-hour period. Given a single ground station with three eight hour shifts, each shift will have to retrieve about 2 and launch 2 platforms each day. This task can be handled by two crewmembers in each shift without extensive training.

A network of UAV communications nodes is probably easier to manage than a great number of sensor-UAVs. Automation is less problematic, as the task is mostly to maintain coverage over the prescribed areas and allocate bandwidth efficiently. Processing sensor data from a large number of platforms is probably more challenging to implement in the short term.

Longer endurance platforms, such as will be discussed in the next chapter, will require even less ground handling. Given the statistical nature of operations, we must probably multiply the above outlined workload by three or four in periods. Each ground facility would thus be manned and equipped as any UAV or air defence missile field unit.

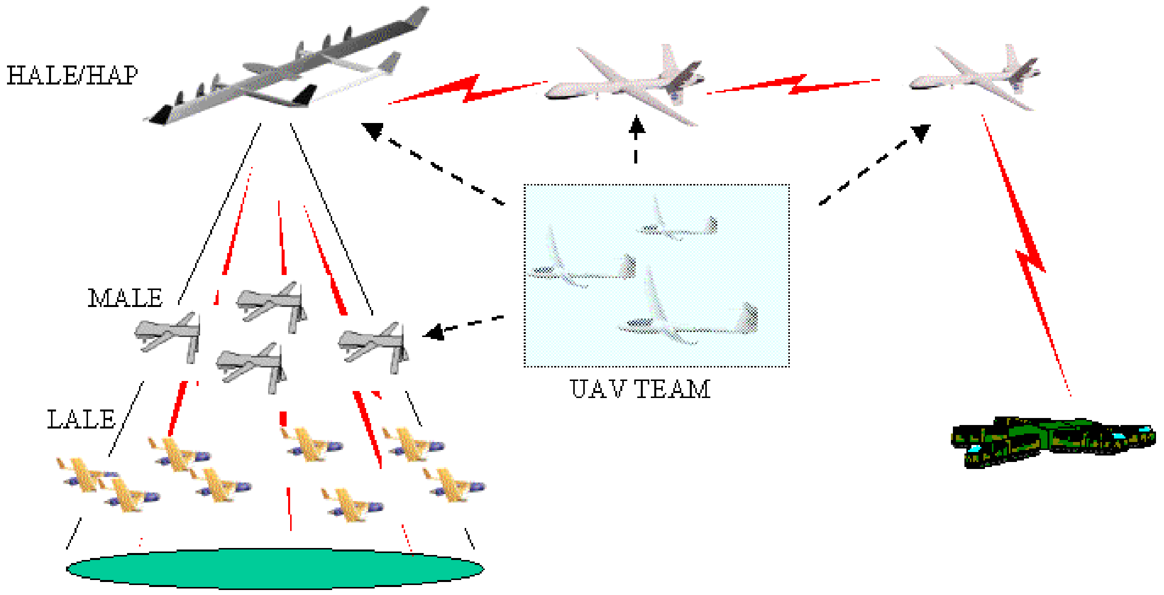

*Figure 6.1 Multi-platform and UAV-team concepts as discussed in chapter 6. On the left, the coverage area of one platform at 20km can be serviced by about five platforms at medium altitude (10km), and 25 platforms at low altitude (5km)(fewer are illustrated to not overcrowd the figure). In the centre is a team of three UAVs that may collectively perform the same tasks as any one single platform, but achieve considerably longer endurance and altitude, and possibly at lower cost compared to complex and large multi-mission aircraft. The figure also illustrates point-to-point links between aircraft or between aircraft and ground facilities, and point-to-multipoint links between aircraft and multiple users on the surface (as discussed in chapter 3).*

## 6.2 Flexibility, robustness and diversity

Change will be a central feature of future warfare. We are seeing this already today. In order to maintain the “edge”, new technologies have to be fielded very rapidly. Several long-term development programs have seen early action in recent years. Examples include the Global Hawk, the Predator and the Dark Star, which have all been used in combat operations while they where still ACTD (Advanced Concept Technology Demonstrator) or research programs. Whoever has a defence system that manages change the best - who can use new and publicly available (COTS) technology in a “smart way” - will be more survivable. This alone is a very strong argument for cheap and modular subsystems. This is especially true for countries with modest defence budgets. Investing in flexibility will be important.

Very expensive UAV platforms will be expected to last for many years, perhaps 20 years. However, the type of UAV that will be available for purchase in 5 years is still a very “early” UAV. It will be very far behind in technology compared to what will be available in fifteen years. The result is a system that is constantly undergoing expensive upgrade programs, or is left behind technologically. Of a few platforms purchased, some will always be under modification and maintenance. This will leave us with very few, and constantly outdated, operational platforms. When expected to contribute to international efforts, we will be left with “nothing” at home. In addition, being outdated, our UAVs will not be highly survivable in modern conflict.

As discussed, the desire to carry “everything” in one package severely restricts altitude and endurance potential. Multiple payload integration in tight spaces also prolongs, complicates and increases cost of development. One possible alternative is to divide a system into many subcomponents, each component being relatively cheap and modular. Upgrading and integrating subsystems will then be less expensive, and can be done quickly to adapt to new threats and technology developments. Some of our platforms may be very modern when needed, while older ones still can do suitable jobs. New and compact payloads may be purchased and put to use quickly. Our UAVs may be used in high-risk missions, thus contributing valuably to joint operations. Losses may be quickly replaced due to the low cost of each platform and payload.

Losses in a multi-platform network will degrade the entire system capability in an incremental way, thus allowing further operations with reallocating remaining UAVs and bandwidth.

A question is whether a network or swarm of small or medium sized UAVs at lower altitudes will be easier to counteract than a few platforms flying higher. All UAVs will be shot down by any moderately advanced foe if they give it high enough priority. The question thus becomes: which concept will demand the most resources from the enemy if they decide to defeat it? We must assume that any adversary has limited resources, and must prioritise between threats to themselves. When facing a military force that is “networked”, as seems to be the trend, the most obvious target to give high priority to is the information infrastructure. If we employ UAVs as integrated and essential parts of operations, as opposed to today’s “cool accessory” situation, any foe will try hard to take them out. Will then a few very sophisticated UAVs survive longer than a system of many cooperating, smaller and more primitive ones?

A multi-platform system may consist of platforms with different performances and operational characteristics. An opposing force will find it difficult to adapt to this system. Yet, smaller and cheaper systems may be used to shoot down the lower flying UAVs. Closer investigations are needed to answer the question of which system will be more survivable.

Experience has shown that large investments are much harder to accept than many smaller ones taken over some time (that still cost the same in total). Fear of not choosing the perfect solution (and thus "wasting" a great sum of money) results in very long acquisition processes. In the end, the chosen solution will not be perfect anyway, because all the important factors cannot be known in advance in a rapidly changing world.

The concept of multiple cooperating UAVs is a "hot" research topic. At UCLA (14), a research team has designed and demonstrated a software system for distributed autonomous control of a team of low cost small UAVs that cooperate to perform tasks. Tasks/subtasks are partitioned among the individual UAVs dynamically. The UAVs themselves adapt to changes in the environment and operational status of UAVs. The Innovative Concepts Inc. LEWK (Loitering Electronic Warfare Killer) (49) comprises multiple UAVs that cooperate to perform their missions. Ad hoc, self-configuring network protocols will be demonstrated in a small swarm. The MAGICC (Multiple Agent Intelligent Coordination and Control) (56) laboratory at Brigham Young University (Utah, USA) is investigating cooperative control of a number of UAVs to perform a single coordinated task. ANSER (55) (Autonomous Navigation and Sensing Experimental Research) at ACFR Aerospace Systems studies decentralized data fusion and navigation without GPS in UAV networks sharing information.

## 7 AUTONOMOUS SOARING

By taking advantage of certain atmospheric conditions, current and future unmanned aircraft can extend their endurance greatly. Examples of favourable conditions are thermals, atmospheric waves and ridge wind. Flights of more than one week, perhaps even months, are very likely possible. Thus we may achieve extreme endurance not only by designing new and better airframes, but also by flying existing platforms "smarter". Norway has unique opportunities in this area, due to our topography and climate. Our exceptionally strong wave conditions may compensate for low solar irradiance during winter (which may reduce the usefulness of many HAP- concepts).

Sailplane pilots have over several decades accumulated a wealth of knowledge about, and experience in, soaring in mountain waves, thermals, ridge lift etc. Sailplanes have been flown great distances and to great heights. The current distance record is more than 3000km. The world endurance record is 58 hours, and was then only limited by the pilot's ability to stay awake. The current altitude record is about 15km. Norway has a very strong sailplane community, and is considered a great place to "soar" - in waves especially.

A research project is underway that has made it their goal to set a new record for altitude with a sailplane ((5), (6), (33) and (40)). The project is named PERLAN (after Mother of Pearl Clouds), and is led by a team from New Zealand. To date, they have performed flights above 12km in waves over California. A DG505M is being used in the attempts to reach heights up to 19km. The ultimate goal is 30km in a specially built pressurized sailplane. The project will provide more knowledge about stratospheric mountain waves and high altitude sailplane flight and design.

Both Sweden and Norway have been considered for the PERLAN record attempts, as the mountain ranges here provide excellent wave conditions. E-mail correspondence with the PERLAN team has revealed that Sweden was chosen due to the availability of scientific and physical support infrastructure. The facilities at Andøya Rocket Range should provide some interesting opportunities as well. The NASA MACWAVE (Mountain and Convective Waves Ascending Vertically) campaign has recently been hosted at Andøya. The results from the PERLAN and MACWAVE projects may be of interest to operators of UAVs.

There are quite a few well-known and very good wave soaring sites in Norway. The Vågå Wave Camp is a gathering of wave enthusiasts from all over the world. Altitudes of more than 10500m have been reached in waves there. Even greater altitudes are possible with unmanned aircraft that are not limited by "freezing pilots". UAVs may be launched there from a ridge, using ridge lift to climb to about 100m, and from there enter the wave system. The endurance is limited only by the duration of the wave conditions. Also Northern Norway has good sites; Alta and Bardufoss are often used. This means that the planned trials of a tactical UAV system in Bardufoss could explore some of the opportunities using a standard platform. Limited endurance is a serious drawback for any TUAV system. Proving whether a standard UAV could extend its endurance in this way should be valuable.

It is very interesting to note that the MWFM (Mountain Wave Forecast Model, Naval Research Laboratory) model calculates very strong stratospheric mountain wave activity over Scandinavia during winter. These waves are also evidenced by the frequent sightings of high altitude ice-clouds ("nacreous" clouds that look like "mother-of-pearl" clouds). A more extensive overview of wave, thermal and other relevant conditions in Norway is proposed.

Modelling and simulation of 3D atmospheric flow fields on a small scale will be a central task in order to realize unmanned soaring. DTED, GIS and meteorology will be linked in a computerized model that will help guide the vehicle. Modelling may initially take place in a ground facility, and coordinates and commands sent via a narrow-band communication link. It should be a goal to achieve a high level of autonomy in the long term.

It should be possible, using existing technology and programming techniques, to develop a “plug-in” module that enables any UAV to exploit atmospheric waves, thermals etc. In some ways, an automated system will perform better than the manual/visual way of flying sailplanes. This assumption is based on the availability of high power computing and modelling and the opportunity to communicate with a network of sensors. Unmanned sailplanes may also exploit conditions that manned sailplanes must avoid for safety reasons. Some aspects of sailplane flying are still going to be challenging to implement, though, such as the ability to interpret clouds in flight.

The operation of such a system would not at the outset be as deterministic as today’s UAV systems. One cannot always plan the exact flight path and obtain a fixed and known performance that is better than a still air model would predict. One can, in other words, not count on extreme endurance all the time. It would be a more opportunistic platform, sometimes obtaining hugely improved range and/or endurance, and other times operating just as any other slow UAV. The concept therefore lends itself readily to multi platform systems, and quasi-stationary relays.

If we envision a number of platforms somewhat spread out in the battlespace, it seems clear that there will often be at least a few that have favourable soaring conditions at any given time, and a number of platforms that can be directed wherever we want them. On average, we will achieve longer endurance per platform and better availability of payloads (e.g. sensors or communications nodes). The statistics of such a concept could be explored in a follow-up work.

Penetrating against the wind may be a problem for a sailplane-based UAV. The limits in safe operating velocity and lack of power will sometimes limit the ability to travel against the wind. However, if the goal is to remain “more or less stationary” over some time, such as in most communications missions, this is not a problem. Given sufficient staying power, previously in this report defined as roughly one week, headwinds will not be a problem. On the contrary, strong winds mean that wave and ridge conditions are very good somewhere in our mountainous land. “Bad flying weather” has thus been turned to good flying weather. Many sailplane pilots can vouch for this, reporting that good wave soaring conditions can be a very rough experience. This means that platforms will need to be able to withstand some strong forces.

The task of developing an autonomous sailplane is well suited for low budget projects and student work with incremental steps towards more capable systems. Contacts in the Norwegian soaring community are eager to participate. A private initiative is underway to produce a preliminary study and a demonstrator (should funding be available). The goal is to develop a low cost UAV that may stay airborne for more than one week. Potential for much longer endurance is strong. The timeframe for development (based on using free time) is one to two years.

Implementing an autopilot in a sailplane is nothing special. Exploiting waves and thermals is, however, a new challenge. Dynamic soaring as practiced by the albatross at sea is another interesting prospect. It seems that autonomous sailplanes are an unexplored area that is open to anyone who is interested. The market potential should be considerable if some of the promise of unmanned soaring can be realized.

# 8 CONCLUSIONS

The requirements for unmanned aerial communications platforms are different from UAVs in other mission scenarios. Service reliability under all conditions and in any geographical region is the central requirement. This requirement will diffuse to many other UAV applications as well.

The ability to remain airborne - possibly “quasi-stationary” - for long periods of time, regardless of weather, is identified as the most important platform characteristic. This has consequences for the optimal design of such specialist platforms. Lack of endurance must be compensated by higher weather tolerance.

Combining communications tasks with sensor tasks within a single mission is, in general, not recommended.

Current “tactical” and “backpack” UAVs are considered unsuitable for reliable communications missions due to their poor endurance and strong weather dependence. Their only application would be to relay data from other similar platforms when weather permits their operation.

Several existing types of UAVs are suitable for many communications mission types. They are very flexible and multimission capable. They may however be “overkill” for many applications, having very expensive structures and power plants that are designed for great payload weight and speed at the expense of endurance. Their high cost will result in few platforms being purchased. This makes the system degrade dramatically with each platform lost.

Far less expensive specialist communications platforms may perhaps be designed and built within a short timeframe. Commercial motor gliders and sailplanes may be ideal for modification. Such platforms may provide greater redundancy to a “family solution” without multiplying cost several times.

The optimal (low cost) communications specialist platform is a medium sized aircraft following a “low, slow and light” concept. A new designation is proposed – LALE (Low altitude Long Endurance) - that will in effect bridge the gap between current “tactical” UAVs and current MALE UAVs size- and altitude-wise. These may have sufficiently long endurance to provide reliable communications services irrespective of weather conditions. The definition of “sufficiently long endurance” is proposed here to be approximately one week. The optimal design and overall concept will depend on the range of applications that are prioritised.

A number of such light platforms would collectively be able to perform the same task as a single platform, but with much improved endurance. Multi-platform configurations may be lower cost, more flexible and more robust than systems based on single platforms with extreme performance.

HAPS (High Altitude Platform Systems) will become interesting long-term alternatives. Technology should become mature enough within the next 10-15 years. Operability of solar powered aircraft in high latitudes should be investigated further.

In the short term (2008), a family solution consisting of a moderate number of MALE UAVs to provide high payload capacity and flexibility, and a larger number of LALE UAVs to provide redundancy, more cost-effective services, and ability to fill coverage voids left by higher-flying platforms may be interesting enough to explore further.

Endurances may be vastly improved by exploiting atmospheric waves, thermals and other meteorological phenomenon. Such a capacity to “fly smarter” will improve the usefulness and cost-effectiveness of anything from high altitude platforms to small UAVs. Existing UAVs may be improved, or new, extreme-endurance designs may be developed taking advantage of commercially available products and existing “know-how”. The novelty of the concept may be attractive to potential partners.

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# A APPENDIX. FORMULAS

**Reynolds number:**

$$\mathrm{Re} = \frac{Vl}{\nu}$$

V = velocity. [V] = m/s  
l = characteristic length. [l] = m. It is common to use the chord length, thus giving the chord Reynolds Number: $\mathrm{Re}_c$.  
ν= kinematic viscosity = μ/ρ (viscosity /density). [ν] = $m^2/s$. Kinematic viscosity increases with altitude. Re thus decreases with altitude for a given velocity and aircraft.

**The Breguet equations for endurance of a propeller driven, fuel-burning aircraft (3):**

For the case of constant α and V (angle of attack and velocity):

$$E = \frac{\eta_P}{c_P}\frac{1}{V}\frac{C_L}{C_D}\ln\left(\frac{W_1}{W_2}\right)$$

$\eta_p$= propeller efficiency. [$\eta_p$]=1  
$c_p$=specific fuel consumption with respect to power. [$c_p$]= $N_{fuel}/W_{power}s$  
V=aircraft velocity (TAS=True Air Speed). [V]=m/s  
$C_l$= Coefficient of lift. [$C_l$]=1  
$C_d$=Coefficient of drag. [$C_d$]=1  
$W_1$=Weight at start of flight. [$W_1$]=kg  
$W_2$=Weight at end of flight. [$W_2$]=kg

For the case of constant α and ρ (angle of attack and altitude):

$$E = \frac{\eta_P}{c_P}\sqrt{2\rho S}\frac{C_L^{3/2}}{C_D}\left(\frac{1}{\sqrt{W_2}} - \frac{1}{\sqrt{W_1}}\right)$$

ρ= fluid (atmospheric) density. [ρ]=$kg/m^3$  
S=wing projected area. [S]=$m^2$

**Power required for steady, level flight (3):**

$$\mathrm{P_r} = W\frac{C_D}{C_L^{3/2}}\sqrt{\frac{2W}{\rho S}}$$

# B APPENDIX. PLATFORM SPECIFICATIONS

*Table B.1 Data for selected manned and unmanned platforms, sorted by endurance. Data are from open sources, RFI (Request For Information) and personal correspondence with manufacturers. All data values are approximate. The exact values will depend on flight condition and configuration.*

| **Platform** | ***manufacturer*** | ***endurance (hrs)*** | ***ceiling (m)*** | ***payload weight (kg)*** | ***Payload weight / MTOW*** | ***cruise velocity (km/h)*** | ***max velocity (km/h)*** | ***Empty weight (kg)*** | ***MTOW (kg)*** | ***wingspan (m)*** |
|---|---|---|---|---|---|---|---|---|---|---|
| Helios/SkyTower | Aerovironment, USA (NASA ERAST) | 6 months | 30000 | 90 | 0,12 | 50 |  | 600 | 750 | 75 |
| Seascan B | The Insitu Group, USA | 70 | 6000 | 9 | 0,41 | 48 |  | 12 | 21 | 3 |
| I-GNAT | General Atomics | 50 | 9100 | 91 |  |  | 220 |  |  |  |
| Predator B-ER | General Atomics Aeronautical Systems Inc, USA | 49 | 15200 | 360 |  | 315 | 390 |  |  | 26 |
| Aerosonde MK3 | Aerosonde Ltd, Australia, The Insitu Group | 48 | 6000 | 5 | 0,36 | 45 |  | 9 | 14 | 3 |
| Predator A | General Atomics Aeronautical Systems Inc, USA | 40 | 7600 | 200 | 0,19 | 180 | 260 | 544 | 1065 | 15 |
| Global Hawk | Northrop Grumman Corporation, Ryan Aeronautical Center, USA | 36 | 19800 | 900 | 0,08 | 600 |  |  | 11600 | 35 |
| Predator B turboprop | General Atomics Aeronautical Systems Inc, USA | 34 | 15200 | 360 | 0,08 | 380 | 414 | 1682 | 4772 | 20 |
| Altair | General Atomics Aeronautical Systems Inc, USA | 32 | 15900 | 300 | 0,09 |  |  |  | 3362 | 26 |
| Perseus B | Aurora Flight Sciences Corp, USA for NASA ERAST | 24 |  | 120 | 0,11 |  |  |  | 1100 | 22 |
| Altus | General Atomics Aeronautical Systems Inc, USA | 24 | 17300 | 150 | 0,15 |  | 207 | 395 | 975 | 17 |
| Predator B Jet | General Atomics Aeronautical Systems Inc, USA | 18 | 18300 | 360 |  |  |  |  |  |  |
| Prowler | General Atomics Aeronautical Systems Inc, USA | 18 | 6100 | 45 | 0,13 | 125 |  | 204 | 340 | 7 |
| Proteus/HALO optionally piloted | Angel Technologies HALO, Scaled Composits (+ Raytheon +Texas Instruments) | 18 | 19800 | 1400 | 0,25 | 500 | 800 | 2655 | 5625 | 24 |
| Pathfinder + | Aerovironment, USA (NASA ERAST) | 15 | 30000 | 70 | 0,22 | 35 |  | 245 | 315 | 36 |
| P3-C ORION | Lockheed, USA | 13 | 8600 |  |  | 400 |  | 35000 | 64000 | 30 |
| U-2R/S | Lockheed, USA | 12 | 19800 | 1360 | 0,09 | 600 |  |  | 15639 | 20 |
| Shadow 200 | AAI Corp. USA | 6 | 4300 | 27 | 0,18 |  |  | 118 | 149 | 4 |

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|---|---|---|
| 2 | | FFI-Bibl |
| 1 | | FFI-ledelse |
| 1 | | FFIE |
| 1 | | FFISYS |
| 1 | | FFIBM |
| 1 | | FFIN |
| 5 | | Forfattereksemplar(er) |
| 5 | | Restopplag til Biblioteket |
| | | **Elektronisk fordeling:** |
| | | FFI-veven |
| | | Stian Løvold (STL) |
| | | Sigbjørn Aune (SAU) |
| | | Nils A Sæthermoen (NAS) |
| | | Eivind Strømman (EST) |
| | | Kjetill Løvbrøtte (KLO) |
| | | Øistein Hoelsæter (OIS) |
| | | Nils G Johansson (NGJ) |
| | | Rune Stensrud (RST) |
| | | Vegard Arneson (VAR) |
| | | Hans Christian Erstad (HER) |
| | | Lorns Harald Bakstad (LBA) |
| | | Knut Øvsthus (KNO) |
| | | Svein Haavik (SVH) |

Benytt ny side om nødvendig.

| EKSTERN FORDELING | | | INTERN FORDELING | | |
|---|---|---|---|---|---|
| ANTALL | EKS NR | TIL | ANTALL | EKS NR | TIL |
| 1 | | KAMPUKS UAV (Bardufoss) | | | |
| 1 | | v/Maj Odd Arthur Larsen | | | |
| 1 | | v/Maj Rune Rasmussen | | | |
| 1 | | v/Maj Bjørnar Nicolaisen | | | |
| 1 | | v/Kapt Morten Raustein | | | |
| 1 | | v/Kapt Morten Bie | | | |
| 1 | | v/Kapt Salve Håkedal | | | |
| 1 | | KNMT | | | |
| 1 | | v/Orlkapt Atle Sommer | | | |
| 1 | | v/Orlkapt Martin G Ramsland | | | |
| 1 | | SSTN Vigdel | | | |
| 1 | | v/Kaptlt Rolf Lund | | | |
| 1 | | Div6/Ebn | | | |
| 1 | | FSS/FSTS | | | |
| 1 | | v/Oblt Tor P Ekroll | | | |
| 1 | | FLO/Luft | | | |
| 1 | | v/Maj Egil Strømsvåg | | | |