Between Air and Space – Zephyr and the Future of High Altitude Pseudo-Satellites within Defence

By Flight Lieutenant Lilie Weaver

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Abstract: As a consequence of the incremental decrease in weight and simultaneous increases in reliability and efficiency of technologies such as batteries, solar cells and satellite communications, the ability to operate high persistence, lightweight air vehicles in the aerodynamically demanding region of the stratosphere has improved. A class of these vehicles is often referred to as High Altitude Pseudo-Satellites (HAPS). This paper will examine the benefits and challenges of operating these vehicles, which fly well above commercial air traffic and the tropopause. They avoid convective weather but are still subject to low air density and quasi-space weather, as well as the photolytic chemistry, the process by which UV light breaks down atmospheric molecules into damaging free radicals, of the medium to high stratosphere.

Introduction

The UK MOD intends to be an early adopter of High Altitude Pseudo-Satellites (HAPS) systems and has already invested in a HAPS Operational Concept Demonstrator (OCD) using Airbus' Zephyr HAPS platform. The Zephyr is a fixed-wing air vehicle (AV) powered by solar energy and rechargeable batteries. It has already broken several altitude and endurance records and looks like a promising programme to convert these concepts from ideas and demonstrators into operational reality within the short to medium term. It is far from the only contender for further investment, however, and air vehicles with similar functionality are being developed all over the world by big aerospace companies such as Boeing, NASA and BAE Systems but also by internet giants such as Google and Amazon, whose applications for the technology include HAPS-enabled internet provision and high-fidelity mapping to remote areas of the globe. The designs of these AVs vary between fixed wing, airships, and balloons.

HAPS are not a complete step-change from current technologies and concepts, but rather represent an opportunity to 'down cost' expensive subsets of both satellite-based capabilities and lower altitude air breathing platforms. As new, lightweight payloads are developed, HAPS will become useful in areas such as electro-optical reconnaissance, satellite and radio communications re-broadcast (rebro) and signals intelligence (SIGINT). One of the major selling points of HAPS could be described as 'agile persistence', where (with multiple assets) the persistence of a satellite could be achieved, but with the ability both to reposition the asset at will, but also recover the asset and payload at the end of its mission or lifecycle. When thinking about the UK's putative high-altitude network, we will need to consider how best to fuse this new 'mixed domain' to our traditional concept of treating 'Air' and 'Space' as completely separate domains. Above FL600 – around 60, 000 feet, flight is essentially unregulated. Until now, that has not been a problem given the very few users of such high airspace, but this may need to change. Regulators will have to think carefully about 'big stratosphere theory' and how to manage the increasing presence of AVs in this air space, particularly given the lack of manoeuvrability and large altitude block requirements of most of these systems. As an early adopter, the UK may have an opportunity to shape this unregulated space going forward and so consideration as to how to shape and exploit this should begin.

Whilst this paper will primarily address the Zephyr programme, it will also suggest that the future of HAPS is a combination of air vehicles of different types, providing a flexible capability set and 'agile persistence' in a given operational theatre. The benefit of being a very early adopter makes the investment in this relatively new technology worthwhile, buying the UK a 'seat at the table' in developing regulation, but also steering wider programmes to the UK's likely requirements, as well as, eventually, providing a relatively cheap and persistently agile network to support and enable operations worldwide.

History

The Zephyr project started life as a side project for a group of engineers at Defence Evaluation and Research Agency (DERA), which became QinetiQ, designed as a way to take pictures of QinetiQ 1, a piloted stratospheric balloon designed to break the balloon altitude record. The Zephyr was to remain tethered to the balloon to take pictures. In the end, the balloon never took flight, but the Zephyr project endured, being bought by EADS Astrium in 2013, which became Airbus Defence and Space. But it is not until the last two to three years, with improving battery technology and solar panels that the air vehicle has been able to demonstrate its ability to stay above FL600 consistently through the day-night cycle. The Zephyr programme has gone from strength to strength, breaking the world altitude record in its class (U1.c) in 2010 and then again in 2018, at the Yuma test site in the USA. It still holds that altitude record of 74,000 feet.[1] But challenges remain, not least continuing development in battery technology, to improve life-cycle durability, and, as ever, weight and efficiency. In addition, the atmospherics of the stratosphere are a challenge, with many of the problems of both high-altitude flight and of the increased effects of space or space-like weather. The programme itself has not been without incident either, with crashes at Ascension in 2014 and at Wyndham, Western Australia in 2019, notably both occurring within the climb/descent phase implying that the weather on launch/recovery is likely to be the greatest catastrophic risk during the typical flight profile.

Figure 1: Airbus Zephyr S on launch.

Stratospheric Technology

The Zephyr is a heavier-than-air (HTA), solar powered, remotely piloted air vehicle. It uses rechargeable batteries to stay aloft overnight, and ultimately loiters in the stratosphere. The stratosphere starts at the tropopause – the point at which the temperature inversion marks the end of the Earth's lower atmosphere, where temperature decreases with height. This inversion marks the top of convective weather systems and the strong winds associated with the jet streams. The height of the tropopause varies from around 20,000 feet over the poles to 60,000 feet over the equator. Flying above FL600 (approximately 60,000 feet) brings another advantage – under ICAO regulation FL600 marks the transition of Class A controlled airspace to Class E airspace, under the remit of High-Level Flight Rules,[2] and is certainly above civilian air traffic. This is a challenging region to fly in. High altitude weather balloons swell to around 80-100 times their size at the earth's surface, and the air density in the stratosphere is between around 1% and 0.1% of that at sea level. This poses problems for lighter-than-air (LTA) HAPS, particularly in selecting a suitable skin material. HTA vehicles must also be designed for low air density flight. Zephyr 8 has a very high aspect wing, very low weight and fixed pitch propellers that have so much helix angle (to maintain efficiency at high altitude) that they don't provide enough thrust at low speed to get airborne from a standing start, so the Zephyr must be launched by hand, by a well coordinated team of five. The Zephyr 8 has an all up mass of only 67kg, with the main structure weighing in at around 30kg (the rest is batteries and a 5kg payload allowance). This is exceptional when you consider its wingspan of 25m – by comparison, an MQ-9 Reaper has a wingspan of 20m and a max all-up-weight (MAUW) of around 4,800kg![3]

Another feature of the stratosphere is the much higher levels of radiation, specifically, high energy particles (which cause the stratospheric temperature inversion through high energy creation of ozone and its energetic decomposition), which are filtered by the thicker atmosphere of the troposphere. This combined with the high diurnal temperature variation (the air temperature in the low stratosphere is around -50°C but solar radiative heating can cause the skin temperature to exceed this by up to 64°C)[4] contributes to the degradation of skin materials used in HAPS and presents an insulation/heat dissipation problem for the batteries, avionics and payload. With current materials, it is likely that after a 6-month flight, the skin would be so degraded that it would need to be completely stripped and replaced.[5]

Battery technology is another limiting factor. Currently, batteries make up over half of the weight of the air vehicle, and well over half the cost of the entire structure. Even with the most efficient battery technology available, only within the last year has Zephyr been consistently able to demonstrate the ability to maintain stratospheric flight through the day-night cycle. Even now, the battery efficiency over several discharge-recharge cycles is the limiting factor on endurance. The good news is that development of better, lighter and more efficient battery technology is key to the success of many future industries, not least electric vehicles, as well as making renewable power reliable and distributable across periods of high and low generation. Solar cell technology is progressing well also, with many of the same drivers. With current technology, the Zephyr 8 holds the world record for endurance, at 25 days, 23 hours and 57 minutes. In the near future, the Zephyr team anticipate a 3,000hr (roughly four month) flight will be achievable; the ultimate aim is to be able to remain airborne for at least a year.[6]

Weather

An aircraft as light and flexible as Zephyr is extremely susceptible to the weather. Its cruise speed is just 12 knots indicated air speed (KIAS) – its never exceed speed (V_{ne}) is just 20 KIAS. This largely only causes issues for launch and recovery – getting up and down through the higher wind speeds and convective weather to reach the (relatively) calm stratosphere. Turbulence aloft is minimal, and whilst winds in the stratosphere can be as high as 130 knots in the polar vortices,[7] they usually peak at around 30-40 knots in the mid-latitudes and average just 20 knots.[8] This might sound high for a machine which cruises at 12 KIAS, but at 60,000′, this converts to 45 knots true airspeed (KTAS), allowing a HTA HAPS freedom of manoeuvre that is greater than would be possible if exposed to tropospheric weather.

Launch and recovery can prove problematic, as can the aerodynamics of a novel airframe. The limiting factor for high altitude/high speed flight is usually flutter, a phenomenon of dynamic aeroelastic instability. With no ailerons to provide positive feedback which exacerbates the simple harmonic motion of flutter, and a highly light and elastic composite airframe, the Zephyr's V_{ne} is based on a static aerodynamic effect. This is basically a divergence speed where, as the angle of attack (AOA) decreases towards zero (operating AOA is 16 deg!), the wing bends up and either reaches structural failure or the aircraft enters a regime of dynamic instability in pitch. In turn this can flip the aircraft or cause structural damage due to out of limits excursions in speed. In 2003 NASA's Helios demonstrator (another record breaking solar/fuel cell HAPS demonstrator) broke up at low altitude in 'normal' turbulence due to this effect,[9] and Facebook's (since abandoned) Aqulia HAPS project suffered a similar fate on final approach in 2016.[10]

Control

The Zephyr can be flown via satellite, or via a direct line of sight control, using S-band frequencies. On the satellite link, the aircraft flies semi-autonomously, and is given instructions by text message on a waypoint system with a latency of around 2 minutes. In S-band, the aircraft control system can share 10Mbps of bandwidth with the payload, or the payload can stream its data on a ROVER[11] -like link. Communication with air traffic agencies is all done by telephone from the ground station. Each ground station can control up to 4 aircraft over two terminals, offering a potentially personnel-efficient way of controlling very long-term missions.

Other HAPS in development[12]

Airship – Thales-Alenia's Stratobus

Thales Alenia Space is designing a HAPS airship, capable (unlike a balloon) of reliable self-positioning through solar powered motors (much like HTA HAPS). But it is a much larger structure and is currently predicted to carry a payload of up to 250kg. The technology is unproven though, with a test flight scheduled for 2020 or 2021. Other HAPS airships have been plagued by budget overruns[13] and problems developing the technology required – most often cited as problems developing the fabric for the skin, which, unlike balloon projects, usually contains the solar cells, and which must be able to maintain a rigid, aerodynamic shape. It must also be able to survive at least six months, if not several years, in the punishing solar environment of the stratosphere. The cost of a HAPS airship is likely to be an 'order of magnitude more' than HTA HAPS.[14]

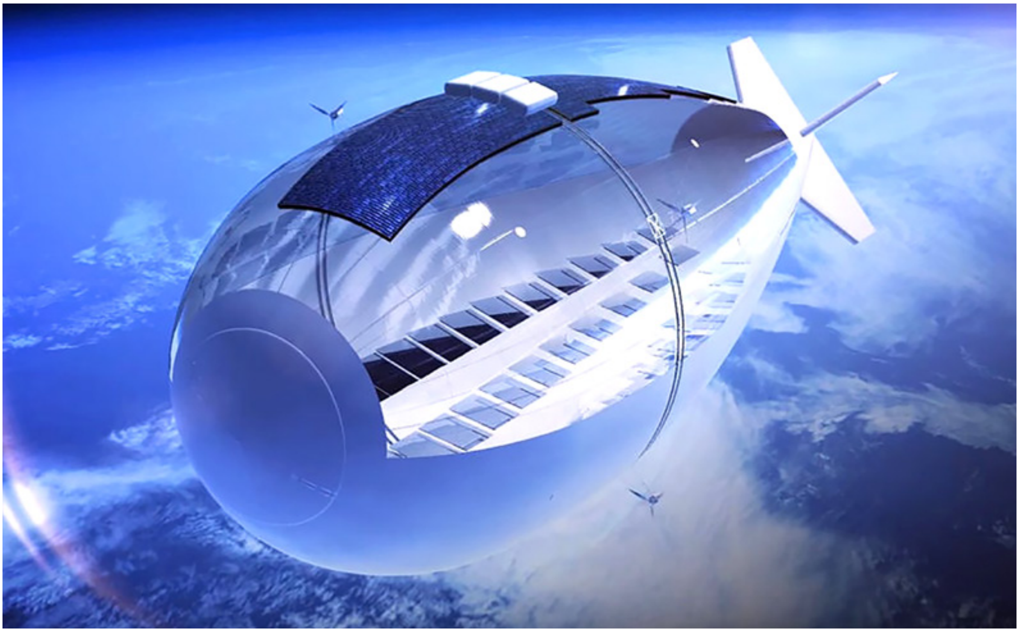

Figure 2: Thales Alenia's LTA HAPS Stratobus. Copyright © Thales Alenia Space

Balloon - Google Loon

The Loon balloons are a civilian project, designed to attempt to bring broadband internet to inaccessible areas, and those with poor native infrastructure. The balloons are not steered, rather they must 'catch a ride' on stratospheric winds and their operation relies on detailed weather planning, ascending or descending to find an area with winds in the required direction. The project is at an advanced stage with plans to start operating commercially in Kenya in 2019. The balloons can carry a 10kg payload and have a small array of solar panels generating 100W of power during the day, with rechargeable batteries powering the craft overnight. The estimated service life of a balloon is 100-200 days, and the payload is designed to be recoverable. The project has experienced a number of structural failures yet is already capable of delivering internet on a temporary basis to, for example, disaster hit areas. Costings are not freely available, but the skin material (similar to a weather balloon) is relatively low cost, and the payload is small, made of commercially available components, so it is likely that the unit cost in full production could be quite low. Notably, the programme seems to rely upon low unit costs of both the balloons and the payloads, and the assumption that at the end of life, either the balloon's steering or material will fail, and the payload must either be recovered or abandoned.[15] This may work well for a civilian application in an area with low population density but must be considered carefully for military application.

Figure 3: A Google Loon balloon on launch. Copyright © Loon

Doctrine

Project AETHER is currently being run within UK Defence to investigate what type of solution the MOD should invest in to meet an 'agile ultra-persistent' requirement; with HAPS as one potential solution. As this is a globally new concept, it is important to take time to get the concept of operations right, without having the advantage of observing others' mistakes. Current Air and Space Power doctrine says little about the details of what the MOD should be investing in, so perhaps more attention should be paid to this area, as HAPS are not only a potential force multiplier, but also a networked-force enabler. The Joint Concept Note from DCDC, 'Future Force Concept', devotes only one paragraph to HAPS, identifying that they 'offer the advantage of being more readily upgradeable than their true-satellite counterparts and can be re-tasked to different geographic areas more easily'. It also observes (but not in relation to HAPS) that 'all air platforms have potential to be … network nodes.'[16]

Joint Doctrine Publication 0-30.2 devotes slightly more space to Zephyr as a UK MOD asset, but says virtually nothing about *how* it should be employed. The United States Air Force (USAF) says little more in its doctrinal documents, although it re-emphasises the importance of all future RPAs/UAVs being interoperable. The USAF paper also identifies a modular approach to payloads as important in preventing the proliferation of custom-built air vehicles for each mission or even mission subset, which is extremely inefficient.[17] The authors propose two examples of HAPS applications on the battlefield, 'extreme persistent ISR', and 'near-perpetual battlefield communications node'.[18]

There is little academic work available on military uses of HAPS – most papers focus on civilian applications of HAPS or are so old as to be outdated. Some of the civilian applications can be re-interpreted for military application, such as the concept of internet (or network) dissemination in remote locations,[19] and HAPS-HAPS/HAPS-satellite integration to minimise expensive satellite bandwidth and increase the efficiency of satellite operations by acting as a surrogate download station, with a much longer communications window with a low-earth orbit (LEO) satellite than a ground station would have.[20]

Capabilities and Integration

HAPS capabilities are largely thought of as being ISTAR related (Intelligence, Surveillance, Target Acquisition and Reconnaissance), but in addition, it could be argued they could be considered as a J6 asset too – a persistent, deployable network that can be taken to a Theatre of operations and used to enable and improve the networked capability of other ground and air based assets, in conjunction with Space comms. This vision is still a long way off, technologically speaking, and relies on ongoing investment in different types of air vehicle, but, if new systems are procured using relatively straightforward principles of modularity and interoperability, it is possible the MOD can multiply the value of its investment in this area.

HAPS as Imagery Intelligence (IMINT) providers:

Electro-optic/Infra-red (EO/IR) imagery is perhaps the most straightforward and mature aspect of HAPS' capabilities. The technology is relatively well explored through a combination of high-quality imaging pods for fast jets, Medium Altitude, Long Enurance (MALE) RPAS, and other airborne ISTAR assets, and imaging from LEO satellites (see Carbonite-2 and others, below). The challenge is to get an imaging payload down to a low enough power consumption and weight to fly on HTA HAPS – which are the current front runners in the race to become operational. On the Zephyr 8S, for example, the payload must weigh around 5kg. With a total air vehicle average power production of between 50W and 2kW the payload power consumption is likely to have a limit of around 50W (day) and 15W (night).[21] OPAZ is an Airbus payload which has been designed to meet this requirement and can provide 20cm resolution imaging from an altitude of 20km.[22] It is not yet reliable enough to produce imagery on demand, but nonetheless, it shows the potential that exists within those weight and power constraints. Synthetic Aperture Radar may be another payload feasible for HTA HAPS, although the speed profile and altitude of the platform may prove a challenge. In a recent study, Baumgartner calculated that the navigation solution would have to provide a relative position accurate to within 0.4cm to achieve 1m resolution at HAPS representative heights and speeds.[23]

LiDAR (Light RADAR, or Laser Imaging, Detection and Ranging) is another good prospect for carriage on an HTA HAPS. Lightweight LiDAR payloads are already in development.[24] Using a laser-based imaging array could have an added benefit, as it may be possible to use the same equipment to support optical communication,[25] a high bandwidth, highly directional option for future HAPS communication. The disadvantage of EO imagery collect is of course weather obscuring the target. This is something overcome by SAR, but not LiDAR. Larger platforms, such as Thales' Stratobus could carry much larger imaging equipment, but, since these are likely to cost an order of magnitude more than HTA vehicles,[26] it would be questionable whether they would offer better value for money in the imaging arena than, say, a constellation of LEO satellites or an air-breathing, high-altitude asset such as the U-2 spyplane or dedicated SAR platform such as the RAF's Sentinel.

HAPS as SIGINT platforms:

Another area where HAPS capability could likely be usefully utilised is SIGINT. Due to its sensitivity, there is little in the public domain about the nature of any SIGINT payloads being developed for HAPS, although Airbus does appear to be developing one for Zephyr.[27] The advantage of using HAPS for SIGINT is their persistence, allowing long-term coverage and/or tracking of a target. Weight will, of course, be an issue, especially with HTA HAPS – and the high altitude might also present a problem in terms of signal strength, and the design of the payload is likely to be specialised (rather than taken from another aircraft) due to HAPS' slow flight profiles and high altitude. From a military perspective, one of the challenges of SIGINT on HAPS will be integrating the payload. This depends on the commercial model chosen for the operation of HAPS, since one model (given the long flight times and specialist skills required to operate and monitor HAPS) could be to lease the capability from a commercial company, bolting on a payload and instructing the company where to fly. This is likely to be most challenging in the area of SIGINT, where the MOD will require assurance that the aircraft systems cannot interact with the payload in any meaningful way.

HAPS as communications and network nodes:

One of the key areas where HAPS may offer a step change in the way the UK military conducts operations is analogous to one of the most spoken about civilian applications of HAPS – networking and communications. On the scale of a ground operation, the footprint of a HAPS (estimated 500km maximum horizon,[28] but a 200km useful operating radius at 20km altitude)[29] would enable one air vehicle with a communications re-broadcasting payload (comms rebro) to act as a point node and, for example, allow beyond line-of-sight (BLOS) radio communications for the troops on the ground. One step further would then allow the broadcast of friendly forces layout, a recognised air picture (or both) from an HQ or C2 node based within that footprint. The next step up would be processing and broadcast of a large-scale C2 picture including elements outside the HAPS' footprint, via direct communication with another HAPS, a geostationary satellite or a distant, air-breathing C2 asset. Large-scale processing of air and ground-based assets is likely to require the ability to carry a relatively large payload. Northrop Grumman's Battlefield Airborne Communications Node[30] (BACN) is operated by the USAF on E-11As. BACN was designed to overcome the fact that different units use different networks to communicate and spread situational awareness and intelligence. The US Army uses Enhanced Position Location Reporting System, to integrate with Situation Awareness Data Link (EPLRS/SADL) on close air support platforms. Most aircraft use Link-16 to contribute to and receive a Recognised Air Picture (RAP); the Common Data Link (CDL) is used to transmit imagery. All of these are available on BACN, along with voice and data rebro.[31] It was realised early on that operating BACN at high altitudes offers the best BLOS coverage – in Afghanistan, NASA's WB-57s (developed from the English Electric Canberra) were used.[32]

The RQ-4 Global Hawk can be modified to carry BACN,[33] and a smaller 'Smart Node' pod is available, shown in Figure 4, carried by an MQ-9 Reaper. Whilst no figures are publicly available on its weight, it looks unlikely to be within the current weight limits of HTA HAPS. Airship HAPS would be a natural fit for carrying larger comms network capability – perhaps for the 'full fat' BACN capability, providing a persistent intelligence picture to all participants in an operation, along with extended range voice and IP comms. A key technology enabler to make full use of this ever-increasing plethora of information will be high bandwidth platform-platform communications. A promising option for this, especially for high altitude platforms like HAPS would be 'free space optical' – i.e. lasers.[34] A full treatment of this technology is outside the scope of this paper but remains an area that should be watched closely to maximise the value of HAPS.

Figure 4. Smart Node Pod on an MQ-9.

HAPS in practice:

For a small-scale operation, two Zephyrs, could be launched (or redirected)—one for pre-deployment imagery or a live image feed, (albeit at 20cm resolution) and one for UHF/VHF re-broadcast (rebro) ensuring that tactical communication can be maintained beyond line-of-sight (BLOS).

Remote locations, such as the South Atlantic Islands, could benefit from long endurance internet rebro from a friendly country in the region, improving communications both for the civilian population of the Falkands, but also the remote research stations of Rothera and scientists based seasonally on South Georgia and the South Sandwich Islands. It would also lower the cost of expensive satellite communications between the South Altantic islands and the UK. A good selection for this long-term, static rebro might be an airship, which can carry a larger payload—such as Thales' Stratobus, which is designed to carry up to 250kg.

For an enduring Operation, such as SHADER one solution could be to use several HAPS balloons or airships to provide satellite rebro (or even an alternative to satellite BLOS) for MALE RPAS and a wide area tactical picture (something like BACN), along with VHF/UHF rebro. A fleet of Zephyrs could provide imaging prior to a compound assault, for example, in EO, IR, or LiDAR, and could provide 'night before' on-demand pattern-of-life for pre-planned targets. This would leave the MALE RPAS such as Reaper free to operate as a close air support platform and do the more detailed and responsive target development, and it would help free up capacity in telecomms satellites to provide the ever-increasing bandwidths needed for high definition remote video feeds and SIGINT payloads.

What about Space?

Are HAPS going to replace Space based capability? In a word, no. Large satellites or satellite constellations, such as AlphaSat, or the MOD's Skynet network are bespoke designs for large, very high bandwidth platforms and can cost hundreds of millions of pounds. The cost of launch is high – up to 75% of total cost[35] (although this may decrease with the anticipated increase in capacity, driven by commercial demand over the coming years).[36] These large satellites are designed typically to a 15-year lifespan, requiring (usually) at least triple redundancy in key areas, to maintain functionality in spite of bombardment with high energy particles (which can damage the semiconductor components of even space-hardened microchips – and the smaller and more modern the chip, the more vulnerable to space weather it is, due to the reduced component size and energy).[37]

There are three main orbit types relevant to this discussion: geostationary or synchronous orbit (GEO and GSO), medium earth orbit (MEO) and low earth orbit (LEO). Each of these orbits brings benefits and drawbacks but once reached, a satellite cannot change between them. LEO is where many imaging satellites are positioned, due to the increased proximity to Earth's surface but also for better access to the poles when they are in offset orbits due to their low orbital period (approximately 90 minutes).

Satellites are rapidly reducing in price, thanks to development work in small, low unit cost 'CubeSats', already tested by the European Space Agency (ESA) and others.[38] The industry is also working towards offering a 'plug and play' capability – again driving down the cost and increasing the certainty that payloads will work as expected when in orbit. With CubeSats and HAPS developing rapidly and on similar timescales, this gives us an opportunity to think about the best way to integrate our capabilities all the way down the stack from GEO at 22,000km, to LEO at roughly 500km, HAPS at 20km (60,000' plus) and MALE RPAS/manned platforms mostly below FL 600.

For the foreseeable future, there will be a need for large satellites. Positioning satellite constellations (GPS, GLONASS etc) sit in MEO, offering the orbital stability to offer nanosecond[39] timings and therefore global position indication. Large GEO or GSO telecomms satellites such as AlphaSat offer positionally stable, wide area, high bandwidth broadcast and communication. LEO imaging satellites offer very high persistence (but not immediate), wide area mapping or environmental observation (RADARSAT 2 for example).[40]

So what about small satellites? The RAF recently invested £4.5m in Carbonite-2, a small satellite imaging demonstrator, capable of delivering 1m resolution HD video in 5km swathes.[41] From design to launch, this programme took ten months, a truly rapid capability. The key here is commercial off-the-shelf (COTS) components, very little redundancy and 'good enough' design. The aim is to launch a fleet of smaller satellites to offer increased coverage and better revisit times for the same cost as a medium or large size imaging satellite would have cost. Currently, this technology is largely aimed towards replacing large imaging satellites in LEO, but it is conceivable that the same principles will be applied to communications satellites in the near future. COTS and the improvement in 'plug and play' satellite super-structures means that it may become feasible to launch a satellite or constellation on a timescale of six months to a year, from design to being operational.

Cost comparison

Carbonite-2 cost approximately £10m[42] of which the RAF contributed £4.5m.[43] It is estimated that the future cost of small (approx 50kg) satellites could be as low as $2m a piece, in a production run of around 20-40.[44] Based on a similar system, a constellation of roughly five LEO satellites is enough to give once-a-day coverage of any particular area, plus the time taken for the imagery to be passed back via a ground station. The design life of a low-cost, non-redundant satellite like Carbonite-2 is around five years[45] (based on space weather), but may be significantly longer or shorter than that; Carbonite-1, built to a similar specification, was launched in 2015 and is still operational after nearly four years.

Currently, a Zephyr 8S (i.e. the single-tailed model) costs around £3m, but Airbus are in the process of ramping-up production at their facility at Farnborough, and it's realistic to project that a unit cost of somewhere around £1m (still with £500,000 being spent on batteries at current technology prices) would be feasible in the near to medium term.[46]

Integration of HAPS and Space

One of the issues with LEO imagery is not just the revisit time, but the time required to then download the image – and the location of the ground terminal. The transit time of a LEO satellite over a point on Earth is short: the orbital period is approximately 90 minutes, and visibility to a ground station is approximately 20-30 minutes.[47] Even if a ground station was co-located with the area of interest, there would not be time to take the images and then download them. If you wanted 'instant' imagery of the theatre in which you were deployed, for example, you would likely need to wait for the satellite to image your area, then wait until its orbit passes one of its ground terminals, then wait for the image to be transmitted back to you, in theatre. With HAPS, since they are able to keep line-of-sight with the LEO sat for a lot longer than a given point on the ground (visibility of around 2.5 hours a day),[48] it would be possible to use a HAPS as a surrogate ground terminal, and access LEO imagery without waiting for a revisit, or for the LEO to pass overhead a ground terminal somewhere else in the world.

In the same way, a network of HAPS could free up bandwidth on MEO or GEO satellites by acting as a local re-broadcast station, allowing users within the same HAPS footprint to communicate directly, and passing information through the satellite channel only when required, thus acting as a 'filter' to minimise the use of expensive satellite bandwidth.[49] Platform-platform visibility could be as much as 1,250nm at 65,000 feet,[50] meaning that if a stable HAPS-HAPS communications relay could be established, satellite bandwidth could be bypassed altogether, used as a backup, or used for critical parts of the mission, if the remote operating location (which could mean any sort of remote connection – a live feed into a Combined Air Operations Centre (CAOC) from a fast jet; operating MALE RPAS; supplying ground based C2 remotely) and the operational theatre were close enough together. For example, the straight line distance between RAF Akrotiri and Raqqa is approximately 350nm, which could make remote operating a feasible prospect – perhaps even from a tethered aerostat in Cyprus to a HAPS overhead Syria.

Conclusions:

HAPS show promise over several applications; however, the technology is not yet mature enough to deliver them all. It is, however, advancing rapidly on all fronts, but until the air vehicles can be shown to be reliable and cost effective, they will not enter widespread use. It is nevertheless sensible for the MOD to invest at this early stage, to help develop vehicles and payloads suitable for military use.

HTA HAPS are at the most mature stage of design now and combine a good degree of flexibility with semi-permanent persistence. Their major downsides are extremely limited weight for payloads, limited excess power, and a binary tendency towards either success or catastrophic failure, although, so far, this seems limited to the launch and recovery phase.

LTA HAPS also show promise for investment but are likely to be further away from maturity for military applications. Google has shown that balloons can be used successfully for distributed networking, but careful consideration must be given to whether military payloads would be suitable, given the high 'in-situ' failure rate.

LTA Airships are perhaps the most promising technology from a broadcast and network perspective given their (putative) ability to carry heavy payloads for a long period of time. But the technology seems the least mature, and unless they can be proven to operate successfully in the long term, their much higher cost must give cause for concern over value for money when compared with air-breathing platforms.

Other than the air vehicles themselves, there are certain key technologies that must be developed in parallel to fully exploit the potential of HAPS. Reliable, high bandwidth and interoperable communications are one such example. Building this type of communication network between HAPS, 'air breathers', MALE RPAS and satellites will take many years due to the long lead- and lifetimes of modern platforms. But the framework should be put in place now, to ensure that systems are designed from the bottom up with interoperability in mind.

Lightweight, lower power payload development specifically for HAPS is another key enabler, especially for HTA HAPS. Airbus and the MOD's investment seems to be paying off in this regard, with several novel applications of existing technologies being designed for the Zephyr. This may have some synergy with COTS payloads for small satellites too, as the drivers are similar – driving down weight and power and therefore overall cost.

HAPS could, in the future, be a key force multiplier, especially when considering the provision of wider SA and communications to ground troops. They could also be a force enabler in our technologically reliant air force of 2020 and beyond – driving down the cost of platform-platform (e.g. LINK-16) or platform-operator (e.g. replacing or augmenting Reaper/Protector satellite communication) communication will be key to ensuring our technology remains affordable to operate. Bringing together and being able to disseminate increasingly complex and accurate pictures of the battlefield will be key to whole force interoperability in future conflicts.

Conversion table of km to feet	
Kilometres (to the nearest 10m)	Feet (to the nearest 10ft)
1.00	3,280
9.14	30,000
20.00	65,620
18.29	60,000
80.00	262,470

Notes

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