# Integrated Project

# ABSOLUTE - Aerial Base Stations with Opportunistic Links for Unexpected & Temporary Events

## Contract No. 318632

# Deliverable

## FP7-ICT-2011-8-318632-ABSOLUTE/D2.3

# Aerial Platforms Study

| | |
|---|---|
| **Contractual date:** | **M12 30/09/2013** |
| **Actual date:** | **30/10/2013** |
| **Authors/Editors:** | **David Grace (UOY), Tao Jiang (UOY),**<br>**Sandy Allsopp (HLK), Laurent Reynaud (FT), Mihael Mohorcic (JSI).** |
| **Participants:** | **UOY, FT, HLK, JSI** |
| **Work package:** | **WP2 (Task 2.3)** |
| **Security:** | **PU** |
| **Nature:** | **Report** |
| **Version:** | **V1.0** |
| **Total number of pages:** | **53** |


**Abstract**

This deliverable discusses the options available for aerial platform deployments for the ABSOLUTE architecture, along with operating characteristics and constraints for the different types of aerial platform. Specifically, low altitude aircraft and airship UAVs, along with tethered platforms are discussed, along with high altitude platform (high altitude UAVs) variants. Significant material is also presented on the Helikite, which is ABSOLUTE's chosen platform for its demonstration. This platform is a hybrid kite and tethered platform, along with its benefits and drawbacks. Key constraints discussed for all platforms include attitude stability, available payload power, weight and volume. Link budgets for both uplink and downlink for several frequencies and altitudes are discussed. The maximum coverage area for a low altitude platform is likely to be approximately 15km radius, given the operating constraints.



**Keywords**

Aerial Platform, Payload, UAV, Aerial Platform Operating Characteristics, Aerial Platform Types, Helikite, Radio Regulation.

# Table of Contents

# List of Figures

# List of Tables

# Abbreviations

| | |
|---|---|
| ABSOLUTE | Aerial Base Stations with Opportunistic Links For Unexpected & Temporary Events |
| ATM | Air Traffic Management |
| BRLOS | Beyond Radio Line of Sight |
| BVLOS | Beyond Visual Line of Sight |
| CAA | Civil Aviation Authority |
| DARPA | Defense Advanced Research Projects Agency |
| EVLOS | Extended Visual Line of Sight |
| HAP | High Altitude Platform |
| HAPS | High Altitude Platform Station |
| IFR | Instrument Flight Rules |
| ITU-R | International Telecommunications Union - Radiocommunication Sector |
| KARI | Korea Aerospace Research Institute |
| RF | Radio Frequency |
| RLOS | Radio Line of Sight |
| RPAS | Remotely Piloted Aircraft Systems |
| UAS | Unmanned Air System |
| UAV | Unmanned Aerial Vehicle |
| UCAV | Unmanned Combat Aerial Vehicle |
| VFR | Visual Flight Rules |
| VLOS | Visual Line of Sight |
| LTE/LTE-A | 3GPP Long Term Evolution and Long Term Evolution-Advanced |
| 3GPP | 3rd Generation Partnership Project |
| AM(R)S | Aeronautical Mobile (Route) Service |
| AMS(R)S | Aeronautical Mobile-Satellite (Route) Service |

# Executive summary

This deliverable investigates possible aerial platforms and the associated operating environment, for use with the ABSOLUTE scenarios. The number and variety of different aerial platform types have increased significantly in the last few years, as manufacturers, the military and civilian operators become aware of their capabilities.

Chapter 2 provides a taxonomy of different types of aerial platform or UAV, which fall generally into three groups, aircraft, airships, and tethered aerostats. Most UAVs tend operate at low altitudes, with a ground based pilot with the UAV in direct sight. They have limited payload capabilities and short flight endurance. Mid-altitude UAVs, cost considerably more and tend to be remotely piloted, with some autonomous variants under investigation. There is also a number of high altitude UAVs (High Altitude Platforms). Currently, these are very limited in number due to technological and funding constraints. However, these have the greatest long term promise, due to several favourable operating conditions, low wind speeds, solar power capability, with the potential capability to operate with payloads up to 1 tonne. A typical current example includes the Zephyr which can carry light weight payloads, with flight durations currently up to 100 hours. Airships are also available for all altitudes. Their advantages include loitering capability and ability to carry moderate to heavy payloads (hundreds of kilogrammes), but adverse weather can be a problem, as can ground handling. The family of tethered aerostats also have loitering capability, with the tethers also potentially providing power and backhaul. Aerostats carrying small scale payloads (up 10kg) can be handled on the ground well. ABSOLUTE's chosen solution for the demo is the Helikite, a hybrid kite and tethered aerostat, which is stable in adverse weather and as such overcomes most the drawbacks mentioned above.

Chapter 3 considers the operating environment in more details, specifically taking into account the Helikite platform. It looks at the aeronautical regulations relating to UAVs and the Helikite, along with the radio regulations, including the issue of governance, and whether terrestrial frequencies can be used from UAVs. Representative link budgets for uplink and downlink LTE-A based services at 700MHz and 2.6GHz for aerial platforms and different coverage areas are covered. Uplink and downlink link budgets close for coverage areas up to 15km radius at 300m of height.

Chapter 4 provides a more detailed examination of the Helikite platform. It also presents details of the launch and recovery procedures, including timescales, number of people required at the Helibase, and transport requirements. Assuming that the ABSOLUTE scenario requires a 34m3 Helikite, then this can be deployed from the Helibase, and fully operational within 56 minutes, by no more than two people, once fully trained. Other Helikite platform sizes are also presented and evaluated for operational applications.

The final main chapter (Chapter 5) considers which aerial platform types will be best suited to the ABSOLUTE scenarios in the future. All classes of UAVs will improve, meaning that their superior deployment capabilities can be exploited. High altitude platforms provide also good long term solution, with potential to operate with long endurance, in a benign part of the atmosphere, potentially using solar power.

# 1. Introduction

The use of aerial platforms forms a key component of the ABSOLUTE project. They are required to deliver wide-area wireless coverage, with many applications also requiring a rapid deployment often to in-hospitable areas, e.g. those post disaster.

The elevated look-angle allowed by aerial platforms should offer significant advantages compared with terrestrial equivalents, also offering the potential to deploy cameras or other sensors at the same time. This is beyond the ABSOLUTE project itself, but there is a clear need for such capabilities in many of the use cases.

In this deliverable we review the state-of-the art in the different aerial platform technologies, and also point out the advantages and disadvantages of the various aerial platform technologies for the purposes of ABSOLUTE.

Much of the focus is on low altitude aerial platforms, including low altitude UAVs, tethered aerostats, along with an extensive discussion on the Helikite, ABSOLUTE's chosen demo platform, which is a hybrid tethered aerostat/kite platform. We also look in some detail at high altitude platforms (HAPs), which have a number of potential advantages, including capability of providing regional coverage, and long endurance. HAPs are in general an aerial platform for the future, although a number exist at the moment, but currently for practical purposes are too expensive for this type of mission.

In the remainder of this chapter we will look at a number of key features of aerial platforms in more details. In chapter 2 we present a detailed taxonomy of different aerial platform types in order to get a broad view of their capabilities, and provide a detailed discussion of how the aerial platform should be selected for different post-disaster and temporary event operations and missions. In Chapter 3 we present the operational environment and a brief examination of the aeronautical and radio regulatory constraints, physical factors, and general link budgets giving an indication of likely coverage areas when using a single cell aerial platform. In chapter 4 we present a detailed overview of the ABSOLUTE's chosen aerial platform for the demo, the Helikite platform. In Chapter 5 we look to the future, and discuss the possible trends in aerial platform design. Chapter 6 presents the conclusions and key recommendations.

## 1.1 Key Features of Aerial Platforms

A perfect airborne platform should be able to deliver instantly unlimited 4G radio capacity over a specific coverage area, with no interference to neighbouring users. Past airborne radio-relay platforms fielded were very expensive per hour but still left a lot to be desired in terms of payload, altitude, endurance, ease of use, all-weather ability, safety and cost. Aerial platform based wireless communications are dependent upon a) the radio equipment itself and b) the characteristics of the platform, so a full understanding of the performance of the platforms is as important as a full knowledge of the radios. In brief, the relevant problems in relation to the potential coverage area over time are:

- **Radio trucks with masts.**
  - High capacity density, but small coverage area, so many masts required.
  - Fixed stable location, delivering excellent predictable communications
  - Deployment overland is required, which could be problematic for some deployments.
  - Unattended masts are very vulnerable to theft.
  - Expensive per sq km, if coverage is required.

- **Satellite.**
  - May be static or moving.
  - Excellent coverage, but limited capacity density.
  - Very expensive per Mbyte.
  - Unavailable in forests and urban canyons.
  - Potentially slow to deploy (depending very much on users and links to corresponding agencies)

- **Manned aircraft.**
  - Ability to fly rapidly to point of use, without the need for people on the ground at remote site.
  - Large payload capability
  - Significant power available to the payload
  - Constantly moving meaning that footprint stabilisation is required, and possibly handoff.
  - Expensive.
  - High wear.
  - Used over long periods of time they place valuable pilots at high risk.
  - Vulnerable to mechanical failure.
  - Fuel hungry.
  - Air traffic control problems

- **Unmanned aircraft.**
  - Ability to fly rapidly to point of use, without the need for people on the ground at remote site.
  - Constantly moving meaning that footprint stabilisation is required, and possibly handoff.
  - Low endurance.
  - Expensive.
  - High attrition.
  - Vulnerable to mechanical failure.
  - Limited capability (capacity) – unless large UAV.
  - They are likely to still need pilots (currently aeronautical regulation does not permit autonomous flight in civilian aerospace).
  - Air traffic control problems.

- **Traditional tethered blimp aerostats.**
  - Potentially large payload capability
  - Low or high altitude use.
  - Wide area coverage
  - Too big to handle easily.
  - Need to travel to point of use by road.
  - Need fair weather and are unstable in high winds.
  - Expensive.
  - Bad ground handling.
  - Require significant helium.
  - Need to manage flight exclusion zone, depending on altitude.

- **Airships.**
  - Potentially large payload capability
  - Wide area coverage
  - Significant payload power
  - Able fly to point of use, rather than travel by road.
  - Excessive attrition.
  - Fair weather only landing and taking off.
  - Large manpower requirement.

- Very expensive per hour and per unit.
- Require significant helium.
- Mechanically unreliable.
- Requires scarce pilots, and used over long periods of time they place valuable pilots at high risk.

- **Helikites.**
  - Potentially easy to use (depending on the size of the platform).
  - Low or high altitude use (similar to blimp platforms).
  - More stable than blimp platforms in high winds.
  - Persistent, Reliable.
  - Versatile.
  - Minimal manpower required for small payloads, with limited capability.
  - Antenna directivity could be a limiting factor on small payload deployments.
  - Inexpensive per hour and per Mbyte (but subject to capacity constraints).
  - Need to travel to point of use by road (the way to transport the platform is a key point)
  - Need to manage flight exclusion zone, depending on altitude.
  -

Table 1.1 presents a general comparison.

**Table 1.1 Aerial platform comparison chart**

| AERIAL eNB PLATFORM CAPABILITIES | TETHERED HELIKITE AEROSTAT | MAST | SATELLITE | MANNED AIRCRAFT | UAV | TETHERED NORMAL AEROSTAT | AIRSHIP |
|---|---|---|---|---|---|---|---|
| High Payload | **Depends on size** | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Wide Area Coverage | ✓ | | ✓ | ✓ | ✓ | ✓ | ✓ |
| Moving Coverage | | | | ✓ | ✓ | | ✓ |
| Heavy/Bulky Payload | **Depends on size** | | ✓ | ✓ | **Depends on size** | **Depends on size** | ✓ |
| Optimum Altitude | ✓ | | | ✓ | ✓ | ✓ | ✓ |
| Extreme Duration | ✓ | ✓ | ✓ | | | ✓ | |
| Ad-Hoc Network Friendly | ✓ | ✓ | | | ✓ | ✓ | ✓ |
| Safe for Operators | ✓ | | ✓ | | ✓ | ✓ | |
| Low Attrition Rate | ✓ | ✓ | ✓ | | | | |
| Instant Deployment | **Depends on size** | ✓ | | ✓ | ✓ | | |
| All-Weather Operation | ✓ | ✓ | ✓ | ✓ | | | |
| All-Weather Deployment | ✓ | ✓ | | ✓ | | | |
| High Technology Security | ✓ | ✓ | ✓ | | | ✓ | |
| Small & Easily Handled | ✓ | | | | ✓ | | |
| Single Person Deployment | **For small platforms** | ✓ | | | | | |
| Airborne Deployment | | | ✓ | ✓ | ✓ | | ✓ |
| Inexpensive Coverage | ✓ | | | | | | |
| Air Traffic Friendly | ✓ | ✓ | ✓ | | | ✓ | |
| Tough | ✓ | ✓ | | | | | |
| Expendable | ✓ | | | | | | |
| Minimal Training | ✓ | | | | | | |
| No Fuel Required | ✓ | ✓ | | | | ✓ | |
| Good Antenna Placement | ✓ | ✓ | ✓ | **Depends on configuration** | | ✓ | ✓ |
| Widely Available | ✓ | ✓ | | ✓ | | ✓ | |
| Established Technology | ✓ | ✓ | ✓ | ✓ | | ✓ | |
| Worldwide Operations | ✓ | ✓ | ✓ | ✓ | | ✓ | |

# 2. Taxonomy of Aerial Platform Types

## 2.1 Introduction

There are a good number of different types of aerial platform, and the aim in this section is to introduce the different types, identifying their critical features.

To get an idea of their increasing popularity it is useful to quote some statistics on the numbers of different types. Currently in the UK there are around 170 companies, universities and private individuals with licences to use remotely piloted aircraft systems (RPAS) / UAVs in UK airspace (not included in these statistics are the large number of smaller UAVs which do not require permission).The following statistics are based on UK Civil Aviation Authority Permissions, given up to March 2013 [1].

- 75% are rotary wing
- 23% fixed wing
- 2% seaplane/airship
- 75% are electrically powered
- 25% turbine, jet, piston
- 31% are 2kg or less
- 67% are 7kg or less
- 95% are 20kg or less
- 5% more than 20kg

Types of RPAS/UAV operations are defined by the distance above ground level to very low level operations and operations under Instrument Flight Rules (IFR) or Visual Flight Rules (VFR) [2]. Very low level operations, typically restricted to the altitude of 400ft above ground level, comprise:

- **Visual Line of Sight (VLOS)**. Here the ground based remote pilot has ‘See and Avoid’ responsibilities through visual observation (visually managed). This means they have limited range, based on their size and colour, and weather conditions, typically restricted to 400ft vertical and 500m horizontal.
- **Extended Visual Line of Sight (EVLOS)** with more flexible conditions attached as to how direct visual contact is maintained with UAV beyond the horizontal distance of 500m from the pilot, typically relying on additional ground based observers and appropriate procedures for communication between them and the remote pilot. This may only apply in the UK.
- **Beyond Visual Line of Sight (BVLOS)**. In this case UAVs need to be equipped with an approved Detect/Sense and Avoid System or be restricted to operation within a segregated Airspace (if no D&A system fitted).

For safety reasons none of these three types of very low level operation is allowed to be used above densely populated areas.

Other types of UAV operation, i.e. flying under IFR or VFR, require UAV to be equipped with collision avoidance systems. These UAVs can be used above 400ft and also above the minimum flight altitudes of manned aircraft. They comprise:

- **Radio Line of Sight (RLOS)** operations of UAVs in non-segregated airspace, i.e. same airspace as used by manned aviation, requiring ‘detect and avoid’ (D&A) methods in relation to cooperative and non-cooperative nearby traffic.

- **Beyond Radio Line of Sight (BRLOS)** operations, where UAVs are no longer in direct radio contact with the remote pilot, which thus relies on wider range communication services, including via satellite, which would typically be provided by external service provider.

Having recognised the enormous economic potential of UAVs, currently there are intense activities underway in the international community (particularly in USA and in Europe) to integrate civil RPAS/UAVs into non-segregated air traffic management (ATM) environments, in USA starting with the integration plan by end 2015 [3] and also in Europe aiming at the integration by 2016 [2].

## 2.2 Low Altitude Unmanned Aerial Vehicles

### 2.2.1 Context

The use of unmanned aircraft is rapidly expanding through a large range of applicative uses; it is however observed that their development initially resulted from their military applications, for which the dominating principles were simple: develop unmanned vehicles that could successfully perform missions normally carried out by manned craft. Many UAV concepts, prototypes and operational craft have been developed during the twentieth century in this context, along with the continual improvements made in domains like propulsion, electronics and computer science. In particular, several UAVs were used during World War II, for various missions including offensive missions (e.g. the unmanned PB4Y craft was used for remotely-controlled bombing missions by the US military) and realistic drills (many planes were modified to serve as manoeuvrable targets). Although early UAVs were essentially remotely-controlled drones, unable to fly autonomously, this progressively changed at the turn of the millennium with the appearance of new generations of unmanned combat aerial vehicles (UCAVs) with more advanced avionics, guidance and auto-pilot systems. In parallel, while space agencies worldwide saw the interest of UAVs for planetary exploration, the Military identified other valuable uses for UAVs, such as performing reconnaissance missions for disaster relief and urban warfare or establishing dynamic and scalable communications networks.

Furthermore, in the wake of military applications for UAVs, an increasing number of civilian uses have emerged and expanded for the last decade. These uses include various types of reconnaissance, search-and-rescue and sensing missions for public protection and disaster relief, wildlife protection, etc. The great variety of missions is particularly eased by the large range of form factors and aerodynamic principles that underlie the diverse types of UAVs, as outlined in the rest of this subsection.

### 2.2.2 Rotary Wing Aircraft

Rotary Wing Aircraft are a special type of aerial vehicles. Due to their relatively low resources, both in terms of payload capacity and autonomy, they are generally restricted to low altitudes or even very low altitudes (i.e. within a range of a few meters to a few hundred meters). Another consequence of their small form factor is that they are necessarily unmanned. As a result, they can be classified as a subtype of Unmanned Aerial Systems (UAS).

#### 2.2.2.1 *Payload*

Due to their small form factor, micro-drones can lift a very limited weight. Generally, the payload ranges from a few dozen grams for the Micro Aerial Vehicles (MAV) to 5-7 kilograms for the larger UAS.

### 2.2.2.2 *Autonomy*

In a similar fashion, UAS autonomy is relatively limited. This is in particular verified for rotary-wings vehicles which require a relatively important amount of energy to sustain their altitude, which adds to the fact that those vehicles generally use small batteries, which only provide a few minutes of autonomy for the whole platform (propulsion, telemetry and payload included). Some techniques could allow much greater autonomy, with for instance the use of energy harvesting techniques [4]. Another approach would be the use of contact-less mechanisms to recharge the vehicles. However, the expected autonomy of MAV and UAS is generally in the range of 10 to 40 minutes, depending mainly on the battery capacity, mission mobility pattern and payload weight.  Examples of off-the-shelf rotary wing aircraft can be found in Figure 2.1.

(a) (b)

(c) (d)

(d) (e)

**Figure 2.1 Examples of rotary wing aircraft**

### 2.2.3 Fixed Wing Aircraft

Unlike military-grade fixed wing aircraft which often exhibit a significant weight and a large wingspan, close to that of a typical manned aircraft (e.g. Global Hawk / EuroHawk, Predator, X-47, GNAT/I-GNAT, …), it can be observed that low altitude UAVs intended for civil uses are generally of more limited dimensions. For these smaller UAVs, different features are desirable: these craft, often close to the MAV form factor, must rely on low-power and energy-efficient lightweight structures, with a sufficient payload capacity and, for the civil market, user-friendly interfaces which allow efficient trajectory management as well as positioning tools. Moreover, their autonomy, compared to that of rotary-wing craft, is generally greater, which allows extended mission durations and range operations.

Among the many commercially available low altitude fixed wing UAVs, a few typical examples can be given: Figure 2.2 represents the Gull 36 from the English manufacturer Warrior (Aero-Marine) Ltd. This model features a 4m wingspan and belongs to a commercial series of low altitude craft with different dimensions, starting with payloads of 2 kg. This UAV is a Short Take-off and Landing aircraft (STOL) and also an amphibian UAV, particularly adapted for coastguard unmanned system operations.

Other UAVs rely on a simpler design but still can fulfil interesting missions, in particular for PPDR purposes. That is the case of the Seeker 1300, from the Seeker low altitude UAV series, manufactured by the French Fly-n-Sense company and illustrated in Figure 2.3. This UAV, with its range of 10 km operating range, its autonomy of 1 hour and its maximum speed of 80 km/h, is a very lightweight UAV: with a Maximum Take-Off Weight (MTOW) of 2.4 kg, it can lift a modular payload of 500 g, and successfully achieve various missions related to fire prevention, border and site surveillance, atmospheric studies, topography, and so on. This latter form factor, which focusses on lightweight and mission range, is increasingly proposed by different manufacturers, which abundantly advertise on the speed and ease of deployment as well as the controlled costs of the solution.

Finally, another typical form factor is illustrated by Figure 2.4, Figure 2.5 and Figure 2.6: with a structure often made of plastic foam material, such as high density Expanded Polypropylene (EPP), these craft are particularly lightweight, with large and detachable wings (or, for instance with the Swinglet CAM from SenseFly, a very reduced wingspan), which allows for small packaging and easy deployment. These UAVs are particularly used in the context of reconnaissance, aerial photography and topography.


**Figure 2.2 – The amphibian Gull 36 UAV from Warrior Ltd., UK.**

**Figure 2.3 – The lightweight Seeker 1300, from Fly-n-Sense, France.**


**Figure 2.4 - The QuestUAV 300 from QuestUAV Ltd., UK.**

**Figure 2.5 – The Ebee from Parrot / SenseFly, France.**


**Figure 2.6 – The swinglet CAM from Parrot / SenseFly, France.**

### 2.2.4 Airships

Compared to rotary and fixed wing aircraft, which are representatives of aerodynamic platforms, kepf aloft due to dynamic forces created by the movement (of wings of aircraft) through the air, airships (as well as balloons) classify as aerostatic platforms making use of buoyancy to float in the air. Airships are much more flexible in terms of weight, size and power consumption of the payload, essentially only depending on the volume of the envelope (which can measure more than 100m in length). As to the operational altitudes, airships can be and have been designed for different altitudes, again through the air density in the formula for the buoyancy force affecting the volume of the envelope. While typical commercial manned airships for cargo or passengers typically fly at low altitudes of approximately 200m to save helium, unmanned airships and balloons have been designed to fly up to almost 30km above the ground level.

If station keeping above the service area at selected operating altitude can be guaranteed with suitable electric motors and propellers, unmanned airships are well capable of staying in the air for long periods of time, even years. The main drawback for the use in disaster recovery actually comes from their size, requiring high-strain envelope material, extensive ground operations centre and appropriate ground facilities including hangars for storing and field for lifting and descending.

Examples of different airships are depicted in Figure 2.7, Figure 2.8 and Figure 2.9.


**Figure 2.7 The manned Zeppelin NT airship for passangers**

**Figure 2.8 The unmanned KARI airship (Via 50)**

**Figure 2.9 The SkyCAT technically a hybrid airship fixed wing craft**

### 2.2.5 Other types

It is also worth mentioning ornithopters, which represent another type of low altitude UAV which has recently met a growing interest for surveillance missions in particular. With ornithopters, the driving airfoils exhibit a back-and-forth motion: those systems are generally said to have “flapping wings”, to take a bio-inspired terminology.

Several recent examples can illustrate the concept, such as the different ornithopters exhibited by Festo, a German supplier of automation technology. BionicOpter [5], a recent prototype of a 175g dragonfly-shaped UAV shows a particular care for wing movement control: as illustrated by Fig. 2.15-a, the four wings, activated by nine servo motors and an ARM microcontroller, feature a frequency and amplitude controller. As a result, the direction and intensity of thrust and can be adjusted on the basis of each individual wing movement, allowing this UAV to be easily steerable indoors and outdoors, besides being able to glide. In particular, it can be observed that, unlike a rotor-based UAV, this ornithopter does not need to tilt forward to generate forward thrust (in other words, it can fly horizontally). Festo also demonstrated SmartBird, as shown by Fig. 2.15-b, a 450 g ornithopter with a wingspan of 2 m, inspired by a herring gull and which can start, fly and land autonomously. The average electrical power requirement of this UAV is 23 W, which can be served by a 7.4 V / 450 mA lithium-polymer (LiPo) accumulator. Likewise, another interesting variation of the flapping wing concept is illustrated by Fig. 2.15-c: Festo’s AirPenguins, a 1 kg ornithopter which also uses the buoyancy properties of a 1 $m^3$ helium-filled balloon, which is able to generate about 1 kg of buoyant force.

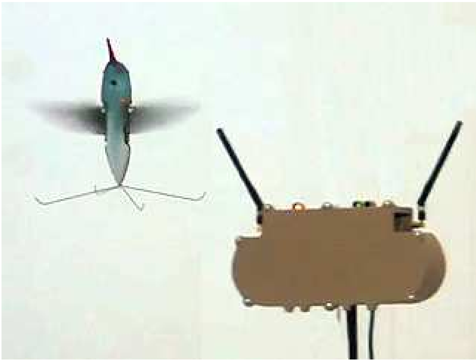
Finally, another significant achievement in the context of ornithopters is AeroVironment’s Nano Hummingbird [6], a 19 g very lightweight UAV equipped with a camera, shown in Fig. 2.15-d, for which the Defense Advanced Research Projects Agency (DARPA) contributed $4 million since 2006.

Those examples highlight that this type of UAV is not generally meant for payload lifting, but can offer useful systems for specific missions, including reconnaissance, where stealth, flight efficiency and adaptation to specific environments are primary requirements.

(a)

(b)


(c)



(d)

**Figure 2.15 - Four examples of ornithopter UAVs: a) BionicOpter, a 4-winged ornithopter, b) SmartBird, a bird-inspired UAV, c) AirPenguin, a hybrid aerostat-ornithopter prototype and d) Aerovironment's hummingbird nano UAV.Mid Altitude Unmanned Aerial Vehicles**

## 2.3 Tethered Platforms

### 2.3.1 Tethered Aerostats

Tethered aerostats have been used for many years for Defence and Homeland Security applications, including communications relays, earth observation monitoring and surveillance, with optical/infrared devices and radar. Payloads may include stabilized electro optical, infrared, radar and acoustic sensors or a combination of multiple sensors. Lightweight sensor packages can be integrated, using the latest state-of-the-art technology. By optimizing the complete aerostat configuration, customer’s requirements can be fulfilled while keeping the logistic footprint to a minimum. They can be deployed at perimeters, during patrols and at ships.

They can typically operate at altitudes of up to 5km. Ultra-strong light weight tethers are very successful, providing the option of power and communications backhaul. Examples of deployments can be seen in Figure 2.10 and Figure 2.11.

In the case of Figure 2.10, the size of each aerostat is 71m, with the systems being designed to operate continuously for 30 days, come down for eight hours of maintenance and go back up for another 30 days.

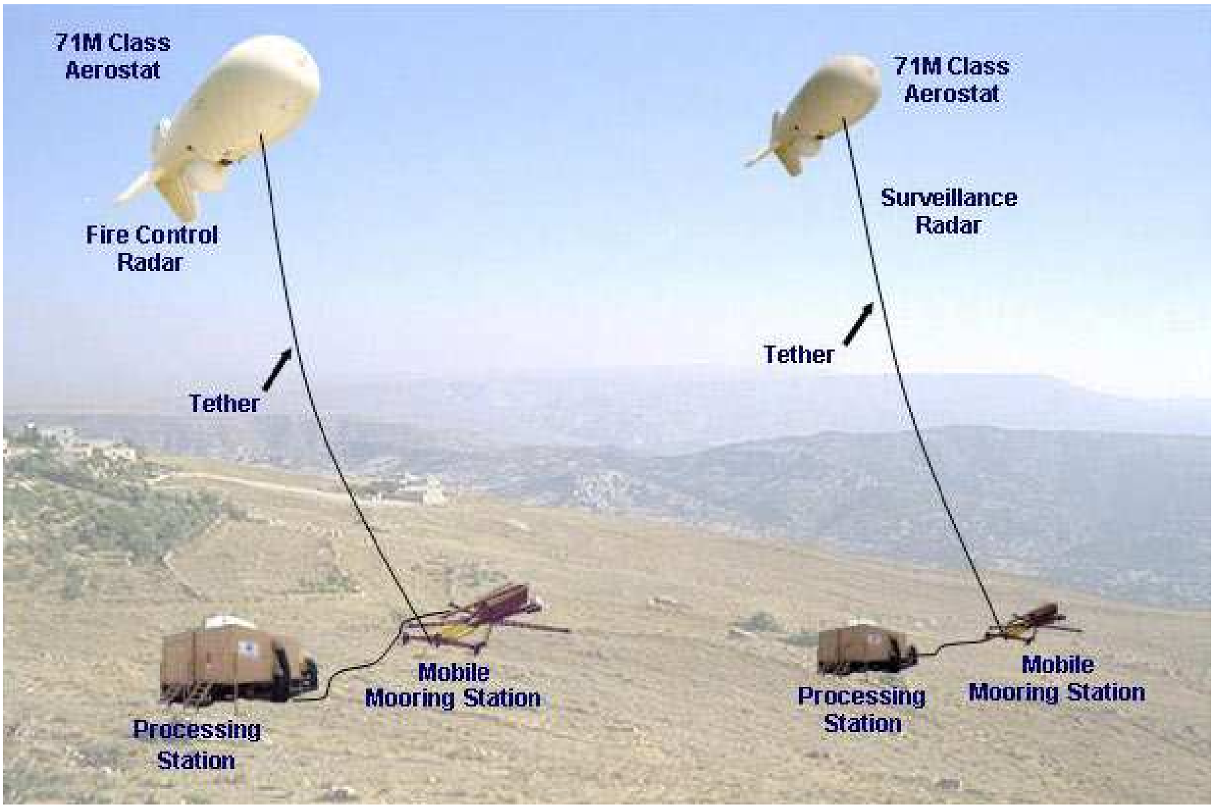



**Figure 2.10 Conventional Tethered Aerostats in use with US Army [7]**

**Figure 2.11 Vigilance Tactical Aerostat system [8]**

In the case of The DB series rapid deployable aerostat systems, as shown in Figure 2.11, are ideal for user payloads up to 50kg. The special patented design of the aerostat allows increased lift with increased winds enabling operations in higher winds than conventional aerostat designs.

### 2.3.2 Helikite

The names Helikite and Helikites, are Allsopp's Registered Trade Marks relating to a new type of kite-style aerostat designed and patented by Sandy Allsopp in England in 1993. The name Helikite relates to a combination of a helium balloon and a kite to form a single, aerodynamically sound tethered aircraft, that exploits both wind and helium for its lift. The balloon is generally oblate-spheroid in shape. The aerodynamic lift is essential to combat the wind and allow even small Helikites to fly at very high altitudes in high winds that push simple balloons to the ground. Helikites are a very popular all-weather, high-altitude, aerostat. Thousands are operated worldwide, flown over both land and sea by both civilians and the military.

The type of Helikite being considered for the ABSOLUTE project is the “Desert Star Helikite”, as shown in Figure 2.12 - Figure 2.14. This was originally designed for the British and US Armies and is very tough. The polyurethane balloon is protected within a composite outer cover and it is capable of operating for many weeks without significant wear. The 34 $m^3$ volume version is the size under consideration for use within the project, and more details of its operation are given in Chapter 3 of this deliverable. However other size could be used depending on the weight of the payload that could be obtained in the scope of ABSOLUTE.

**Figure 2.12 34$m^3$ Desert Star Helikite on Helibase with winch**

**Figure 2.13 34m$^3$ Desert Star Helikite in flight with camera payload**

**Figure 2.14 10m$^3$ Desert Star Helikite with antenna payload**

**Figure 2.15 34m$^3$ Desert Star Helikite at high altitude - Mast is 30m (100ft) high**

## 2.4 High Altitude Platforms

High altitude platforms have attracted considerable interest over the last 15 years. They are defined as craft that are located typically 17-22km altitude [9]. Again they can be divided into two broad categories aircraft and airships. Different from the low altitude and mid altitude, many of these concepts are still on the drawing board, as they require technological advances, and substantial funding before they come to fruition.

There are a number of advantages of HAPs over other forms of UAV, and these include:

- Coverage improvements
- Can operate autonomously as they are not in regulated airspace
- Less likely to be destroyed from the ground (in military, or hostile situations)
- Can operate with solar power
- Operate in a very benign part of the atmosphere.

In the following sections we discuss some of the most important projects, which may be directly relevant to the ABSOLUTE scenario.

### 2.4.1 FP6 CAPANINA Project

The FP6 CAPANINA Project [10] examined the use of aerial platforms (particularly HAPs) to deliver high data rate broadband services to both fixed and mobile users. Key requirements were high data rate links of up to 120Mbps, and also moderate to high capacity densities over a footprint of 60km diameter. Capacity would be delivered using mm-wave bands (as specified by the Radio Regulations – see chapter 3), with up to 121 cells. Permanent coverage was to be provided by either HAPs operating in fleets, or with High Altitude Long Endurance Craft. They also compared and contrasted different forms of HAP, and these are summarized in Table 2.1 and Table 2.2.

| | Manned | Unmanned | | |
|---|---|---|---|---|
| | Plane | Plane (fuel) | Plane (solar) | Airship (solar) |
| Fronthaul | | | | |
| Availability at min data rate (%) | 99.9 | | | |
| Max clear air cell capacity (Mbps) | 120 | | | |
| Number of cells | 121 | 7 | 19 | 121 |
| Total fronthaul capacity (Mbps) | 14520 | 840 | 2280 | 14520 |
| Cell diameter (km) | 6 | 15 | | 6 |
| Coverage area diameter (km) | 60 | 36 | 59 | 60 |
| Redundancy | 0% | | 5% | 20% |
| Backhaul | | | | |
| Gateway capacity (Mbps) | 960 | | | |
| Capacity per 50MHz backhaul carrier | 320 | | | |
| No of carriers per gateway station | 3 | | | |
| Link redundancy | 0% | | 5% | 30% |

**Table 2.1 Communications operating parameters (based on [11])**

They also proposed a modular payload. The vehicle is one of the most costly items in the business and it is important it is fully and widely utilised, enabling volume production to create economies of scale, minimising costs. HAPs with a generic multi-module payload bay, with a standard set of operating constraints suitable for a wide range of payload modules should be developed. This will make the HAP simpler for non-specialists to use boosting, the take up of the technology. A payload module should be thought of as a fundamental functional unit, for example a backhaul link, a fronthaul cell, a sensor for remote sensing applications. Modules can be mixed and matched on a HAP to support a specific mission, and it will be the norm for services to be supplied to more than one service provider. There are 4 different types of HAP, manned planned plane, unmanned plane (fuel), unmanned plane (solar), unmanned airship (solar). Each HAP has different operating constraints and payload capabilities (in terms of the number of modules they can support), which are again outlined in Table 2.2.

| | Manned | Unmanned | | |
|---|---|---|---|---|
| | Plane | Plane (fuel) | Plane (solar) | Airship (solar) |
| Total Development cost (€M) | 0 | 50 | | 225 |
| CAPEX per unit (€M) | 18 | 4 | | 30 |
| OPEX per annum continuous operation (€M) | 6 | 1 | | 4 |
| Payload –mass (kg) | 1000 | 250 | 150 | 1000 |
| Payload –power (kW) | 10 | 1 | | 10 |
| Operating altitude (km) | 20 | 17 | | 20 |
| Flight duration | 12 hours | 3 days | weeks | years |
| Staff required | 4 pilots + 20 ground crew | 1 pilot + 10 ground crew on launch | | 1 pilot + 20 ground crew on launch |
| Platform lifetime (years) | 10 | 5 | | |
| Number for continuous operation per coverage area | 2 | | 1 | |
| Redundancy factor | 0.3 | | 0.2 | |
| Fleet/ Reserve multiplier | 0.6 | | 0.2 | |

**Table 2.2 HAP operating parameters and costs (based on [11])**

A key difficulty still remains in that these HAPs which are capable of delivering such high payloads, are mostly on the drawing board, or are perceived, in the case of manned HAPs, too costly, so these technologies have not advanced significantly in the last few years. Later sections will show though areas and market segments that are well served and are flourishing.

### 2.4.2 Aircraft

#### 2.4.2.1 ***Global Hawk***

One of the most widely used stratospheric UAVs is the Global Hawk, as shown in Figure 2.16. The Global Hawk was developed by Northrop Grumman for the US military, but is also being used for civilian use by

NASA [12]. It is a short duration UAV, powered by liquid fuel, and a fleet of these has been in use since 2001 [13]. It has significant payload capability, but is costly compared with the other options shown in this report. Given these negative aspects it is not thought suitable for the ABSOLUTE scenario.

**Figure 2.16 Global Hawk developed for the US Military [13], and joint use by NASA [12]**

Key specifications include [13]:

- **Wingspan**: 39.9 m
- **Length**: 14.5m
- **Height**: 4.7 m
- **Gross Take-off Weight**: 14,628 kg
- **Maximum Altitude**: 18.3 km
- **Payload** : 1,360 kg
- **Ferry Range**: 22,780 km
- **Loiter Velocity**: 310 knots True Air Speed (TAS)
- **On-station Endurance** at 1,200 nm: 24 hrs
- **Maximum Endurance**: 32+hrs

#### 2.4.2.2 *Zephyr*

QinetiQ's Zephyr [14] is a solar powered high altitude UAV that is capable of remaining aloft for days at a time. It currently holds the world record for longest continuous flight. The aircraft is equipped with batteries which are charged during the day using the solar power, and then this stored power is used during the night to allow it to remain on station. Its payload capabilities are extremely limited, typically restricted to a maximum of a 1kg payload, with also a very limited form factor.

**Figure 2.17 QinetiQ's Zephyr Aircraft [14]**

### 2.4.2.3 *Ascenta UAV*

The Ascenta-Hale UAV [15] This UAV is solar powered and capable of remaining aloft for 3 months or more, and will carry a payload of up to 25kg, as shown in Figure 2.18. It is currently at the concept stage and is intended for both military and civilian applications.

**Figure 2.18 Ascenta solar powered UAV for stratospheric altitudes [15]**

### 2.4.3 Airships

#### 2.4.3.1 *Varialift*

The Varialift Hybrid Airship, whose concept is shown in Figure 2.19 is being suggested for high altitude use to provide traditional HAP type services. The term hybrid refers to the fact that it is part airship, and part aircraft – it receives some buoyancy from helium, put needs to undertake forward motion to provide some lift to keep it airborne. This has the advantage that take-off and landing is easier control (similar to an aircraft) and it is also more stable in wind. A key selling point for this craft is that it is being designed to accommodate a heavy payload up to 50 or 250 metric tonnes for the two different models. Nonetheless, according to the foreseen specifications given in Table 2.3 (as taken from [16]), this airship is predominantly a cargo airship of rather extreme proportions and also operating requirements, not likely suitable for the ABSOLUTE scenarios unless combined with other mission requirements, e.g. also as a cargo ship to bring the first aid and disaster recovery supplies.

**Figure 2.19 Varialift Hybrid Airship [16]**

| Specifications | ARH 50 | ARH 250 |
|---|---|---|
| Length (m) | 150 | 300 |
| Span (m) | 52 | 110 |
| Max Payload (Metric tonnes) | 50 | 250 |
| Range at Max payload (nm) | 6000 | 8000 |
| Cargo hold length, width, height (m) | 100, 50, 10 | 250, 100, 20 |
| Cargo hold volume (m3) | 25,000 | 500,000 |
| Max operating altitude (ft) | 30,000 | 30,000 |
| Estimated Speed sea level mph | 155 | 155 |

| | | |
|---|---|---|
| Estimated Cruise Speed @ 20,000 ft (mph) | 218 | 218 |
| Vertical take-off and landing | Yes | Yes |
| Minimum Landing field dimensions (m) | 200 x 200 | 400 x 400 |
| Estimated fuel consumption l/hr | 900 | 2500 |
| Avionics Full Glass cockpit, Full IFR | Yes | Yes |
| Crew | 2 | 3 |
| Roll-on roll off Cargo bay decks (10m high) | 1 | 2 |
| Outsize Bulky Cargo crane capability | Yes | Yes |
| Specific task custom cargo hold design | Yes | Yes |

**Table 2.3 Specifications of Varialift airship models ARH50 and ARH250 [16]**

### 2.4.4 Balloons

#### 2.4.4.1 *Google Loon*

The Google Loon experiment is the initial public phase of a R&D project intended to provide network coverage to rural or remote areas. In particular, the underlying technology is presented as a part of Google's plans to fund and develop wireless networks in emerging markets. As far as the project Loon is involved, a fleet of high-altitude balloons, operating at an altitude of about 20 km in the low stratosphere, will be coordinated to cover the designated large scale areas and offer the surrounding users a wireless network with, at best, similar bitrates as those of 3G.

The Google Loon project addresses the stratospheric flight issue with a novel approach: the clear objective is here to obtain low unitary prices for their high-altitude platforms. To do so, Google abandoned the generally well-accepted idea that a high-altitude craft must always keep a stationary position though the permanent use of propellers to fight the dominant winds. Instead of this energy-consuming approach, which implies the use of costly vehicles with heavy batteries and energy sources, Google investigates the ability for their vehicles to passively fly with the dominant winds and to intermittently change their altitude and enter different layers in the atmosphere with winds of opposite directions. Thanks to a challenging observation and prediction of the winds in the different parts of the low stratosphere, Google should be able to loosely control the positions of the crafts without significant energy consumption. Therefore, the viability of potential business models will certainly depend on the ability for each platform to be remotely controlled, and this crucial aspect must still be validated by the ongoing experiments.

In the current form of the Loon experiment, Google deployed 40 balloons in New Zealand, but intends to send up 300 to 400 balloons around the world at the 35th parallel south that would provide coverage to southern countries that include New Zealand, Australia, South Africa, Uruguay, Chile, and Argentina. More generally, with individual ground coverage of about 1200 km$^2$, a significant amount of balloons will be required to cover large scale areas, and this certainly can be seen as a limitation of the solution.

Despite the very limited returns of experience for the Loon approach, it is perhaps possible to speculate that if the further phases of the Loon project confirm the alleged performance of their high-altitude balloon network, this alternate type of flexible, rapidly deployable and scalable network may provide an efficient and affordable mean to cover remote and rural areas of emerging countries. **However, it must be also highlighted that the viability of the potential business models largely depends on the ability for each**

**platform to be remotely controlled, and whether each can supply sufficient capacity density, and this crucial aspect, at the time of writing this report, is still under scrutiny.**

Furthermore, in the context of the FP7 project ABSOLUTE, we believe in the virtues of low altitude platforms, and in particular of tethered balloons, which allow quick, easy, scalable and cost-efficient LTE platform deployments with the ability to provide high-capacity and low-latency capabilities with adapted radio coverage. Indeed it's possible to offer with tethered balloons a reliable communication infrastructure tailored to a large range of services in the context of public protection and disaster relief (PPDR) and temporary events. For these applications, reliability is indeed an important issue.

## 2.5 Conclusions

There is an ever increasing number of different types of aerial platform that are available to deliver wireless communication systems. The low altitude UAVs (either airships or aircraft) have the advantage that they are capable of being flown in to a disaster site, but generally have a short duration mission. Many of these have been realised already, with many others in development. Tethered aerostats have the advantage of carrying large payloads. The biggest drawback is the need to manage air space (depending on altitude), and their ability to cope with weather conditions. High altitude platforms show great potential, in terms of coverage and capacity capabilities, but are mostly on the drawing board, with the exception of limited payload variants such as the Zephyr. Google Loon is a possible game changer, with many free floating balloons being used with handover to maintain continuous service, but for PPDR application scenarios which need reliable communications; this does not seem a viable solution.

The chosen solution for the ABSOLUTE demos, the Helikite, which is a hybrid kite and tethered aerostat, delivers many advantages. It is cost-effective, available now, and has been used extensively in practical deployments. It is capable of being able to operate at low altitudes, in much higher winds than conventional aerostats. Disadvantages are that it has to be deployed from the ground (at the site of the disaster), and in order to be easily deployable its payload is likely to be quite limited (compared to the larger tethered aerostat options which necessarily have to operate at much higher altitudes).

# 3. Operating Environment and Performance

## 3.1 Introduction

Emergency services operate as a civilian force under civilian legislation. They are subject to the same laws and regulations as any other member of the public. They often are operating under manpower pressure, acute stress and time constraints.

The aerial platform must be as easy to operate as possible whilst at the same time giving excellent radio coverage. If the radio coverage is poor from the platform, then many platforms will be needed, which in turn will require more manpower and cost. The platform must be able to be stored for very long periods of time before use. It must be easy to transport by normal vehicles. The deployment must be straightforward for any trained person, but training must not be difficult. The platform must operate in any likely weather conditions and from land or sea. The altitude reached must be high enough to give good coverage and the payload capacity large enough to carry the 4G payload and attendant power. The platform must also carry the antennas in a stable manner to give good radio reception and propagation. The platform needs to be safe to use for both the operators and the public nearby.

## 3.2 Legislation and Regulatory Issues

### 3.2.1 Aeronautical Legislation

Aeronautical regulations are complex and depend heavily on the type of craft used, and the operating altitude, and whether the craft is remotely piloted. Here we focus on the aeronautical regulations associated with the Helikite. These are presented from the UK perspective, as a representative set of regulations across the EU. It is important to consult with the appropriate national aeronautical regulator prior to any real deployments.

Helikites are generally considered for reasons of legislation as “kites” and/or “balloons” by European aviation authorities. The British Civil Aviation Authority has a separate classification of “Helikites”, however they still need to comply with the regulations pertaining to both kites and balloons. In the UK Helikites may operate in daytime, up to 200ft, outside any registered “Air-Traffic Zone” without the need to inform the Air Traffic Control authorities. Above 200ft permission needs to be sought from the CAA before flying. For non-emergencies such as training flights a long-term NOTAM for many months is easy to get. A short term non-emergency NOTAM usually only takes a couple of weeks. Permission up to 1000ft is almost always granted if the flying area is safe. A “NOTAM” (Notification to Airmen) is then issued to flying clubs, airports etc. Above 1000ft is less certain, but perfectly possible if reasonable time has been given to inform local pilots. In emergencies permission to fly can be granted very fast indeed in the UK, in fact immediately if necessary. Pre-planning with the CAA to identify likely launch sites in advance would be an excellent idea that would be welcomed.

When flying above 200ft flags or drogues are required to be flown from the line at 50 metre intervals during the day. At night, certain types of lighting need to be flown on the aerostat and placed on the ground too. See [17]

In the UK, both tethered (Captive) balloons and kites have to follow essentially the same procedures regarding flying. An excellent explanation of the full rules and regulations pertaining to kites is provided by the British Kite Flyers Association [18].

The regulations regarding kites and captive balloons in other EU countries will be essentially similar to the UK, but there will be variations in details regarding permitted altitude, aircraft mass, lighting etc. All the rules may not be contained within one set of regulations. Long experience suggests that within most European countries, it is not likely that the tethered aerostat/kite/balloon regulations are so easy to pick out from the mass of flying regulations, as they are in the UK. These local regulations need to be discovered and adhered to. The services of a suitable local lawyer is recommended.

### 3.2.2 Radio Regulatory Legislation

With respect to candidate types of aerial platforms for the use in ABSOLUTE the radio regulation distinguishes between radio frequencies needed for the flight safety (the same ATM service frequencies apply as to other commercial aviation) and remote control of unmanned aircraft on one hand, and radio frequencies for the provision of communication services.

Aeronautical communications for the flight safety in manned aircraft typically support services for surveillance/collision avoidance, navigation, data communications and voice communications. Voice communications between ground and air still represent the primary means for ATM. In the case of unmanned aircraft voice communication is still needed between air traffic control centres and UAV control centre, but needs to be complemented by data control communication between UAV control centre on the ground and the UAV, paying special attention to aspects such as [19]:

- Safety critical control links
- Communication security
- Reduction of communication load
- Telemetry for aircraft status
- Payload data.

These considerations clearly call for dedicated allocations in already overcrowded frequency spectrum. Control communications for military and defence UAS, designated as mission-critical communications that must not suffer harmful interference, are typically operating in dedicated bands for defence services within 230–400 MHz, 2.9–3.4 GHz and 4.4–5 GHz, typically different types of craft using different frequencies for different types of communication. With the projections for large increase of UAVs for civil applications such as weather research, crop monitoring and coastal patrols, it was clear that all demands could not be accommodated in existing spectrum allocations. So, a resolution 421 was adopted at WRC-07 resolving that ITU-R studies were to be conducted for further consideration at WRC-12 with respect to:

(i) the spectrum requirements and possible regulatory actions, including additional allocations, to support the remote pilot in commanding and controlling the unmanned aircraft systems and in relaying the ATC communications;

(ii) the spectrum requirements and possible regulatory actions, including additional allocations, to support the safe operation of unmanned aircraft systems.

An outcome of these activities and the WRC-12 was the allocation of frequency band at 5,030–5,091 MHz for primary use for aeronautical mobile (route) service (AM(R)S) and existing aeronautical mobile-satellite (Route) service (AMS(R)S) for unmanned aircraft systems line of sight controls. This allocation is restricted to use for safety and regularity of flight [20]. At the same time a new agenda item has been developed for WRC-15 to consider satellite allocations for UAS.

As to provision of communication services, the radio regulation has been mainly concerned in the last decade with meeting the requirements for broadband communications from HAPs and to this end the International Telecommunications Union - Radiocommunication Sector (ITU-R) released several recommendations related to the RF operation from HAPS (ITU-R definition of High Altitude Platform Station assumes for the aerial sector only platforms flying above 20km altitude [21]) and corresponding ground equipment, and prevention from causing harmful interference to other user types sharing the same frequency band. For different types of services and different regions of the world the following frequency bands have been specified and/or investigated by ITU-R for HAPS:

- ITU Recommendation ITU-R F.1500 specifies 300MHz bandwidth at 48/47 GHz in uplink and downlink on a worldwide basis [21]
- ITU Recommendation ITU-R F.1569 specifies 300MHz bandwidth at 31/28 GHz in uplink and downlink for use in over 40 countries worldwide (including North and South America yet excluding all of Europe) [22]
- ITU Recommendation M.1456 specifies the use of 2 GHz frequency band for worldwide support to IMT-2000 services from HAPS [23]
- WRC-07 Resolution 734 proposed ITU R preparatory studies and spectrum identification for IMT-2000 gateway links for HAPS in the range 5,850-7,075 MHz [24].

A list of main current ITU-R Recommendations related to the operation of High Altitude Platform Stations is included in Table 3.1. These regulations, however, are leaving several issues open with respect to ABSOLUTE project such as

(iii) definition of HAPS by ITU-R, i.e. are HAPS related recommendations to be strictly used only for aerial platforms above 20km altitude? Are HAPs flying between 17 km and 20 km as well as medium/low altitude platforms prohibited from using these frequencies?

(iv) lack of specific radio frequency provision for “airborne” LTE/LTE-A communication systems, yet explicitly mentioning IMT-2000 (=3G) services.

Furthermore, it appears that ITU-R is not likely allocating any further frequency bands explicitly for the provision of services from aerial platforms. Thus it is of primary concern to airborne communication platforms that ITU-R adopts/retains sufficiently flexible spectrum licensing policy, to allow aerial platforms equipped with terrestrial system base station and flying below 20km (i.e. strictly speaking not qualifying as HAPS but rather as tall mast) to share the spectrum allocated to terrestrial services, provided they will not cause any harmful interference to existing terrestrial systems. Having said this, however, it must be noted that provision of non-harmful coexistence of aerial and terrestrial systems is very challenging both for radio network planning and interference avoidance. Clearly, the higher the operating altitude of aerial platform, the larger the coverage area with better line of sight propagation conditions, resulting in higher potential interference to terrestrial primary systems. These problems are being investigated in ABSOLUTE, as well as in broader research community, from the perspective of cognitive radio and dynamic spectrum assignment, which have an important role in interference avoidance and thus compliance with radio regulations. The list of ITU-R based recommendations related to HAPS is shown in Table 3.1

| Number | Title |
|---|---|
| F.1500 (05/00) | Preferred characteristics of systems in the fixed service using high altitude platforms operating in the bands 47.2-47.5 GHz and 47.9-48.2 GHz In force |
| F.1569 (05/02) | Technical and operational characteristics for the fixed service using high altitude platform stations in the bands 27.5-28.35 GHz and 31-31.3 GHz |
| F.1570 (05/02)<br>F.1570-1 (02/03) | Impact of uplink transmission in the fixed service using high altitude platform stations on the Earth exploration-satellite service (passive) in the 31.3-31.8 GHz band |
| F.1607 (02/03) | Interference mitigation techniques for use by high altitude platform stations in the 27.5-28.35 GHz and 31.0-31.3 GHz bands |
| F.1608 (02/03) | Frequency sharing between systems in the fixed service using high altitude platform stations and conventional systems in the fixed service in the bands 47.2-47.5 and 47.9-48.2 GHz |
| F.1609 (02/03)<br>F.1609-1 (04/06) | Interference evaluation from fixed service systems using high altitude platform stations to conventional fixed service systems in the bands 27.5-28.35 GHz and 31.0-31.3 GHz |
| F.1612 (02/03) | Interference evaluation of the fixed service using high altitude platform stations to protect the radio astronomy service from uplink transmission in high altitude platform station systems in the 31.3-31.8 GHz band |
| F.1764 (04/06) | Methodology to evaluate interference from fixed service systems using high altitude platform stations to fixed wireless systems in the bands above 3 GHz |
| F.1819 (09/07) | Protection of the radio astronomy service in the 48.94-49.04 GHz band from unwanted emissions from HAPS in the 47.2-47.5 GHz and 47.9-48.2 GHz bands |
| F.1820 (09/07) | Power flux-density at international borders for high altitude platform stations providing fixed wireless access services to protect the fixed service in neighbouring countries in the 47.2-47.5 GHz and 47.9-48.2 GHz bands |
| M.1456 (05/00) | Minimum performance characteristics and operational conditions for high altitude platform stations providing IMT-2000 in the bands 1 885-1 980 MHz, 2 010-2 025 MHz and 2 110-2 170 MHz in Regions 1 and 3 and 1 885-1 980 MHz and 2 110-2 160 MHz in Region 2 |
| M.1641 (06/03) | A methodology for co-channel interference evaluation to determine separation distance from a system using high-altitude platform stations to a cellular system to provide IMT-2000 service within the boundary of an administration |

| | |
|---|---|
| P.1409 (10/99) | Propagation data and prediction methods required for the design of systems using high altitude platform stations at about 47 GHz |
| SF.1601 (02/03),<br>SF.1601-1 (04/05)<br>SF.1601-2 (02/07) | A methodology for interference evaluation from the downlink of the fixed service using high altitude platform stations to the uplink of the fixed-satellite service using the geostationary satellites within the band 27.5-28.35 GHz |
| SF.1843 (2007) | Methodology for determining the power level for high altitude platform stations ground terminals to facilitate sharing with space station receivers in the bands 47.2-47.5 GHz and 47.9-48.2 GHz |
| SM.1633 (06/03) | Compatibility analysis between a passive service and an active service allocated in adjacent and nearby bands |

**Table 3.1 List of ITU-R main Recommendations on HAPS in January 2010 [25]**

## 3.3 Performance Characteristics

Desert Star Helikites are presently available in sizes from $3m^3$ to $100m^3$ helium gas volumes. About 60% of the lighter-than-air helium is needed pull up the Helikite and the other 40% is available as “net” helium lift. If there is wind available, then the aerodynamic lift will far outweigh the net helium lift. However, wind cannot be relied on, so the net helium lift may be all that is available in many circumstances. Also, precipitation needs to be taken into account as it can add considerable weight to any flying object. High base altitudes also reduce lift in a predictable manner. So as far as the Helikite is concerned, payload includes the 4G radio, the battery, fibre-optic cable, Dyneema tether line, snow, sleet, rain and dew. Running power up the flying line is not an option due to the weight of the copper cable required.

For this project the Helikite deemed most suitable in size is the $34m^3$ Desert Star Helikite. It has a net lift of 14kg. With allowance for 1,000ft of flying line and precipitation, the maximum lift available for the 4G part of the payload is 10kg. However, if the payload weight can be reduced (and this is one of the goal of the development research), then a smaller platform could be used. Indeed a smaller platform would allow a quicker operational deployment even if the 34 m3 can be deployed in less than 1 hour. Indeed, for some deployments, it should be needed to have a deployment in less than half an hour.

Attitude control is automatic with Helikites. They keep the same airframe attitude in all winds.

## 3.4 Maturity and Availability

The Helikite design was granted a UK patent in 1993 and a US patent in 1999. Helikites have been made since 1993 and operated on every continent in the world from minus 40C to plus 50C in winds up to gale force. Thousands have been sold to civilians for aerial photography, radio-relay, position marking, advertising, and bird control. They have been successfully operated by the British Army in Afghanistan, US Army in Afghanistan, US Marines in Iraq, Australian Defence Force in Australia, British Antarctic Survey, Norwegian Navy in the Arctic Ocean and Norwegian mountains, US Navy on operations, and the

US Air Force in the Gulf of Mexico. Helikites regularly fly from both land and moving ships or boats at sea. The Desert Star Helikite is a well tested aerostat capable of withstanding high winds, precipitation, dust storms, and ice particles. The Desert Star Helikite is generally considered to be the most advanced and capable compact aerostat in the world. Helikites have been used to lift radio payloads for many operations and trials and so the correct positioning of the electronics, batteries, fibre-optics and antenna is well understood. Desert Star Helikites are a mature platform and presently available from Allsopp Helikites Ltd.

## 3.5 Practicality of Deployment

The usual method of deploying the $34m^3$ Desert Star Helikite is from Allsopp Helikites' "Helibase" launch system. The air-inflatable Helibase, winch, ground anchor, Helikite and helium cylinders are easily transported in a small trailer or 4WD pick-up truck to a suitable deployment site. Such sites are easily found. Any agricultural field, woodland clearing, sports field, or town square are potential sites. Some rooftops, piers or boats can be used too. The site just needs to be free of overhead cables and not in an "Air-Traffic Zone". Permission from the landowner may be required in some circumstances. This is not normally a problem as the Helibase "footprint" is minimal.

Set-up involves:

| ACTION | TIME IN MINUTES |
|---|---|
| A. Survey site | 10 |
| B. Insert ground anchors | 10 |
| C. Position and inflate Helibase | 5 |
| D. Position and secure winch | 5 |
| E. Lay out and tie down Helikite | 5 |
| F. Insert spars into Helikite | 5 |
| G. Attach flying line to Helikite | 1 |
| H. Attach payload | 2 |
| I. Inflate Helikite with helium | 10 |
| J. Fly Helikite to 1000ft | 3 |
| TOTAL TIME | 56 |

To bring the Helikite down and pack up ready to go, takes approximately the same time.

Only one or two people is required and the operation is very safe when done as instructed.

For a smaller platform such as a 15m3 the total time could be reduced.

## 3.6 Impact of Aeronautic Characteristics on Wireless Link Performance

Aerial platform delivery of wireless communications systems need to take into account significantly more factors than their purely terrestrial counterparts. In the case of terrestrial systems transmitter EIRP, link length and propagation environment play a dominant part in viability of a wireless link, and in the case of a cellular system help to control the frequency reuse distance. This is also true to some extent in the airborne systems, but now the aerial platform antenna plays a significant part in shaping the beam, and more importantly controls the interference to other services operating in the same band. The high look angle of an aerial platform can mean that interference travels much further than the equivalent powered system deployed terrestrially. A rule of thumb is that harmful interference is likely to occur a distance of 3 times the radius of an aerial platforms beam footprint(s). In the case of ABSOLUTE this will be important with the proposed mixed terrestrial and aerial platform system, and the desirability to reuse spectrum from systems which are temporarily out of action.

A second critical issue is the station keeping performance of the aerial platform. This can include the lateral movement (or drift), as well as changes in motion (in terms of pitch, roll and yaw). Depending on the directionality of the aerial platform antenna, this has the ability to cause the footprint (and any interference to move on the ground. The attitude effects can be mitigated through the use of a stabilised platform. In the case of highly directional antennas on the ground equipment, then it may be necessary for them to track the lateral motion of the aerial platform.

Helikites are an aerial platform where radio waves travel well because they are free from interference from the ground, trees, buildings, vehicles etc. Clean line-of-sight is beneficial and it provides good line-of-sight over long and highly predictable ranges. This makes planning for radio coverage very easy. Helikites platforms are also large enough to have very large, but lightweight, antennas fixed on them relatively easily.

Furthermore, unlike manned aircraft, UAV's, normal aerostats, or airships, Helikites are much more stable in flight – virtually unmoving at high altitude. The platform stays at about the same airframe attitude in the air whether there is wind or not. The line angle will change depending on the wind speed, but the attitude is always about the same. So an antenna positioned on a Helikite in a vertical position will tend to stay vertical whatever the weather.

Unlike free-flying aircraft, Helikites allow the use of fibre-optic cables to the ground via the tether. This is an important feature as in ABSOLUTE architecture it has then be decided to put only the LTE Radio remote Head on the aerial platform and the Baseband on the ground. This will in turn reduce the power requirement and so reduce weight further.

The chosen aerial platforms are capable of long endurance, with about a day between predictable and very rapid battery changes. This means good reception almost all the time. Manned aircraft and most UAV's often have to land and take off much more frequently, which in trials proved highly unsuitable for some radio-relay applications.

## 3.7 Link budgets

The radio link budget from the aerial platform is highly dependent on the operating environment. Key parameters include link length, elevation angle, operating frequency and antenna characteristics. Table 3.2 – Table 3.5 are examples generic link budgets for the uplink and downlink of a LTE-A based system at both 700MHz and 2.6GHz (the chosen ABSOLUTE core bands), where a UE connects to an Aerial eNB, for differing altitudes and horizontal ground distances from the sub-platform point (the point on the ground immediately below the platform).

Where possible representative parameter values have been chosen, e.g. for transmit power, uplink and downlink bandwidth, antenna gain, and LTE-A modulation and coding sets. The aerial platform antenna is assumed to point vertically downwards, with gain rolling off towards the edge of the coverage area by 3dB. This might be somewhat pessimistic, as it may be possible to shape the gain of the antenna to deliver more gain towards the end of the coverage area, thereby maximising the size of coverage area. A key uncertainty with these link budgets is a suitable propagation model. Here we have chosen to use Free Space Path Loss (given much of the path is travelling unobstructed (until the final obstacle), and then obstacles and clutter are compensated using a 'worst-case' 13.1dB shadowing coefficient. This is based on the 95$^{th}$ percentile value of a lognormal distribution, whose standard deviation is 8dB common for an urban area, i.e. 95% of links have a shadowing value less than 13.1dB. It is likely that in many applications edge of coverage could well be in a rural area, which in general have lower shadowing coefficients.

In the case of 700MHz, the link budgets close with low and mid altitude UAVs with a coverage area radius of 15km, with the lowest modulation and coding scheme combination. In the case of HAPs the link budget is marginal, and may operate only as far as a 10km radius (although due to the higher elevation angle is less likely to be prone to shadowing which is not adjusted here). High rate modulation and coding is possible on both uplink and downlink immediately beneath the platform, falling off at higher coverage radii.

In the case of 2.6GHz both of the link budgets are marginal, providing coverage at the lowest level of modulation and coding immediately beneath the platform. This is mainly due to the increased free space path loss, which cannot be compensated for by the antennas. Thus, it is not recommended that this frequency is used for the aerial platform configuration proposed by ABSOLUTE.

It is worth noting that harmful interference is likely to extend 2 to 3 times the distance of the proposed coverage areas, so this needs to be taken into account when considering the wider operating environment.

## Table 3.2 Uplink Link Budget at 700MHz

### User Link from AeNBs at 700MHz (Uplink)



| # | Parameter | | | | | |
|---|---|---|---|---|---|---|
| 1 | **Receiver (AeNB)** | | | | | |
| 2 | Antenna beamwidth - theta (degrees) | 120.0 | | | | |
| 3 | Antenna beamwidth - phi (degrees) | 120.0 | | | | |
| 4 | Antenna electrical efficiency | 0.70 | | | | |
| 5 | Antenna gain (dBi) (Cell Center) | 2.5 | | | b | |
| 6 | Antenna feed loss (dB) | 0.5 | | | c | |
| 7 | AeNB Gain (dBm) | 2.0 | | | d=b-c | |
| 8 | | | | | | |
| 9 | **Transmitter (UE)** | | | | | |
| 10 | The Boltzmann Constant (dBJ/K) | -228.6 | | | | |
| 11 | Noise Temperature (K) | 300.0 | | | | |
| 12 | Power per carrier (dBm) | 23.0 | | | | |
| 13 | Thermal noise density (dBm/Hz) | -173.8 | | | e | |
| 14 | Receiver noise figure (dB) | 2.5 | | | f | |
| 15 | Receiver noise density (dBm/Hz) | -171.3 | | | g=e+f | |
| 16 | Receiver interference noise density (dBm/Hz) | -171.3 | | | j = g | |
| 17 | Total effective noise density (dBm/Hz) | -168.3 | | | k= 10*log(10^(g/10)+10^(j/10)) | |
| 18 | | | | | | |
| 19 | Antenna gain (dBi) | 1.5 | | | l | |
| 20 | Misc losses | 0.5 | | | m | |
| 21 | UE EIRP | 24.0 | | | | |
| 22 | Maximum C/(Io+No) (dBHz) | 194.3 | | | o=UE EIRP+d-k | |
| 23 | | | | | | |
| 24 | Modulation Scheme | 64QAM | 16QAM | QPSK | | |
| 25 | Required Eb/No (BER 10-9) | 20 | 16 | 7.8 | | ab |
| 26 | Bit/symbol | 6 | 4 | 2 | | ac |
| 27 | | | | | | |
| 28 | Bandwidth (MHz) | 2.0 | 2.0 | 2.0 | | |
| 29 | Code Rate | 0.45 | 0.37 | 0.19 | | aj |
| 30 | Data Rate (Mbit/s) (25% rolloff) | 4 | 2 | 0.6 | | ad |
| 31 | Data Rate (dBbit/s) | 66.4 | 63.7 | 57.8 | | p |
| 32 | Required C/(Io+No) (dBHz) | 86.4 | 79.7 | 65.6 | | ae=ab+p |
| 33 | | | | | | |
| 34 | Maximum allowed losses (dB) | 107.9 | 114.6 | 128.7 | | q=o-ae |
| 35 | | | | | | |
| 36 | **Link Parameters** | | | | | |
| 37 | Frequency (GHz) | 0.7 | | | | |
| 38 | Wavelength (m) | 0.429 | | | | |
| 39 | Misc Atmospheric Losses (dB) | 0.0 | | | s | |
| 40 | Additional Shadowing Loss (dB) | 13.1 | | | shd | % 95 percentile |
| 41 | Edge of cell and antenna beam losses | 2.0 | | | sa | |
| 42 | | | | | | |
| 43 | **Calculation Results** | | | | | |

| # | | Low Altitude | | | Mid Altitude | | | High Altitude | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 44 | | | | | | | | | | |
| 45 | Ground Distance (km) | 0.00 | 10.00 | 15.00 | 0.00 | 10.00 | 15.00 | 0.00 | 10.00 | 15.00 |
| 46 | Platform height (km) | 0.40 | 0.40 | 0.40 | 3.00 | 3.00 | 3.00 | 20.00 | 20.00 | 20.00 |
| 47 | LOS Distance (dB) | 0.40 | 10.01 | 15.01 | 3.00 | 10.44 | 15.30 | 20.00 | 22.36 | 25.00 |
| 48 | PL (dB)(FSPL(GD<=10km), Hata(GD>10km)) | 81.38 | 109.35 | 112.87 | 98.89 | 109.72 | 113.04 | 115.36 | 116.33 | 117.30 |
| 49 | Clear air losses (dB) | 96.48 | 124.45 | 127.97 | 113.99 | 124.82 | 128.14 | 130.46 | 131.43 | 132.40 |
| 50 | **Received margin clear air (dB)** | | | | | | | | | |
| 51 | 64QAM | **11.46** | **-16.51** | **-20.03** | **-6.04** | **-16.88** | **-20.19** | **-22.52** | **-23.49** | **-24.46** |
| 52 | 16QAM | **18.07** | **-9.90** | **-13.41** | **0.57** | **-10.26** | **-13.58** | **-15.91** | **-16.88** | **-17.85** |
| 53 | QPSK | **32.17** | **4.21** | **0.69** | **14.67** | **3.84** | **0.52** | **-1.81** | **-2.77** | **-3.74** |

## Table 3.3 Downlink Link Budget at 700MHz

### User Link from AeNBs at 700MHz (Downlink)



| | | | | | | |
|---|---|---|---|---|---|---|
| 1 | **Transmitter (AeNB)** | | | | | |
| 2 | Power carrier (dBm) | 30.0 | | | a | |
| 3 | Antenna beamwidth - theta (degrees) | 120.0 | | | | |
| 4 | Antenna beamwidth - phi (degrees) | 120.0 | | | | |
| 5 | Antenna electrical efficiency | 0.70 | | | | |
| 6 | Antenna gain (dBi) (Boresight gain) | 2.5 | | | b | |
| 7 | Antenna feed loss (dB) | 0.5 | | | c | |
| 8 | AeNB EIRP (dBm) | 32.0 | | | d=a+b-c | |
| 9 | | | | | | |
| 10 | **Receiver (UE)** | | | | | |
| 11 | The Boltzmann Constant (dBJ/K) | -228.6 | | | | |
| 12 | Noise Temperature (K) | 300.0 | | | | |
| 13 | Thermal noise density (dBm/Hz) | -173.8 | | | e | |
| 14 | Receiver noise figure (dB) | 2.5 | | | f | |
| 15 | Receiver noise density (dBm/Hz) | -171.3 | | | g=e+f | |
| 16 | Receiver interference noise density (dBm/Hz) | -171.3 | | | j = g | |
| 17 | Total effective noise density (dBm/Hz) | -168.3 | | | k= 10*log(10^(g/10)+10^(j/10)) | |
| 18 | | | | | | |
| 19 | Antenna gain (dBi) | 1.5 | | | l | |
| 20 | Misc losses | 0.5 | | | m | |
| 21 | Maximum C/(Io+No) (dBHz) | 201.3 | | | o=d-k+l-m | |
| 22 | | | | | | |
| 23 | Modulation Scheme | 64QAM | 16QAM | QPSK | | |
| 24 | Required Eb/No (BER 10-9) | 20 | 16 | 7.8 | ab | |
| 25 | Bit/symbol | 6 | 4 | 2 | ac | |
| 26 | | | | | | |
| 27 | Bandwidth (MHz) | 5.0 | 5.0 | 5.0 | | |
| 28 | Code Rate | 0.45 | 0.37 | 0.19 | aj | |
| 29 | Data Rate (Mbit/s) (25% rolloff) | 11 | 6 | 2 | ad | |
| 30 | Data Rate (dBbit/s) | 70.3 | 67.7 | 61.8 | p | |
| 31 | Required C/(Io+No) (dBHz) | 90.3 | 83.7 | 69.6 | ae=ab+p | |
| 32 | | | | | | |
| 33 | Maximum allowed losses (dB) | 111.0 | 117.6 | 131.7 | q=o-ae | |
| 34 | | | | | | |
| 35 | **Link Parameters** | | | | | |
| 36 | Frequency (GHz) | 0.7 | | | | |
| 37 | Wavelength (m) | 0.429 | | | | |
| 38 | Misc Atmospheric Losses (dB) | 0.0 | | | s | |
| 39 | Additional Shadowing Loss (dB) | 13.1 | | | shd | % 95 percentile |
| 40 | Edge of cell antenna beam losses | 2.0 | | | sa | |
| 41 | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 42 | **Calculation Results** | | | | | | | | | |
| 43 | | Low Altitude | | | Mid Altitude | | | High Altitude | | |
| 44 | Ground Distance (km) | 0.00 | 10.00 | 15.00 | 0.00 | 10.00 | 15.00 | 0.00 | 10.00 | 15.00 |
| 45 | Platform height (km) | 0.40 | 0.40 | 0.40 | 3.00 | 3.00 | 3.00 | 20.00 | 20.00 | 20.00 |
| 46 | LOS Distance (dB) | 0.40 | 10.01 | 15.01 | 3.00 | 10.44 | 15.30 | 20.00 | 22.36 | 25.00 |
| 47 | PL (dB) - FSPL | 81.38 | 109.35 | 112.87 | 98.89 | 109.72 | 113.04 | 115.36 | 116.33 | 117.30 |
| 48 | Clear air losses (dB) | 96.48 | 124.45 | 127.97 | 113.99 | 124.82 | 128.14 | 130.46 | 131.43 | 132.40 |
| 49 | **Received margin clear air (dB)** | | | | | | | | | |
| 50 | 64QAM | **14.48** | **-13.49** | **-17.01** | **-3.02** | **-13.85** | **-17.17** | **-19.50** | **-20.47** | **-21.44** |
| 51 | 16QAM | **21.09** | **-6.88** | **-10.39** | **3.59** | **-7.24** | **-10.56** | **-12.89** | **-13.86** | **-14.83** |
| 52 | QPSK | **35.19** | **7.23** | **3.71** | **17.69** | **6.86** | **3.54** | **1.21** | **0.25** | **-0.72** |

## Table 3.4 Uplink Link Budget at 2.6GHz

### User Link from AeNBs at 2.6GHz (Uplink)



| # | Parameter | Value / 64QAM | 16QAM | QPSK | Formula | Note |
|---|---|---|---|---|---|---|
| 1 | **Receiver (AeNB)** | | | | | |
| 2 | Antenna beamwidth - theta (degrees) | 120.0 | | | | |
| 3 | Antenna beamwidth - phi (degrees) | 120.0 | | | | |
| 4 | Antenna electrical efficiency | 0.70 | | | | |
| 5 | Antenna gain (dBi) (Cell Center) | 2.5 | | | b | |
| 6 | Antenna feed loss (dB) | 0.5 | | | c | |
| 7 | AeNB Gain (dBm) | 2.0 | | | d=b-c | |
| 8 | | | | | | |
| 9 | **Transmitter (UE)** | | | | | |
| 10 | The Boltzmann Constant (dBJ/K) | -228.6 | | | | |
| 11 | Noise Temperature (K) | 300.0 | | | | |
| 12 | Power per carrier (dBm) | 23.0 | | | | |
| 13 | Thermal noise density (dBm/Hz) | -173.8 | | | e | |
| 14 | Receiver noise figure (dB) | 2.5 | | | f | |
| 15 | Receiver noise density (dBm/Hz) | -171.3 | | | g=e+f | |
| 16 | Receiver interference noise density (dBm/Hz) | -171.3 | | | j = g | |
| 17 | Total effective noise density (dBm/Hz) | -168.3 | | | k= 10*log(10^(g/10)+10^(j/10)) | |
| 18 | | | | | | |
| 19 | Antenna gain (dBi) | 1.5 | | | l | |
| 20 | Misc losses | 0.5 | | | m | |
| 21 | UE EIRP | 24.0 | | | | |
| 22 | Maximum C/(Io+No) (dBHz) | 194.3 | | | o=UE EIRP+d-k | |
| 23 | | | | | | |
| 24 | Modulation Scheme | 64QAM | 16QAM | QPSK | | |
| 25 | Required Eb/No (BER 10-9) | 20 | 16 | 7.8 | ab | |
| 26 | Bit/symbol | 6 | 4 | 2 | ac | |
| 27 | | | | | | |
| 28 | Bandwidth (MHz) | 2.0 | 2.0 | 2.0 | | |
| 29 | Code Rate | 0.45 | 0.37 | 0.19 | aj | |
| 30 | Data Rate (Mbit/s) (25% rolloff) | 4 | 2 | 0.6 | ad | |
| 31 | Data Rate (dBbit/s) | 66.4 | 63.7 | 57.8 | p | |
| 32 | Required C/(Io+No) (dBHz) | 86.4 | 79.7 | 65.6 | ae=ab+p | |
| 33 | | | | | | |
| 34 | Maximum allowed losses (dB) | 107.9 | 114.6 | 128.7 | q=o-ae | |
| 35 | | | | | | |
| 36 | **Link Parameters** | | | | | |
| 37 | Frequency (GHz) | 2.6 | | | | |
| 38 | Wavelength (m) | 0.115 | | | | |
| 39 | Misc Atmospheric Losses (dB) | 0.0 | | | s | |
| 40 | Additional Shadowing Loss (dB) | 13.1 | | | shd | % 95 percentile |
| 41 | Edge of cell and antenna beam losses | 2.0 | | | sa | |
| 42 | | | | | | |

| # | Parameter | Low Altitude | | | Mid Altitude | | | High Altitude | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 43 | **Calculation Results** | | | | | | | | | |
| 44 | | Low Altitude | | | Mid Altitude | | | High Altitude | | |
| 45 | Ground Distance (km) | 0.00 | 10.00 | 15.00 | 0.00 | 10.00 | 15.00 | 0.00 | 10.00 | 15.00 |
| 46 | Platform height (km) | 0.40 | 0.40 | 0.40 | 3.00 | 3.00 | 3.00 | 20.00 | 20.00 | 20.00 |
| 47 | LOS Distance (dB) | 0.40 | 10.01 | 15.01 | 3.00 | 10.44 | 15.30 | 20.00 | 22.36 | 25.00 |
| 48 | PL (dB)(FSPL(GD<=10km), Hata(GD>10km)) | 92.78 | 120.75 | 124.27 | 110.28 | 121.12 | 124.43 | 126.76 | 127.73 | 128.70 |
| 49 | Clear air losses (dB) | 107.88 | 135.85 | 139.37 | 125.38 | 136.22 | 139.53 | 141.86 | 142.83 | 143.80 |
| 50 | **Received margin clear air (dB)** | | | | | | | | | |
| 51 | 64QAM | **0.06** | **-27.91** | **-31.42** | **-17.44** | **-28.27** | **-31.59** | **-33.92** | **-34.89** | **-35.86** |
| 52 | 16QAM | **6.67** | **-21.29** | **-24.81** | **-10.83** | **-21.66** | **-24.98** | **-27.31** | **-28.28** | **-29.25** |
| 53 | QPSK | **20.78** | **-7.19** | **-10.71** | **3.28** | **-7.56** | **-10.87** | **-13.20** | **-14.17** | **-15.14** |

**Table 3.5 Downlink Link Budget at 2.6GHz**

**User Link from AeNBs at 2.6GHz (Downlink)**



| # | Parameter | | | | | |
|---|---|---|---|---|---|---|
| 1 | **Transmitter (AeNB)** | | | | | |
| 2 | Power carrier (dBm) | 30.0 | | a | | |
| 3 | Antenna beamwidth - theta (degrees) | 120.0 | | | | |
| 4 | Antenna beamwidth - phi (degrees) | 120.0 | | | | |
| 5 | Antenna electrical efficiency | 0.70 | | | | |
| 6 | Antenna gain (dBi) (Boresight gain) | 2.5 | | b | | |
| 7 | Antenna feed loss (dB) | 0.5 | | c | | |
| 8 | AeNB EIRP (dBm) | 32.0 | | d=a+b-c | | |
| 9 | | | | | | |
| 10 | **Receiver (UE)** | | | | | |
| 11 | The Boltzmann Constant (dBJ/K) | -228.6 | | | | |
| 12 | Noise Temperature (K) | 300.0 | | | | |
| 13 | Thermal noise density (dBm/Hz) | -173.8 | | e | | |
| 14 | Receiver noise figure (dB) | 2.5 | | f | | |
| 15 | Receiver noise density (dBm/Hz) | -171.3 | | g=e+f | | |
| 16 | Receiver interference noise density (dBm/Hz) | -171.3 | | j = g | | |
| 17 | Total effective noise density (dBm/Hz) | -168.3 | | k= 10*log(10^(g/10)+10^(j/10)) | | |
| 18 | | | | | | |
| 19 | Antenna gain (dBi) | 1.5 | | l | | |
| 20 | Misc losses | 0.5 | | m | | |
| 21 | Maximum C/(Io+No) (dBHz) | 201.3 | | o=d-k+l-m | | |
| 22 | | | | | | |
| 23 | Modulation Scheme | 64QAM | 16QAM | QPSK | | |
| 24 | Required Eb/No (BER 10-9) | 20 | 16 | 7.8 | | ab |
| 25 | Bit/symbol | 6 | 4 | 2 | | ac |
| 26 | | | | | | |
| 27 | Bandwidth (MHz) | 5.0 | 5.0 | 5.0 | | |
| 28 | Code Rate | 0.45 | 0.37 | 0.19 | | aj |
| 29 | Data Rate (Mbit/s) (25% rolloff) | 11 | 6 | 2 | | ad |
| 30 | Data Rate (dBbit/s) | 70.3 | 67.7 | 61.8 | | p |
| 31 | Required C/(Io+No) (dBHz) | 90.3 | 83.7 | 69.6 | | ae=ab+p |
| 32 | | | | | | |
| 33 | Maximum allowed losses (dB) | 111.0 | 117.6 | 131.7 | | q=o-ae |
| 34 | | | | | | |
| 35 | **Link Parameters** | | | | | |
| 36 | Frequency (GHz) | 2.6 | | | | |
| 37 | Wavelength (m) | 0.115 | | | | |
| 38 | Misc Atmospheric Losses (dB) | 0.0 | | s | | |
| 39 | Additional Shadowing Loss (dB) | 13.1 | | shd | % 95 percentile | |
| 40 | Edge of cell antenna beam losses | 2.0 | | sa | | |
| 41 | | | | | | |

| # | | Low Altitude | | | Mid Altitude | | | High Altitude | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 42 | **Calculation Results** | | | | | | | | | |
| 43 | | | | | | | | | | |
| 44 | Ground Distance (km) | 0.00 | 10.00 | 15.00 | 0.00 | 10.00 | 15.00 | 0.00 | 10.00 | 15.00 |
| 45 | Platform height (km) | 0.40 | 0.40 | 0.40 | 3.00 | 3.00 | 3.00 | 20.00 | 20.00 | 20.00 |
| 46 | LOS Distance (dB) | 0.40 | 10.01 | 15.01 | 3.00 | 10.44 | 15.30 | 20.00 | 22.36 | 25.00 |
| 47 | PL (dB) - FSPL | 92.78 | 120.75 | 124.27 | 110.28 | 121.12 | 124.43 | 126.76 | 127.73 | 128.70 |
| 48 | Clear air losses (dB) | 107.88 | 135.85 | 139.37 | 125.38 | 136.22 | 139.53 | 141.86 | 142.83 | 143.80 |
| 49 | **Received margin clear air (dB)** | | | | | | | | | |
| 50 | 64QAM | 3.08 | -24.88 | -28.40 | -14.42 | -25.25 | -28.57 | -30.90 | -31.87 | -32.84 |
| 51 | 16QAM | 9.69 | -18.27 | -21.79 | -7.81 | -18.64 | -21.96 | -24.29 | -25.26 | -26.23 |
| 52 | QPSK | 23.80 | -4.17 | -7.69 | 6.30 | -4.54 | -7.85 | -10.18 | -11.15 | -12.12 |

# 3.8 Conclusions

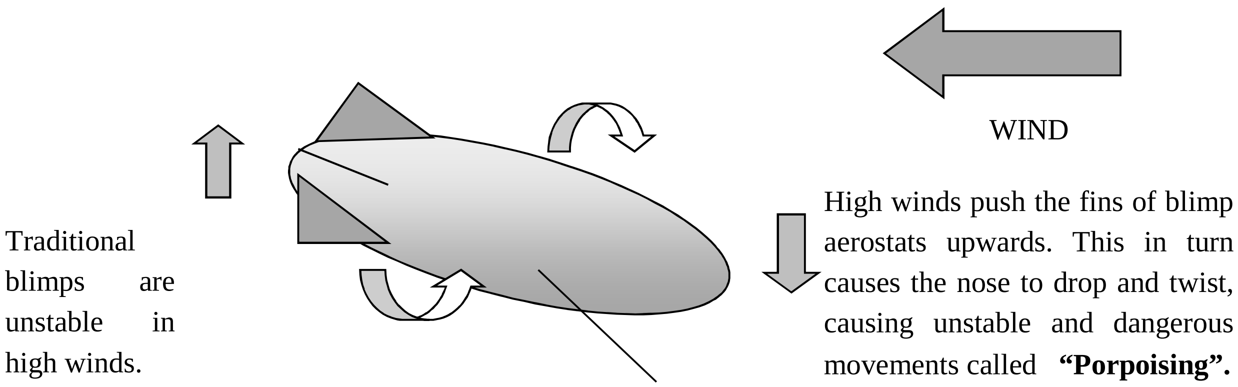
This chapter has looked in detail at some key issues surrounding the aerial platform operating environment and use. Critical parameters relate to the payload, including its size, mass and required power and thermal management, which significantly affects the size of craft that needs to be used. Currently there are many options for sub-15kg payloads, which would be sufficient for the ABSOLUTE scenario. Even smaller Heikites platforms are envisaged if the payload can be reduced below 10kg (including the lines). There is also the operational height of the craft. Operating at mid to high altitudes delivers the potential benefit of improved line-of-sight coverage, but could worsen the link budget due to increased line of sight distance. Lower altitudes favour craft such as the Helikite, with the tethered doubling up as backhaul. Tethered craft do require a flight exclusion zone, unless operating below the minimum altitude. Atmospheric ground effects can prove problematic for some craft. It is crucial that both aeronautical and radio regulations are taken into account. These tend to be country specific. It is not clear at this stage whether terrestrial radio regulations should be applied to aerial platforms, or whether they are treated as aircraft. This will affect the chosen frequencies available. Approval is in the hands of national radio regulators, where cross-border interference is not an issue. Link budget analysis has shown that the ABSOLUTE 700MHz band should operate well up to a coverage radius of 15km at 300m of height, but the issue of harmful interference to other terrestrial systems needs to be considered beyond 15km.

# 4. Helikite – Critical Parameters and Performance

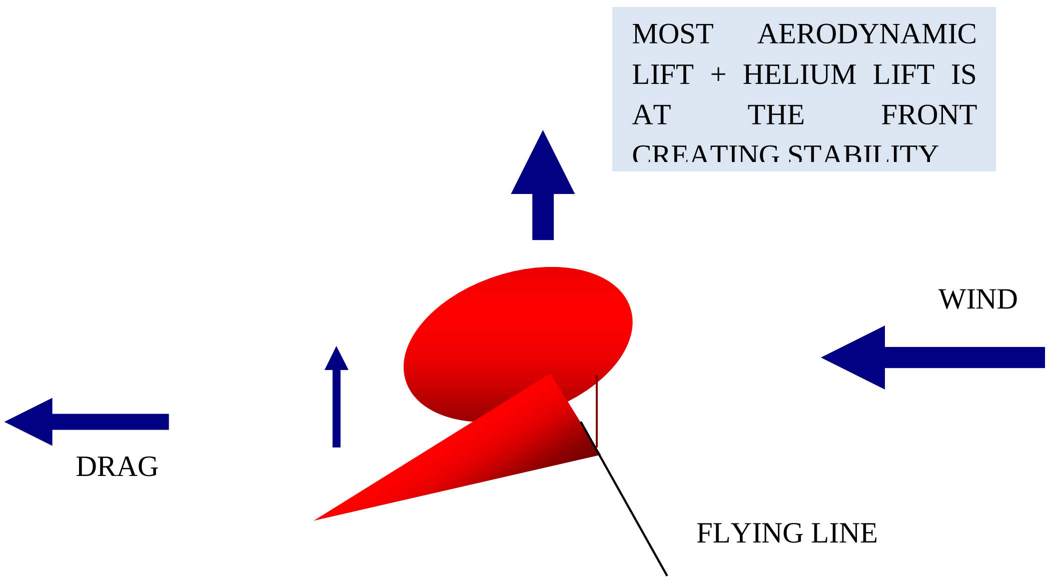
## 4.1 Introduction

Helikites are pushed up by the wind, rather than downward like normal blimps. They are kept stable by wind rather than being made unstable. Therefore Helikites do not need large volumes of helium to combat the wind. So all-weather Helikites are far smaller than blimps and fly at many times greater altitude. The design solves the fundamental problems of normal aerostats.

It is worth looking in a little more detail at the platform given that their characteristics are less well known. Figure 4.1 illustrates the main principles of how a Helikite differs from a normal tethered blimp aerostat when in flight.




**(a) Theory of normal blimp aerostat flight**




**(b) Theory of Helikite flight**

**Figure 4.1 Comparison of tethered blimp aerostat and Helikite flight characteristics.**

Table 4.1 provides general performance data and key parameters for different sizes of Helikites.

**Table 4.1 Desert Star Helikite performance data[1]**

| VOLUME | BALLOON THICKNESS | PAYLOAD IN NIL WIND | PAYLOAD 15MPH WIND | MAX WIND SPEED | MAX ALTITUDE | LENGTH | WIDTH |
|---|---|---|---|---|---|---|---|
| Cubic Metres | Thou/Inch | kg | kg | MPH | Feet | Feet | Feet |
| 3 | 2 | 0.5 | 4 | 35 | 1,500 | 9 | 6 |
| 5 | 2 | 1.5 | 9 | 40 | 2,000 | 10 | 7 |
| 6 | 2 | 2 | 9 | 40 | 2,100 | 10.5 | 7.5 |
| 10 | 2 | 3.5 | 10 | 45 | 3,000 | 12 | 9 |
| 15 | 2 | 6 | 12 | 46 | 3,500 | 14 | 10 |
| 20 | 2 | 8 | 16 | 48 | 4,000 | 16 | 11 |
| 24 | 2 | 9 | 23 | 50 | 4,500 | 20 | 13 |
| 34 | 4 | 14 | 30 | 50 | 6,000[1] | 22 | 15 |

Bigger sizes are also available and data can be found on Helikites web site.

Helikite flying performance allows them to match the critical parameters required for lifting the ABSOLUTE communications equipment:

1) **1000ft Altitude**
   Helikites utilise both wind lift and helium lift to enable high altitude flight in almost all weather conditions and from base altitudes far higher than other similar-sized aerostats. 1000ft is a standard altitude that the 34m$^3$ Desert Star Helikite can reach while lifting the 10kg of equipment that is presently estimated as being required.
2) **Keeping Station**
   Helikites are extremely stable, both in airframe attitude and position in the sky in all weathers. Keeping station is no problem in all weathers up to storm force.
3) **Payload**
   Helikites use wind for lift as well as helium, so for a similar size, Helikites can carry more payload than any other aerostat in high or low wind conditions. They are capable of lifting the required payload and in the correct position
4) **Endurance**

[1] The operating altitudes between 6000-11000ft are based on calculated estimates. No deployments have been requested at these altitudes.

Helikites need no electrical power to operate a ballonet and lose very little helium through their gas-tight inner balloon. So they can stay in the air for many days unattended. The battery endurance of the 4G payload is the limiting factor and this could be mitigated by using a bigger Helikite if necessary, although it seems likely that 24 hours endurance will be fine as long as the battery swop only takes a few minutes.

## 4.2 Conclusions

Desert Star Helikite lighter-than-air aerostats are a mature and reliable aerial platform, highly suited to lifting 4G radio-relay equipment. They can provide the steady altitude required of about 1000ft in all likely weather conditions and from many suitable platforms. They are fast enough to deploy and easy to transport in standard vehicles. They can be operated by just one or two trained personnel day or night. They are capable of holding the antenna in the correct attitude for good radio reception and propagation and can stay up for extended periods unattended. Helikites can lift the required ABSOLUTE radio payload and attendant batteries for 24 hours use and can run fibre-optic cable down to the ground. The winch and ground-handling equipment is specially designed for the most reliable operation possible by the fewest personnel.

# 5. Future Aerial Platform Deployment Possibilities for ABSOLUTE Scenarios

This deliverable has examined in detail different forms of aerial platform for use with ABSOLUTE like scenarios. For the purpose of the demo, it has been decided to make use of the Helikite, given its obvious advantages, but it is perhaps worth considering what types of craft would be best used in future real deployments.

The biggest constraints of the Helikite is its ability to carry large payloads (assuming easy deployment and transport), limiting its capacity and capacity density. This means that while it may be good for serving a limited number of first responder users, it will never be able to meet the full demand of consumer UEs at a disaster site. Thus, it cannot practically be used for full service restoration. A second disadvantage is that it needs to be delivered close to the site of disaster probably by road, which requires the road infrastructure to be present. A better alternative would be for a free flying platform that could be flown to the disaster area, but most of these come with limited flight endurance and again limited payload. A third disadvantage is the need to use a tether, meaning flight restrictions.

In the longer term it is expected that all classes of aircraft based UAV will increase their payload capabilities and flight endurance, as well as their production costs. There will come a time when aircraft based UAVs will be able to provide an alternative to the Helikite.

Looking further into the future High Altitude Platforms continue to show great promise. Even those with limited payload capabilities (similar to the Helikite as proposed) could provide long endurance capabilities, operating by solar power, and outside of controlled airspace. Eventually again as payload capabilities increase, they should be capable of providing high capacity densities serving both first responder and consumer UEs, as well as being ideal for temporary events too. HAPs could remain on standby at altitude ready for rapid deployment/footprint reconfiguration to serve a disaster area.

The key question though with all of the above is when? This is unlikely to be any time soon. The Helikite provides a low-cost flexible solution, which while having limited capacity, is versatile, is able to provide a first responder based system for use after disasters, which when coupled with the other ABSOLUTE infrastructure will significantly extend capability beyond what is available now. This intermediate approach will additionally help further focus the minds of manufacturers and the research and development community to address the shortcomings of existing craft, as well as investors who will see further investment opportunities.

# 6. Conclusions

This deliverable has investigated possible aerial platforms and the associated operating environment, for use with the ABSOLUTE post-disaster and temporary event scenarios. It is clear that the number and variety of different aerial platform types have increased significantly in the last few years, as manufacturers, the military and civilian operators become aware of their capabilities. The time is now ripe to exploit aerial platform based technologies for a range of applications, including environmental monitoring, security applications as well as the ABSOLUTE scenarios.

In chapter 2 we provided a taxonomy of different types of aerial platform or UAV. These fall generally into three groups, aircraft, airships, and tethered aerostats. Most UAVs tend operate at low altitudes, with a ground based pilot, with the UAV in direct sight of the pilot. They have limited payload capabilities and short flight endurance. There are both civilian and military applications. The mid-altitude UAVs, cost considerably more and tend to be remotely piloted, with some autonomous variants under investigation. They tend to have longer flight endurances and carry heavier payloads and applications tend to be military. There are also a number of high altitude UAVs (aka High Altitude Platforms). These have the greatest long term promise, due to several favourable operating conditions, low wind speeds, solar power capability, with the capability to operate with payloads up to 1 tonne. Most are still on the drawing board, due to funding and technological constraints. There are a number like the Zephyr that are capable of carrying light weight payloads, with flight durations currently up to 100 hours. Airships are available and proposed in all categories, and have some advantages including their loitering capability and ability to carry moderate to heavy payloads (hundreds of kilogrammes), but adverse weather can be a problem, as can ground handling. The family of tethered aerostats have loitering capability, with the tethers providing power and backhaul capability. The weight of the payload they can carry is related to their size. Aerostats carrying small scale payloads (up 10kg) can be handled on the ground well. Depending on altitude they may require aeronautical exclusion zones to be established. ABSOLUTE’s chosen solution for the demo is the Helikite, a hybrid kite and tethered aerostat, which is much more stable in adverse weather, and as such overcomes most the drawbacks mentioned above.

Chapter 3 examined the operating environment in more detail, specifically taking into account the Helikite based solution. It looked at the aeronautical regulations relating to UAVs and the Helikite, discussing issues such as remote piloting and air exclusion zones. It also considered the radio regulations, including the issue of governance, and whether terrestrial frequencies can be used from UAVs. Specific examples were given of the radio regulatory work done for high altitude platforms over the last 15 years. The chapter also included some examples of representative link budgets for uplink and downlink LTE-A based services at 700MHz and 2.6GHz for aerial platforms and different coverage areas. They show that both uplink and downlink link budgets close for coverage areas up to 15km radius at 300m height , at the lowest level of LTE-A modulation and coding.

Chapter 4 provided a more detailed examination of the capabilities of the Helikite, including the size of the platform, in terms of volume of helium gas required, and how payloads can be attached to the craft. It also presented details of the launch and recovery procedures, including timescales, number of people required at the Helibase, transport requirements. Assuming that the ABSOLUTE scenario requires a 34m$^3$ Helikite, then this can be deployed from the Helibase, and fully operational within 56 minutes, by no more than two people, once fully trained. It is also envisaged to use a smaller platform if the weight of the payload is well optimised.

In the final main chapter, Chapter 5, considered which aerial platform types will be best suited to the ABSOLUTE scenarios in the future. Currently, capabilities are limited primarily by logistics, including transporting and deployment of the Helikite. UAVs are costly and/or have limited payload capabilities. In the future it is expected that the capabilities of all classes of UAVs will improve, meaning that their superior deployment capabilities (airborne rather than road deployment can be utilised). High altitude platforms provide the best long term solution, with potential to operate with long endurance, in a benign part of the atmosphere, potentially using solar power. There could even be a possibility where HAPs could remain on standby at altitude ready for rapid deployment/footprint reconfiguration to serve a disaster area.

# Acknowledgement

This document has been produced in the context of the ABSOLUTE project. ABSOLUTE consortium would like to acknowledge that the research leading to these results has received funding from the European Commission's Seventh Framework Programme (FP7-2011-8) under the Grant Agreement FP7-ICT-318632.

# 7. References

[1] A. Badham, UK ATM and UAS Operations, IET Seminar UAVs in Civilian Aerospace, 22 March 2013

[2] RPAS Steering Group, Roadmap for the integration of civil Remotely-Piloted Aircraft Systems into the European Aviation System: Annex 2 - A Strategic R&D Plan for the integration of civil RPAS into the European Aviation System, Final report from the European RPAS Steering Group, June 2013.

[3] Bart Elias, Pilotless Drones: Background and Considerations for Congress Regarding Unmanned Aircraft Operations in the National Airspace System, Congressional Research Service R42718, September 10, 2012.

[4] T. V. Prabhakar, K. Prakruthi, S. Devasenapathy, H. S. Jamadagni, R. V. Prasad, and I. Niemegeers, Exploring system parameters for viability of energy harvesting technologies, In proc. of the third Int. Conf. on Communication Systems and Networks (COMSNETS'11), 2011

[5] Festo Website, information about the BionicOpter, http://www.festo.com/cms/en_corp/13165.htm

[6] URL of Aerovironment's nano hummingbird UAV, http://www.avinc.com/nano

[7] US Army Tethered Aerostats, http://www.carnetdevol.org/actualite-ballon/aerostat/usArmy.html, September 2013

[8] Vigilance System, http://www.vigilance.nl/tactical-aerostat-systems.html?gclid=COm32u2X_bcCFfMQtAodNDoA5A, September 2013

[9] D. Grace and M. Mohorcic, Broadband Communications from High Altitude Platforms, John Wiley and Sons, October 2010, ISBN: 978-0-470-69445-9

[10] FP6 CAPANINA Website, www.capanina.org, Accessed September 2013

[11] D. Grace and P. Likitthanasate, *A Business Modelling Approach for Broadband Services from High Altitude Platforms*, Invited paper to International Conference on Telecommunications (ICT'06), Madeira, Portugal, May 2006.

[12] NASA Global Hawk, http://www.northropgrumman.com/Capabilities/NASAGlobalHawk/Pages/default.aspx, September 2013

[13] Global Hawk Capabilities , http://www.northropgrumman.com/capabilities/globalhawk/Pages/default.aspx, September 2013

[14] QinetiQ Zephyr, http://www.qinetiq.com/news/pressreleases/Pages/zephyr-sets-world-record.aspx, September 2013

[15] Ascenta Hale Website, www.ascenta-hale.co.uk, September 2013

[16] VariLift Website, www.varilift.com, September 2013

[17]: **2007 No. 734 CIVIL AVIATION** The Rules of the Air Regulations 2007, ISBN 9780110759944

[18]British Kite Flyers Assoication, http://www.bkfa.org.uk/files/Kite%20Flying%20legislation%20-CAP%20393%20Analysis.pdf, September 2013

[19] A. J. Clot, Communications Command and Control - The crowded spectrum, presented at RTO AVT Course on "Development and Operation of UAVs for Military and Civil Applications", Rhode-Saint-Genese, Belgium, 13-17 September 1999.

[20] ACMA, Five-year spectrum outlook 2012–2016: The ACMA's spectrum demand analysis and strategic direction for the next five years, May 2012.

[21] ITU Recommendation ITU-R F.1500, Preferred Characteristics of Systems in the Fixed Service Using High Altitude Platforms Operating in the Bands 47.2-47.5 GHz and 47.9-48.2 GHz, International Telecommunications Union, Geneva, Switzerland, 2000.

[22] ITU Recommendation ITU-R F.1569, Technical and operational characteristics for the fixed service using high altitude platform stations in the bands 27.5-28.35 GHz and 31-31.3 GHz, International Telecommunications Union, Geneva, Switzerland, 2002.

[23] ITU Recommendation M.1456, Minimum performance characteristics and operational conditions for HAPS providing IMT-2000 in the bands 1885-1980 MHz, 2010-2025 MHz and 2110-2170 MHz in Regions 1 and 3 and 1885-1980 MHz and 2110-2160 MHz in Region 2, International Telecommunications Union, Geneva, Switzerland, 2000.

[24] Resolution 734 (Rev.WRC-07), Studies for spectrum identification for gateway links for high altitude platform stations in the range from 5 850 to 7 250 MHz, World Radiocommunication Conference (Geneva, 2007).

[25] International Telecommunications Union Website, www.itu.int