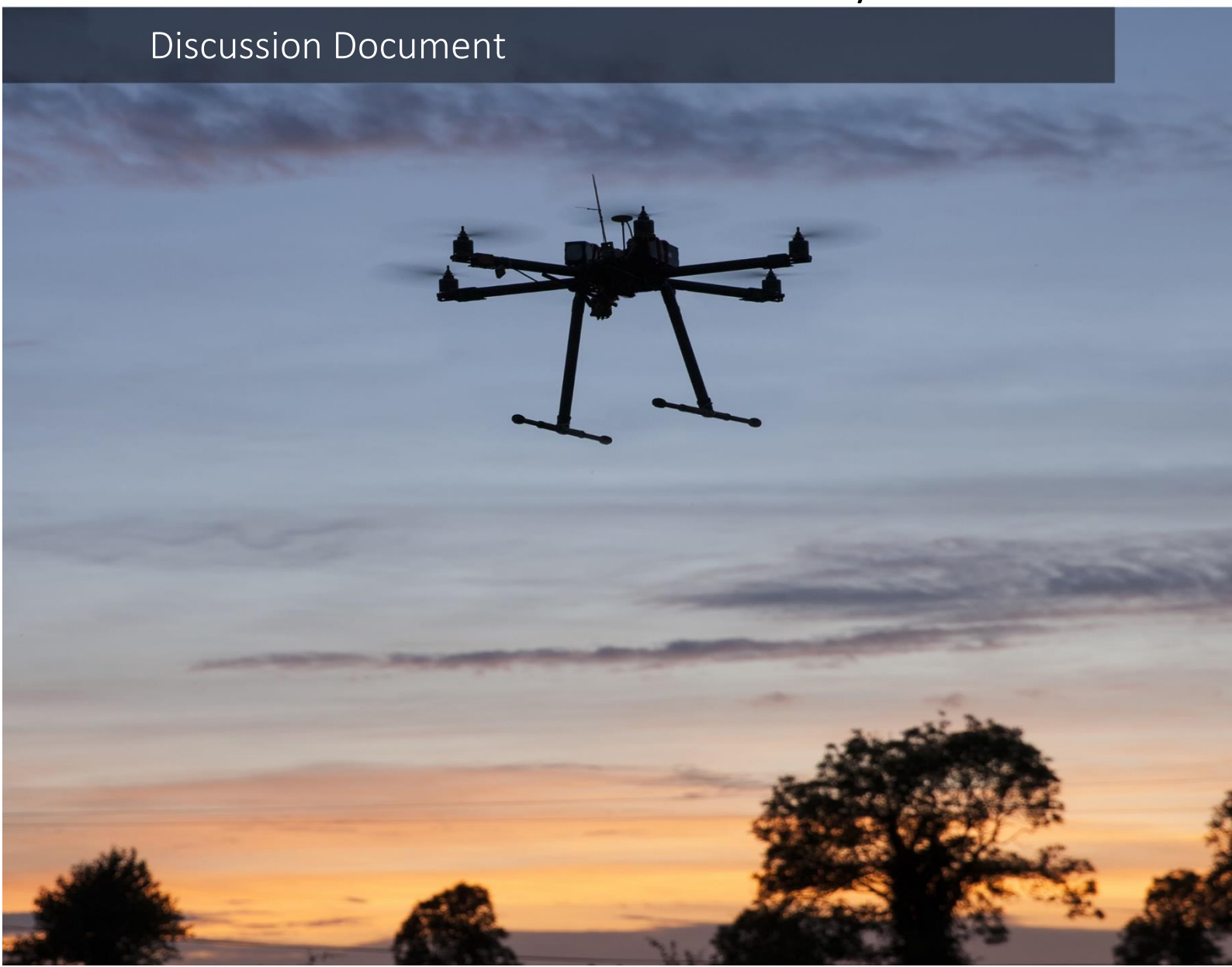
UAS ATM CARS

Common Altitude Reference System

Discussion Document



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Common Altitude Reference System

Discussion Document

European Organisation for the Safety of the Air Navigation (EUROCONTROL)
Directorate of European Civil-Military Aviation (DECMA)
Aviation Cooperation and Strategies Division (ACS)

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Note

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EXECUTIVE SUMMARY

The many activities for which unmanned air systems (UAS) are used – from military through commercial to leisure – can lead to their sharing airspace with conventional aircraft. For separation to be maintained between all users of this airspace, it is essential that the altitudes of all of these aircraft be known unambiguously.

However, whereas conventional manned aviation uses pressure altitude obtained from barometric readings, UAS often use other systems such as satellite-derived altitudes. While each of these different systems can enable safe separation on its own, they can each furnish different altitude values from each other. A common altitude reference system needs to be established.

This document provides a basis for discussion on such a system, following a workshop and a series of webinars organised by EUROCONTROL in collaboration with the European Aviation Safety Agency (EASA).

There are many advantages and disadvantages, economic and technical, to all of the altitude measurement systems available. In the conclusions of this document, a solution is proposed that will enable two different systems to co-habit safely.

1 INTRODUCTION

This is one of a collection of three documents discussing distinct points raised in the 1st UAS-ATM Integration Workshop organised at EUROCONTROL Brussels in April 2017. The purpose of this workshop was to discuss the problems associated with integrating Unmanned Aircraft Systems (UAS) - colloquially called "Drones" - including Remotely-Piloted Aircraft Systems (RPAS), into the airspace that also includes many manned flights and, therefore, presents a definite safety hazard.

The three distinct points are:

- Flight rules;
- Airspace, or operating environment, assessment;
- A common altitude reference system (this document).

Following on from the above-mentioned workshop, a series of webinars were organised in the first half of 2018 to enable interested stakeholders to express their points of view on these questions, to offer solutions where possible, and most importantly to ensure a “common understanding” on any issues related to the topic.

The outcome of these discussions, presented here, is a proposal for guidelines on establishing a common altitude reference system, part of a joint approach between EUROCONTROL and EASA to develop a UAS Integration manual and the joint EUROCONTROL/EASA UAS ATM Operational Concept document, and will be taken into account in the Concept of Operations produced by the on-going CORUS project.

1.1 INTENDED AUDIENCE

This document is primarily for use by stakeholders interested in understanding the problem and solution set out herein. This can include civil aviation authorities, Air Navigation Service Providers (ANSPs), Unmanned Traffic Management (UTM) system providers, drone manufacturers, etc. However, it is hopefully written in a way that is also accessible to any layman interested the problems related to integrating UAS into the airspace.

1.2 ORGANISATION OF THIS DOCUMENT

After this introduction, section 2 specifies the problem statement and any specificities to this problem, together with background information. Section 3 gives a discussion on the different technical systems available for altitude/height measurement and section 4 provides a possible solution as a conclusion..

2 THE PROBLEM

There are currently three acknowledged methods of determining the altitude of an aircraft using a pressure difference with respect to a known datum, using standard equipment, within the International Standard Atmosphere (ISA).

- QFE - height above the local airport etc. ("home point");
- QNH - altitude above a given reference mean sea level (MSL), based on the current air pressure at a regional point of reference;
- Flight Level (FL) - A surface of constant atmospheric pressure relative to a specific pressure datum, 1013.2hPa (defined as 0FL), and separated from other such surfaces by specific pressure intervals. One FL is the pressure differential of a 100ft altitude change in the International Standard Atmosphere [ISO, 1975].

Figure 1 shows these three methods.

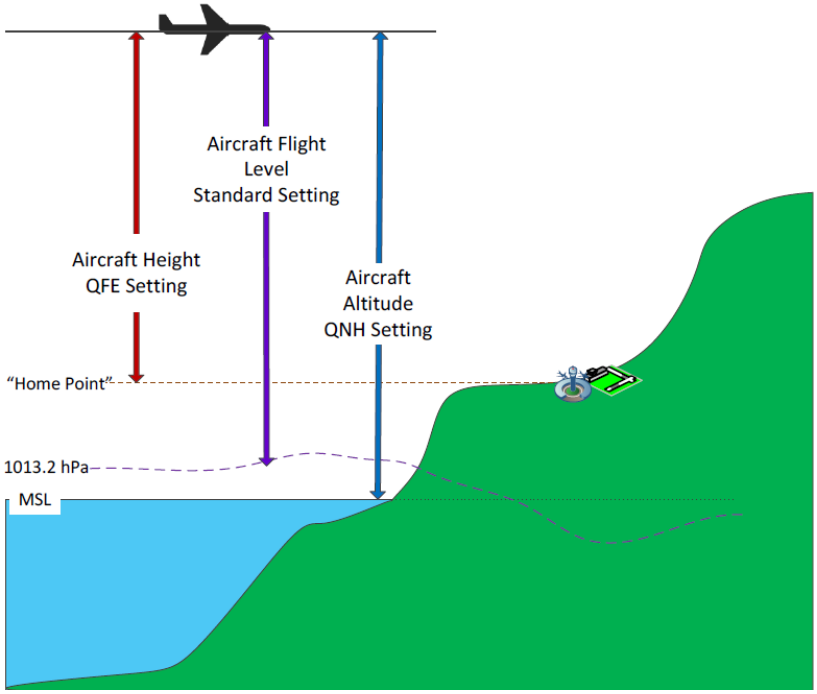

Figure 1 - 3 different height/altitude measurement options

- It is now also possible to measure height using GNSS or its augmentations GBAS or SBAS. In civil aviation, for example, RNP approaches using SBAS have their vertical guidance based on the outputs of a GNSS receiver (in the WGS84 reference system). Such systems are not yet in wide use by general aviation and other users of VLL airspace.

2.1 AIRCRAFT SEPARATION

In article 3.2 of the ICAO "Application of Separation Minima - North Atlantic Region" document [ICAO, 2017], the minimum vertical separation between aircraft, airspace reservations, and between airspace reservations and other aircraft are given as:

A. 4000 feet at or above FL 450 between supersonic aircraft, and between supersonic aircraft and any other aircraft,

B. 2000 feet at or above FL 290 between a formation flight and any other aircraft, or

C. 2000 feet at or above FL 290, or

D. 1000 feet from FL 290 to FL 410 inclusive between [Reduced Vertical Separation Minima] RVSM aircraft, or

E. 1000 feet below FL 290

Although these flight-level altitudes may not correspond to the actual altitude above sea level, vertical separation can be ensured if all aircraft altimeters are calibrated identically.

Closer to the ground, aircraft have to be careful not just to avoid other aircraft, but also terrain and other obstacles. For this reason, pilots need a datum that will enable them to understand their position with respect to the ground. Below a particular region-dependent transition level, therefore, they recalibrate their altimeters to the QNH pressure for the appropriate QNH region.

Again, as long as all aircraft altimeters are similarly calibrated in the same region, vertical separation can be assured.

2.2 UAS ALTIMETRY

UAS also need altimetry. It is necessary to ensure that they stay within their mandated limits, including geo-fencing, geo-caging, etc., and for them to avoid hitting obstacles on the ground. However, the arrival of UAS operations has introduced a new altitude/height challenge: how to ensure separation between UAS and other aircraft (manned or unmanned) in the same airspace by ensuring they are using the same height/altitude reference. Although UTM functions such as mission planning, flight planning, authorisation, geo-fencing, etc. will ensure a certain level of separation, height is a necessary input to other functions supplied by a UTM system.

Small-UAS altimeters (which are generally GNSS-based) are generally set to 0 at the beginning of each flight. This start position is generally referred to as the "home point". However, if an aircraft is flying at, say, 200ft, it is essential that others users in the same airspace volume have the same reference for 200ft.

2.3 SOURCES OF HEIGHT/ALTITUDE DISCREPANCY

Every UAS can be considered to start from a different "home point". It follows therefore that two UAS that are flying at the same indicated height are likely to be actually at different true altitudes. As can be seen in Figure 2 the "height" a given UAS has to attain to clear an obstacle, for example a tall building, will depend not just on the height of the building, but also on the elevation of the "home point" compared with the building.

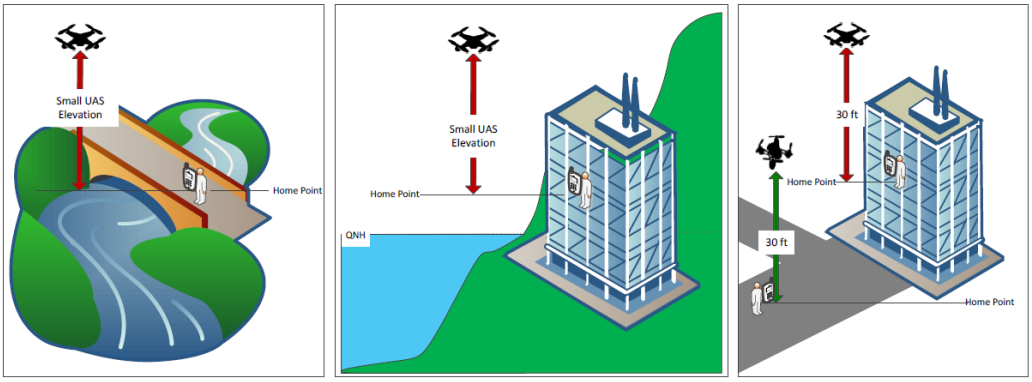

Figure 2 - The effect of a drone's "home point" specification

In addition, this height is completely independent of the QNH used by manned aircraft.

It is also possible that new and future technologies could be used for determining the altitude of an aircraft, manned or unmanned. As well as standard barometric pressure, lidar or radar, or more importantly GNSS/EGNOS-based systems, could be used for height measurement. In fact, many GNSS receivers output the orthometric height above MSL since they incorporate the EGM96 model of the geoid, recognised worldwide and which provides accuracies of a few centimetres. However, in order to know an aircraft's height with respect to obstacles such as buildings, a Digital Terrain Model (DTM) or obstacle database would be needed.

2.4 VERY LOW-LEVEL AIRSPACE

Most of the discussion in this document concerns UAS that will be flown in Very Low-Level (VLL) airspace. This is the airspace below the specified minimum height for VFR flights. According to part (f) of rule SERA.5005 (Visual flight rules) of the Standardised European Rules of the Air (SERA) [EU, 2012][1]:

> *Except when necessary for take-off or landing, or except by permission from the competent authority, a VFR flight shall not be flown:*
>
> *(1) over the congested areas of cities, towns or settlements or over an open-air assembly of persons at a height less than 300m (1,000ft) above the highest obstacle within a radius of 600m from the aircraft;*
>
> *(2) elsewhere than as specified in (1), at a height less than 150m (500ft) above the ground or water, or 150m (500ft) above the highest obstacle within a radius of 150m (500ft) from the aircraft.*

"Permission for the competent authority" is, however, often given to fly VFR below these minima, especially to state aircraft such as police helicopter, air ambulances, the military, etc. The many other users of this VLL airspace are paragliders, model-aircraft flyers, ultra-lights, hang-gliders etc.

It should not be forgotten that UAS will often be able to fly above this VLL airspace - not only in the rest of class G airspace but also in controlled airspace and above it, in Very High Level (VHL) airspace. While UAS flight in these other airspaces will also have to rely on a common altitude reference system, it is considered that, for the moment, VLL is the priority; current UAS users of other airspace classes are less common, and the types of UAS that are flown there are generally equipped to fly IFR.

[1] based on Annex 2, Section 4 of the ICAO Chicago Convention [ICAO, 2005]

2.5 MAIN AREAS OF CONCERN

UAS must be able to keep clear of each other, and of manned aircraft using the same airspace. To ensure vertical separation from these aircraft, it is essential that they use the same altitude reference. They must also be able to keep clear of objects on the ground - buildings, cranes, trees, etc. - and of course people and property in general. Their pilots (or their on-board flight controllers) need, therefore, to be able to understand their height above the ground in an unambiguous way, to be able to relate this to databases of objects and terrain, and to the declared altitude of other aircraft.

For a UAS Traffic Management (UTM) system to be able to inform air-traffic authorities of the accurate trajectory of a UAS, it is necessary that the altitude at which the UAS will be flown be transmitted and adhered to unambiguously. This is especially true when flying in upper limit of VLL airspace and airspace close to the airports. This is primarily a concern for small UAS operations; larger UAS flying under IFR must use the same means of defining their altitude as manned aircraft.

This guideline document needs to answer two principal questions:

1. Which technology should be used to measure the altitude at which a UAV is flying, and to what precision and accuracy?
2. This must be technologically feasible on a UAV and provide an altitude/height value compatible with other users of the same airspace and with reference data concerning obstacles on the ground.
3. Which reference datum should be used to ensure that every user of a given airspace is flying in the same altitude/height reference system?

3 GUIDELINES FOR A COMMON ALTITUDE REFERENCE SYSTEM (CARS)

3.1 SEPARATING VLOS FROM OTHER TRAFFIC

ATM/UTM have as a primary objective maintaining separation between aircraft (manned or unmanned) and between UAS and obstacles/buildings, although work on Detect and Avoid (DAA) systems aims to enable such separation to be performed automatically by the UAs. The rules of the air such as the SERA include articles on rights of way etc. to ensure this separation. However, vertical separation remains the key to airspace safety and VLOS rules require the remote pilot (RP) to limit the VLOS height flown to ensure that they are visually able to separate vertically.

The initial view of the EUROCAE DAA group was that, rather than using vertical separation, other airspace users should simply be avoided in areas where UAS operations are limited to VLL, below 150m. However, the relative speeds of the two aircraft to be separated becomes a major point when UA are part of the problem. In many cases UAs are stationary or very slow moving and it is not even clear which direction they are moving in to determine any right of way rules etc.

An RP is barely capable of ensuring separation in VLOS and might not be able to avoid other traffic such as VFR or BVLOS, even if a DAA system is installed. They will certainly not be able to react in time to avoid fast moving military traffic. In the future, the roles may be reversed it will be very hard for low-flying VFR traffic such as HEMA to see very fast (up to 250kts) but relatively small UAs soon enough.

Strategic vertical separation is going to be key to solving this problem.

3.2 THE NEED FOR A CARS

At present, there are several problems associated with altitude for UAS/manned-aviation: barometric pressure altitude is not very accurate; current obstacle databases are made for manned aviation; use of a "home point" for zero reference could lead to a UAs flying in VFR airspace without being aware of it due to uneven terrain, e.g. flying from a hilltop, etc. Additionally, for traffic separation between UTM and ATM (150m/500ft), or intra UTM (between 0m and 150m/500ft), visual assessment of relative height between two flying objects is not accurate enough and a true, qualified measurement is needed.

Only terrain and obstacle protection are likely to be possible by visual means from the ground. On the other hand, whereas it might not be critical to have precise measurement equipment on board a UA flying VLOS, a BVLOS pilot also needs to be able to avoid obstacles on the ground, without the benefit of line-of-sight.

As stated in 3.1 above, VLOS implies that separation is managed visually by the RP with only their eyes to assist them and their job is simply to stay out of the way of other traffic. In this case VLOS only need a means of staying within the normal AGL vertical limit. However, visual separation of one UA from another one relatively far away is impossible. Additionally, functions like geo-fencing and geo-caging will assist RPs, so that they do not only rely on their eyes but these functions need to know the height the UA is flying at. This is especially the case when close to an aerodrome, say, where the height limit may be variable. Additionally, if a drone goes BVLOS it needs a common reference with the other

aircraft around it. Furthermore, the EASA Opinion requires e-identification and geo-awareness for UAS Class 1 to 3 in the Open Category. Therefore, geo-data and particularly height data are needed.

In cases like these, it is necessary to have an unequivocal reference for height or altitude measurement. A CARS is required by VLOS because there are no other means of determining their altitude and extending this to U-Space. There has to be at least an indication of the altitude for VLOS operations since even if a block of airspace is reserved by a flight plan, there is no way of visually determining if a VLOS UAS is within the vertical airspace authorised or not.

Such a CARS implies a need for a common technology for determining height or altitude and the need for a common datum. This guidance document is a necessary requirement for arriving at these needs. The reference for safety and performance requirements should be established before reviewing and selecting a datum and defining requirements for positioning sensor technologies.

It is fundamental that the present document be aligned with the roadmap in Europe. Recent material issued by EUROCONTROL (Integrated CNS vision, SESAR project 14.01.01) and SJU (SESAR CNS Avionics and Spectrum Strategy) state that in the future GNSS will be the primary means of navigation. However, this work is concerned with commercial aviation, and its applicability to low-level flight is not certain since general aviation was not taken into account.

3.3 REFERENCE DATUM

The starting point for this discussion should be the common altitude reference datum rather than the technology used, since this datum will determine the map data and altitude. This in turn could determine the technology required.

3.3.1 HOME POINT

Many UAS use height from the "home point", which poses a problem since the upper limit of VLL, the lower normal limit of VFR, is 150m/500ft above ground level (AGL). However, ground level is only the same as the home point at take-off and could vary significantly during a flight.

3.3.2 WGS84

The WGS84 geoid gives the difference between the ellipsoid and the MSL. It is publicly available and is generally included in most GPS receivers today.

The geometric altitude in WGS84 could be appropriate for all aircraft. Almost all relevant drones already use WGS84 and SBAS-augmented GNSS - EGNOS is also available. Galileo is already providing initial services and, as part of the enhanced service declaration, new services such as high accuracy down to 20cm and authentication, which will increase robustness and resilience against cyber attacks, will be provided.

Although the WGS 84 ellipsoid is up to 100m different from mean sea level in some parts of the world, the largest error is in India, not Europe. Separation is still assured if everybody uses the same datum e.g. everybody flies at -100m. Translation between WGS84 height and AGL altitude should be done by ATM/UTM or other on-board functions.

Ground-plan databases applicable to UAs should also apply WGS84 to ensure obstacle clearance. Denmark, for example, uses a publicly available digital height model based on WGS84. It has 1.6m^2 resolution and should enable a UAS to know when it is close to any obstacles.

3.4 TECHNOLOGIES

3.4.1 BAROMETRIC PRESSURE

Barometric pressure is, today, the standard method of ensuring separation between aircraft, which are all equipped to use it and whose pilots are all trained for it. As explained in section 2.1, as long as two aircraft are flying on different iso-pressure layers, they will not come into conflict. It may be needed for determining the upper limit of VLL because manned aviation uses it for this.

However, it might not work for avoiding obstacles on the ground. An aircraft/UAV trying to use it to keep clear of buildings/objects needs the real geometric height of that object, which could be different from that measured by barometric equipment that assumes a standard atmosphere. If the air is colder, for example, the pressure levels are compressed and hence the height of an obstacle measured by air pressure is not the same as the geometric height.

Two aircraft in the same area at the same time should use the same altitude setting. However, BVLOS flights might not have pressure data available for their entire route and would have to use the 'regional QNH' (i.e. the lowest QNH of a specific set of QNH reporting stations) used by manned aviation. The nearest QNH could be automatically uplinked to a UA via datalink. For collision avoidance, either VLOS flights should also use this regional QNH or BVLOS flights should not enter airspace used by VLOS flights - this is similar to the manned aviation case where en-route aircraft has to remain clear of traffic patterns at aerodromes.

The need for transmitting the QNH is a clear drawback of barometric height. Additionally, QNH is not available everywhere, and can be very limited in scope.

Barometric pressure presents many other problems in VLL:

- Atmospheric pressure over cities (probably the most challenging environment and the one that poses the most risk to the public) is difficult to measure due to high temperature gradients. Buildings generally radiate heat, in particular when there are large air-conditioning units on top of them, whereas parks and lakes that could be nearby could be cool. This could considerably affect the measurement of barometric altitude on UAs/aircraft.
- Air pressure is not constant but changes over time, so the (regional) QNH does as well. If air pressure is used for de-confliction between different airspace users, UAS may need to be able to change their QNH-setting in-flight.
- The certified resolution of the barometric measurement in airplanes is 25ft, which is very coarse for using in VLL. In fact, errors up to 75ft are fairly common.
- It can be difficult to measure air pressure in a UA since the rotors could be quite close to the pressure sensors and cause constant changes in pressure. In an normal aircraft the sensors are far away from the propellers.

Other height measurement sensors e.g. sound, light, radio or a geodetic approach could be more accurate than a barometric one.

3.4.2 TCAS/ACAS

The techniques used in TCAS/ACAS logics could bring useful information though there is uncertainty concerning the ACAS-Xu reference used on the vertical axis.

3.4.3 GNSS-BASED TECHNIQUES

ICAO is developing the Dual-Frequency, Multi-Constellation (DMFC) GNSS concept, which will have many technical and operational benefits for civil aviation. The CONOPS and the corresponding Annex 10 SARPs for GNSS systems are currently being developed at the ICAO NSP level. Other standardisation bodies such as EUROCAE and RTCA are working on the DFMC antenna and receiver MOPS. EGNOS v3 will support the DFMC concept by augmenting GPS and Galileo, and providing corrections on L1 and L5 frequency bands.

Most small UAS will probably keep a GNSS-only based reference in the near future. Some manufacturers have already coded a conversion to the manned-aviation reference, but they consider the pressure sensors used to be error-prone. Conversion between the systems could be automatic in a U-Space system. Perhaps it would be feasible to introduce GNSS-based altitude to manned aircraft as well as UAS.

3.4.3.1 GNSS ACCURACY

EGNOS already normally provides accuracy well within 1 metre horizontally and 2 metres vertically and it has recently been announced that Galileo will provide a high-accuracy service down to 20cm free of charge. ESSP provides a monthly EGNOS performance report (e.g. [ESSP, 2018]) that deals with GPS+SBAS vertical accuracy values.

Some UAS already use low cost Real-Time Kinematics (RTK) kits for VLOS and/or "short range", some use both a digital terrain model and GNSS information, and some of the slower ones merge this with sensor data. RTK provides centimetre-level accuracies, but needs good quality measurements in order to fix the ambiguity computation involved in the carrier phase measurement. However, it is questionable if the UAS market actually needs centimetre-level accuracies.

3.5 IMPLEMENTATION

3.5.1 GENERAL IMPLEMENTATION OBSERVATIONS

Although a common altitude reference is considered absolutely necessary, EASA does not expect any measurement of UA height for Open-category VLOS operations. It considers it the responsibility of the operator or the pilot, who might have a limited knowledge of the UA's height, to keep it away from other airspace users. However, the EASA Opinion [EASA, 2018] says that e-identification and geo-awareness are required for ‘Open’ category classes C1, C2, and C3, and geo-data data is needed for both functions. On the other hand, for the "Specific" and "Certified" categories as well as small UAS used professionally under IFR, the barometric reference should be used, though these UAs will certainly also be equipped with GNSS, as are the vast majority of manned aircraft worldwide.

From a legal perspective there are issues with two entities - ATM and UTM - managing traffic in the same airspace. The ANSP is responsible for managing the FIR which goes all the way to the ground; airspace class G is not unmanaged. In addition, if UTM deals with airspace above 150m, where there is VFR and IFR traffic, airspace structures, and different airspace classes, these legal issues are greatly aggravated.

3.5.2 MAXIMUM HEIGHTS AND A BOUNDARY LAYER

The priority right now, since the first U-Space services will start in 2019, is to enable UTM in VLL, limited to below the theoretical lower limit of VFR traffic of 150m/500ft AGL. Even though there are statements that U4 will go higher that 150m, this is more an idea than a decision, and is the reason why there are on-going projects to show some scenarios and see how further the U-space can go. Additionally, member states have requested that UA height be restricted to 150m AGL.

If a 30m/100ft buffer were available between this 150m/500ft lower limit of VFR traffic and a maximum small UA altitude of 120m/400ft, this could be sufficient to accommodate errors caused by either barometric errors or GNSS/GPS inaccuracies and loss of integrity. However, a margin of 20% in the vertical dimension would significantly reduce the airspace available and would pose more burden on other UTM functions since the density of drones would be higher.

More importantly, there are already many manned flights under the 150m/500ft limit: emergency descents; civil helicopter landings; medical services; search and rescue (SAR); police and civil protection helicopters; gliders, hang-gliders, parachutes and paragliders; aerial banners, etc. There can also be military jets flying at 420kts at 30m/100ft AGL in some states. There is, therefore, no point in having such a boundary layer.

3.5.3 DATA ACCURACY, RELIABILITY AND INTEGRITY

The question of accuracy and reliability is more important in a higher risk environment, where more accuracy is needed, than in lower risk environments, but in any case, it is important to define a minimum accuracy for the UAS pressure sensor.

Integrity of data is a major concern. Whereas weather data, which enables pressure to be converted to altitude, can be subject to major integrity and accuracy questions, EGNOS has been designed according to ICAO SARPs Annex 10 and certified by EASA for supporting very demanding SBAS CAT-I operations (and other less demanding ones). The level of integrity is therefore as per ICAO SARPs 10-7.

4 CONCLUSIONS

4.1 INTRODUCTION

The safety of manned commercial IFR operations is assured, in part, through the use of a common altitude reference system (CARS) that enables a known level of vertical separation when used in accordance with implemented procedures and a given airspace design[2]. This barometric pressure altitude system is based on the difference between a given fixed pressure setting – sea level in the international standard atmosphere (ISA) when flying at high level, or a local setting (called QNH) used when aircraft are flying below a locally determined minimum altitude - and a measurement of the current outside air pressure made by the aircraft itself. The defined altitude of a given aircraft is, therefore, independent of and non-cooperative with other traffic.

It is apparent, that the best option for determining the altitude of BVLOS[3] UAs flying in airspace classes A to C is to match the requirements of manned aviation.

In low-level airspace, the safety of aircraft using this pressure altitude system relies on 2 main essentials:

- The same QNH is used on all aircraft in the same airspace;
- VFR provides other elements to be used as means of mitigation.

Barometric pressure altitude is calculated using air temperature as well as pressure. Both of these are highly variable at low-level above cities where temperatures can be as much a 3°C higher than the surrounding countryside and where pressure can be affected by “urban canyons” etc.

A GNSS-based altitude system is dependent on the GNSS constellations it uses, and is non-cooperative with traffic. A systematic error can affect all the local airspace users and in complex areas such as cities the altitude error can be significant compared with the VLL airspace height of 500ft/150m. This system is backed-up by ground infrastructure in the event of a systemic failure of the GNSS constellations. Manned aircraft use it, with augmentation systems and adapted procedures, for landing.

Other altitude reference systems based on the operator point of view aggregate static errors and dynamic errors. They are dependent on the operator and are non-cooperative.

Finally, the use of UTM services to efficiently support mitigation means and minimise the occurrence of a loss of vertical separation should not be overlooked.

4.2 OPTIONS FOR A CARS

VFR flights normally abide by the SERA/ICAO Annex 2 limits of a minimum pressure altitude of 500ft (1000ft above cities). However, the SERA (and ICAO Annex 2) authorises these limits to be decreased nationally or regionally: aircraft obviously have to take-off, land etc. and there are many other

[2] These guidelines only address separation. Other aspects of collision avoidance exist as an additional safety net.

[3] VLOS operations are intended to be performed at very short range, at very low altitude (50 m or lower) and in a manner that meets VFR practices.

authorised airspace users flying below this level. A UAS-VFR traffic mix below 500ft is, therefore, inevitable.

Three options for altitude measurement in VLL emerge from this document:

1. pressure altitude (QNH) for both UAS and manned VFR aircraft with no other means;
2. GNSS altitude for both UAS and manned VFR aircraft with no other means;
3. different reference altitude systems for UAS and manned VFR aircraft with additional means.

4.2.1 OPTION 1: ALL LOCAL VLL OPERATIONS USE BAROMETRIC ALTIMETRY BASED ON LOCAL QNH; NO UTM FUNCTIONALITIES ARE USED

Pressure altitude is currently the reference altitude system used by manned aviation in most flight segments. It is safe as long as every airspace user is using the same QNH and separation is assisted by air traffic services – depending on the services provided in the airspace and using surveillance information.

In VLL, GNSS height accuracy is expected to be around 5ft/1.5m. Pressure altitude will probably not be able to provide such accuracy in all situations. In addition, the QNH setting used by a UAS may be different from the one used by a manned aircraft overflying that UAS's operational airspace volume. Such a discrepancy in QNH settings can create a difference in the given altitudes of the aircraft, which may result in loss of separation, even if the two aircraft are interacting by radio, because the two figures do not use the same reference.

This is not considered an issue between two manned VFR aircraft because flight rules can be expected to mitigate the risk. However, it is an issue for UAS (except in VLOS under certain limited operational conditions) because they do not abide by the VFR requirements. VFR mitigation means do not therefore apply to BVLOS operations, and no other mitigation means are envisaged for this option, as stated above.

In addition, in the short term, studies forecast large volumes of UAS traffic. This will mainly be in VLL, which is defined as the airspace below 500ft (or 1000ft) and where the pressure altitude difference from QNH is the most difficult to use because of the small altitude differences between the aircraft. Using pressure altitude in VLL would induce a systemic risk of air collision due to a loss of vertical separation, both between manned aircraft and UAS, and between UAS themselves.

In conclusion, option 1 is not the preferred option because:

- QNH settings of a VFR manned aircraft and a local UAS operation might be different;
- there is no effective mitigation means such as VFR rules applicable to both aircraft;
- pressure altitude lacks the precision necessary to distinguish between two UAs with very similar altitudes in the same airspace.

4.2.2 OPTION 2: ALL LOCAL VLL OPERATIONS USE GNSS-BASED ALTIMETRY; NO UTM FUNCTIONALITIES ARE USED

It is obvious that, at some point in the future, all aircraft will be equipped with a more accurate height measurement system that barometric pressure. EGNOS can already provide a vertical accuracy within 2 metres and Galileo will soon provide accuracy to 20cm.

However, despite ICAO's DMFC GNSS concept, CONOPS, and corresponding SARPs for GNSS systems and, although many commercial flights currently have access to GNSS-based altitude information, barometric pressure works well as a means of assuring vertical separation between commercial aircraft. Much research and proof of concept will be required before both pilots and controllers will accept a change.

Although most small UAS already use a GNSS-based reference and will probably continue to do so in the future, general aviation (GA) is not generally as well-equipped with non-barometric means and will be reticent to spend extra money on equipment simply to avoid UAs.

Option 2 is rejected, therefore, due to the cost of equipping VFR aircraft with GNSS-based height measuring equipment and the probability that the GA community will reject having to use it.

4.2.3 OPTION 3: EACH AIRSPACE USER WILL USE AN APPROVED ALTIMETRY SYSTEM BEST SUITED TO THE AIRSPACE OR CERTIFICATION REQUIREMENTS, AND UTM FUNCTIONALITIES ARE USED.

It has been demonstrated that there is no permanent accurate analytical method for linking all the different means and systems used for measuring altitude or height.

Ensuring vertical separation using a technical approach simply requires adding all the error margins of each altitude measurement system and defining a safety margin to mitigate the risk of loss of separation. This method would not be practical in such a thin airspace (500ft height) since the sum of all the errors plus the safety margin would be too great.

The solution is to combine a technical approach with operational requirements, and procedural and regulatory mitigations:

- Technical
    - The UAS operator choses a UAS with the most accurate altitude measurement system available (including barometric) for the type of mission the UAS operates (urban, non-urban, etc.)
- Operational capabilities
    - All of the measurement systems described are non-cooperative and cooperation cannot be included into them. The task is rather to complement them to the necessary cooperation level using an adequate surveillance system designed to compensate for the fact that UAS do not comply with VFR requirements. With the resulting information, the UTM system will connect all the VLL airspace users together and provide a separation information service.
    - The UAS operator will be required to provide their flight intentions using the UTM flight planning service and could be assigned to traffic layers for low-level 'en-route'-like traffic.
- Procedural
    - New flight rules will protect manned aircraft from UAS.
    - An airspace assessment will provide a permanent safety net to protect manned aviation and third parties. Dynamic geo-fencing complements the airspace assessment and

provides a satisfactory mitigation means for unplanned manned priority traffic in urban areas (HEMS, air taxis, firefighting, etc.).

- Note: it is recommended that a temporary 120m/400ft ceiling be set for UAS VLL operations. Safety monitoring may reduce this buffer as separation data are collected.

- Regulatory
  - Regulations will define the method for calculating the UAS-UAS and UAS-VFR traffic separation minima.

Option 3 is preferred because it provides the right balance between the adequate and necessary requirements imposed on both the UAS industry and manned aviation, and it provides common benefits through increased safety levels. It still requires research and validation campaigns to specify the performance requirements of each of the airspace users and sub-systems.

- Requirements and benefits for UAS and UTM
  - Technical solutions for UAS altitude measurement systems are left open: the UAS designer maintains maximum technical flexibility in the choice of altitude system, provided that it meets the operational safety objectives of the EASA-specified category in which it will be used.
  - Connectivity with a UTM service provider will furnish a large part of the collision-mitigation means (see the annex). The burden falls primarily on
  - UAS traffic to protect manned traffic;
    - the performance (such as integrity, continuity and availability, and latency) of UTM services. The performance requirements of a UTM separation information service are proportional to the separation minima defined for achieving the target level of airspace safety (TLS). It will also have to be able to correct static errors in vertical position.
    - A BVLOS operator will need to be connected to UTM services. Procedures will have to be developed for VLOS operations.

- Requirements and benefits for manned VFR traffic
  - Manned VFR traffic are not required to change their altitude measurement equipment. There is no change to regulations or ICAO standards.
  - Manned VFR traffic will be required to be cooperative (by connecting to a UTM system) but VFR rules will remain unchanged.
  - It should be noted, however, that:
    - Low-level horizontal separation between two manned VFR flights will also benefit from this cooperation;
    - connectivity to a UTM system would improve also the safety level of VFR operations in general by contributing to a reduction in VFR-VFR collision risk.

4.3 RESEARCH AND DEVELOPMENT REQUIREMENTS

Some R&D is necessary before allowing mixed UAS-VFR operations in VLL. This non-exhaustive list highlights some of these:

- Validate option 3: “a TLS of about $5x10^{-5}$ (the current VFR TLS) can be maintained when all VLL airspace users are connected to a UTM system and each uses any given altitude measurement system”.
    - Specify performance parameters and values required for the UTM separation information service;
    - Provide connectivity standards that meet the UTM specifications for the separation service;
    - Specify a compliant UTM surveillance service;
    - Specify the performance parameters of dynamic geo-fencing to meet the TLS.
- Set up a method
    - for setting separation standards between UAS and UAS, and between UAS and manned aircraft;
    - for allowing the temporary height limit of 120m (i.e. a 30m upper buffer) to be modified, using monitoring data;
- Study the static pressure gradient in urban environments compared with non-urban environments;
- Develop procedures for VLOS-VFR operational compatibility.

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APPENDIX 1 USING UTM TO MITIGATE DIFFERENCES BETWEEN DIFFERENT ALTITUDE SYSTEMS

In option 3 (section 4.2.3), the UTM infrastructure mitigates the issues coming from the different altitude measurement systems. The main services used are the e-identification service and the vertical-separation information service (VSIS). The logic of the process is as follows:

- collect altitude measurement from all airspace users, either via the tracking service (TS) or via a dedicated service if the TS is not tailored to support the VSIS;
- identify the airspace users in potential conflict and correlate them to the altitude information received;
- process the information to calculate a calibrated vertical separation (Δh);
- send Δh to those airspace users that have a need to know (vertical separation hazard or not). Pushing too much information to all airspace users is not foreseen, to avoid saturation.

Figure 3 shows this concept. Since all operations are local, the UTM infrastructure (including the services provided) provides reference altitudes for both barometric and GNSS systems, the main altitude systems considered in this annex. Not all the errors applicable to the measurement systems into account here; additional study and validation will be required for calculating the total error for Δh.

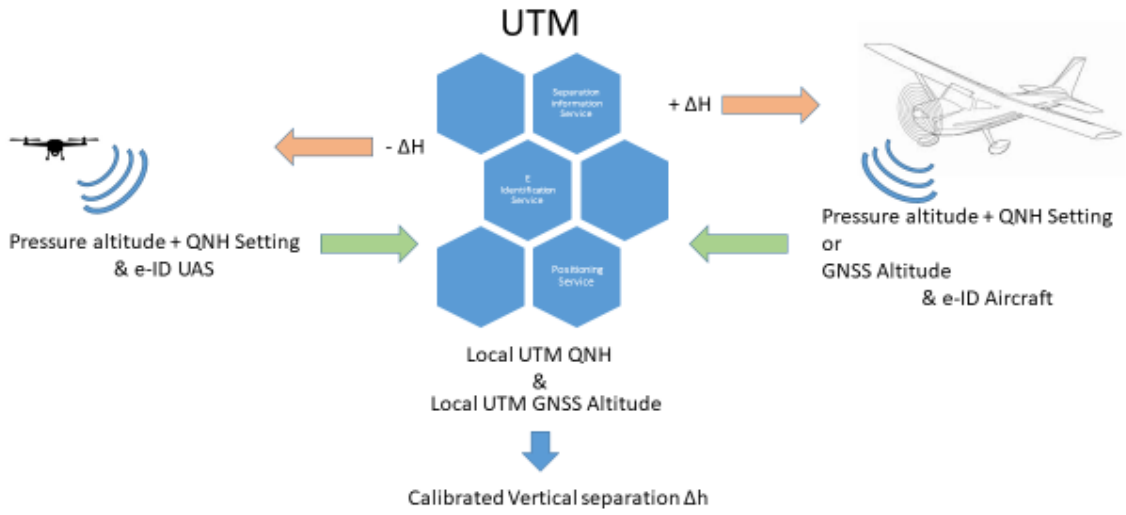

Figure 3 - UTM based calibrated vertical separation calculation Δh

The two altimetry measurement systems studied in this proof of concept give rise to three possible combinations of two: called cases 1, 2 and 3 below. Since any of these three cases are likely, this will set the reference requirements for UTM services and physical infrastructure.

Case 1, the most general case, shown in Figure 4, involves two airspace users (here a UAS and a manned aircraft) both using barometric pressure to measure their altitude, with each one having a different QNH setting. The UTM system uses its local barometric altitude, QNH Ref, as a reference for calibrating the two different QNH settings. In the calculation of Δh, this reference QNH disappears,

but it provides additional information on both airspace users' true local altitudes for use by other services.

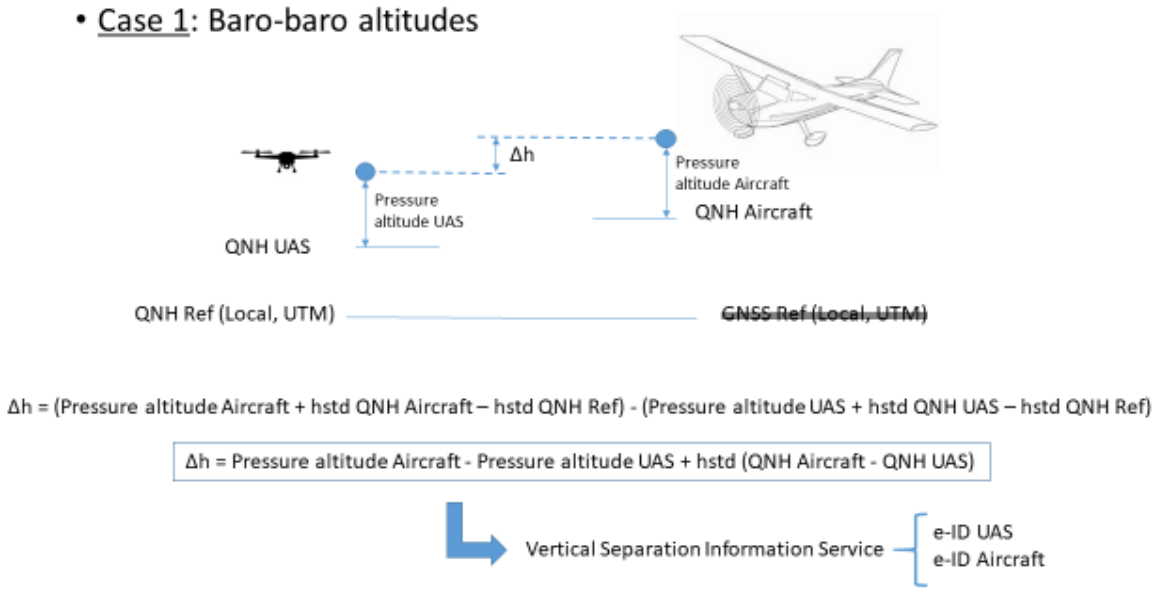

Figure 4 - Barometric-barometric altitudes received by UTM

Case 2 has two airspace users using different altitude measurement systems that cannot be matched analytically. This is the most complex situation. The UTM infrastructure calibrates the different measures by measuring its local QNH and its GNSS altitude, QNH Ref and GNSS Ref respectively. Once transformed into pressure altitude, the QNH side of the equation is equal to the GNSS altitude one. It thus provides Δh as shown in Figure 5.

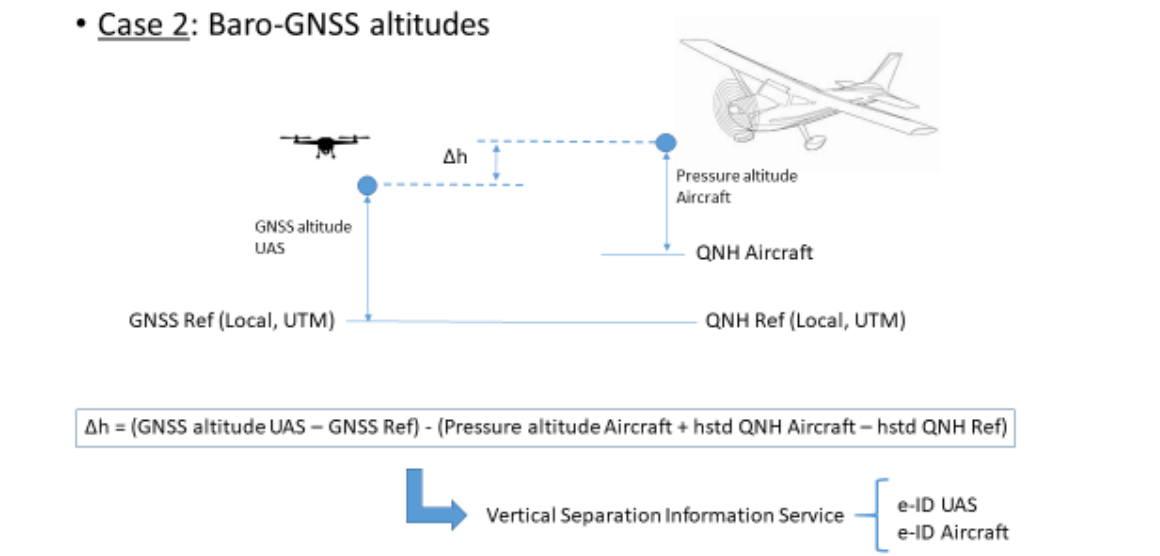

Figure 5 - Barometric-GNSS altitudes received by UTM

Case 3, shown in Figure 6, has two airspace users both using GNSS altitude. The UTM system uses its local GNSS altitude, GNSS Ref, as a reference for calibrating the two different GNSS altitudes. This reference GNSS altitude disappears in the calculation of Δh, but it provides additional information about the true local altitude of the two airspace users that can be used by another service.

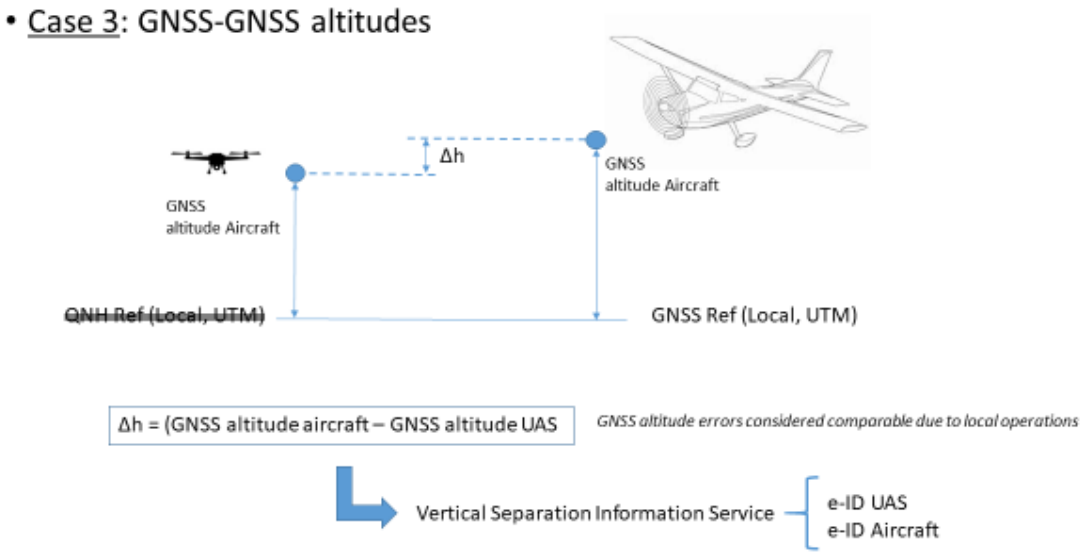

Figure 6 - GNSS-GNSS altitudes received by UTM

DEFINITIONS, ACRONYMS AND ABBREVIATIONS

Term	Definition
ACAS	Airborne Collision Avoidance System
ADS-B	Automatic Dependent Surveillance-Broadcast
AFUA	Advanced Flexible Use of Airspace
AGL	Above Ground Level
AIM	Aeronautical Information Management
AIRAC	Aeronautical Information Regulation And Control
AIS	Aeronautical Information Service
AMC	Airspace Management Cell
ANS	Air Navigation Service
ANSP	Air Navigation Service Provider
ASBU	Aviation Systems Block Upgrades
ATC	Air Traffic Control
ATCO	Air Traffic Control Officer
ATM	Air Traffic Management
ATZ	Aerodrome Traffic Zone
BRLOS	Beyond Radio Line of Sight
BVLOS	Beyond Visual Line of Sight
C2	Command and Control Link
CAA	Civil Aviation Authority
CEF	Connecting Europe Facility
CFR	Code of Federal Regulations
CNS	Communications, Navigation, Surveillance
COM	Communications Technology
CONOPS	Concept of Operations
CPDLC	Controller Pilot Datalink Communication
CTR	Control Zone
D&A / DAA	Detect and Avoid
DTM	Drone Traffic Management
EAD	European Aviation Database
EASA	European Aviation Safety Agency
EC	European Commission
ECAC	European Civil Aviation Conference
EDZ	Exclusive drone zone
EOC	Essential Operational Change
eIDAS	electronic Identification and Trust Services
EU	European Union
EVLOS	Extended Visual Line Of Sight
FCC	Flight Control Computer
FIS	Flight Information Service
FL	Flight Level
FLARM	Flight Alarm
FOC	Full Operational Capability
FPL	Flight Plan
FUA	Flexible Use of Airspace
GA	General Aviation
GANP	Global Air Navigation Plan
GIS	Geographic Information System
GRA	Generic risk assessment
HALE	High-altitude long endurance

HIRAT	High Intensity Radio Transmissions
HFR	High-evel flight rules
IBAF	Integrated Briefing Automated Facility
ICAO	International Civil Aviation Organisation
IFR	Instrument flight rules
JARUS	Joint Authority on Rulemaking for Unmanned Systems
LDZ	Limited drone zone
LFR	Low-level flight rules
LSSIP	Local Single Sky ImPlementation
MASPS	Minimum aviation system performance standards
MATZ	Military Aerodrome Traffic Zones
MET	Meteorological
MOPS	Minimum operational performance specification
MoT	Ministry of Transport
NDZ	No drone zone
NOTAM	Notice to Airmen
RCC	Rescue Coordination Centre
RLOS	Radio line-of-sight
RPA	Remotely Piloted Aircraft
RPAS	Remote Piloted Aircraft System
SERA	Standard European Rules of the Air
SESAR	Single European Sky ATM Research
SID	Standard instrument departure
SIM	Subscriber Identification Module
SJU	SESAR Joint Undertaking
SORA	JARUS Standard Operational Risk Assessment
SRA	Strategic risk assessment
STAR	Standard Terminal Arrival Route
sUAS	Small Unmanned Aircraft System
TDD	Traffic dynamic data
TMA	Terminal Area
TRA	Tactical risk assessment
TSD	Traffic static data
UAS	Unmanned Aircraft System
UAV	Unmanned Aerial Vehicle
UIR	Upper information region
UTM	Unmanned Traffic Management
UTMS	Unmanned Traffic Management System
VFR	Visual flight rules
VHL	Very high level
VLL	Very Low Level
VLOS	Visual Line Of Sight

Table 1 - Definitions, acronyms, and abbreviations