PRINCIPLES FOR THE DEVELOPMENT OF A FUTURE OPERATIONAL CONCEPT FOR THE HIGHER AIRSPACE

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Abstract
An increasing number of technologies and concepts are being developed for the operation of aircraft and spacecraft in the so-called Higher Airspace. A multitude of different vehicle classes pose individual requirements for the management of this volume of airspace and the transition through the existing controlled airspace below as well as re-entries from orbit. The results of an evaluation of existing literature, presentations and preliminary work on this subject is presented here, identifying transferable elements and key principles for the traffic management in the Higher Airspace.

Keywords
Airspace Management, Cooperative Management, Higher Airspace Operations, Strategic Separation, Trajectory-Based Operations

1. INTRODUCTION

While operations in the Higher Airspace (HA) have historically been limited due to technical constraints of conventional fixed wing aircraft in the reduced atmospheric density, new technologies have led (and will lead) to an increased number of vehicles that can operate in such challenging conditions. There is a wide range of technological solutions leading to various shapes and types of vehicles, ranging from low-speed balloons, airships or sophisticated long endurance vehicles to new kinds of high to very-high speed vehicles like super-/hypersonic aircraft, spaceplanes or so-called mini-/micro-launcher. [1] The accommodation of the new entrants poses challenges and requires adapted and to a certain extend novel concepts for operations.

2. CHARACTERISTICS OF THE HIGHER AIRSPACE ENVIRONMENT

The lower boundary of the Higher Airspace (the upper limit of the controlled upper airspace) is designated differently around the globe (e.g. FL600, FL660). The controlled airspace in the US for example extends up to FL600 whereas airspace classifications in Europe list FL660 with uncontrolled or unclassified airspace followed by outer space above these respective altitudes. [2] Although there is no global consensus, the lowest common standard could be phrased as HA referring to the airspace above controlled airspace reaching up to outer space. [3] Theoretically, at an altitude of around 327,000 ft. or 100 km (in middle latitudes, varying slightly across the globe) the speed required for an aircraft to produce aerodynamic lift is greater than the speed required to achieve orbital velocity. Therefore, technically speaking, an aircraft becomes a spacecraft at this altitude (globally referred to as the Kármán line). Again, this boundary is not internationally uniformly recognized or designated. [4]

2.1. Legal & Regulatory Frameworks

In the given context, the principles of law must be distinguished in space and aviation law. The main difficulty with respect to the legal regime is the missing international consensus on the demarcation point between airspace and outer space. If ever defined, the boundary between airspace and outer space would mark the limit of a states' sovereignty. Especially for sub-orbital (point-to-point) operations, the missing classification is considered to be an issue. [5] Each state can choose to consider sub-orbital operations to be covered by either Air Law, a national Space Law, or a hybrid or a sui generis law. An agreement on a legal delimitation of space is currently reasonably unlikely to occur because the question is inherently tied to the question of sovereignty. Nevertheless, it is important to note, that an integrated approach to aviation and space policy would help to overcome many issues. [6]

The legal basis for space law is the Outer Space Treaty, whereas the basis for aviation law is the Chicago Convention. The United Nations (UN) Treaties on Outer Space as well as the UN Space Law resolutions set out international rules and standards for space activities shared by the international community. The fundamental underlying principle is the freedom of access for exploration and use for the benefit and in the interest of all countries. Other matters addressed are among others the preservation of the space and earth environment and

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liability for damages caused by space objects.

Airspace on the other hand is in the supreme and exclusive sovereignty of the state above its territory. International standards and recommended practices are applicable to all countries. Based on decades of operating experience, this well-tailored regulatory framework enabled international aviation to develop into a safe, interoperable and efficient global transport industry. [5] The standards include certification and licensing. It is to be noted, that some new types of spacecraft like spaceplanes may be suggested having to meet the definition of aircraft, so that existing aviation safety regulation would apply to them. [7]

3. DESCRIPTION OF HIGHER AIRSPACE OPERATIONS (HAO)

Within this chapter, the main vehicle categories of HAO and their specific characteristics are described.

3.1. High Altitude Platform Systems (HAPS)

HAPS represent a major development in the HA with some vehicles already field-tested and operative. Applications are diverse, from earth observation, remote sensing, surveillance, telecommunication to navigation. [8] [9] [10] While sharing key characteristics like long endurance and operating altitudes in the HA, multiple concepts and shapes exist. Generally, a distinction is made between “Heavier than air” (HTA) and “Lighter than air” (LTA) vehicles, though hybrid platform concepts are under development too. [11] While research is extensive around the globe, with most scientific articles published in the US, Italy, UK, Japan and China. technological challenges and hurdles still exist. For reference, out of 12 projects analysed in a market overview and kicked-off in the time frame between the early 2000s and the early 2010s, 7 were closed by 2016. (In the meantime, new projects emerged). As of today, out of this “initial” group, only Airbus Zephyr UAS and Thales Stratobus Airship/UAS are the only active projects. [12]

HAPS are unmanned aircraft systems (UAS) positioned at around 20km altitude in the stratosphere. Initially, the term High Altitude Platform Station had been established in the late 1990s, representing the fact, that there was a growing interest utilising this technology to complement terrestrial and satellite-based communication networks. Later on, other possible use cases like remote sensing, earth observation and surveillance for military/state and civilian applications emerged. [12]

Like mentioned, the concepts for HAPS are generally distinguishable in HTA and LTA vehicles. The current technology readiness level (TRL) is considered to be higher for the HTA category. Key enabling technologies are battery technology, solar cells and (lightweight) materials. [11] Due to weight constraints, the power consumption is critical especially during night-time. Staying at high altitude is therefore at least challenging (or sometimes impossible), depending on latitude and season. [13] This can be countered by significantly lowering the altitude as a trade-off for energy savings during the night-time. Some applications like telecommunications however usually require a quasi-stationary movement for HAPS relative to the earth. Rigorous station-keeping requirements for certain types of operations thus may limit the payload capabilities. [14] In this regard, HTA HAPS generally offer better manoeuvrability and are more resilient to wind. [15]

A unique characteristic of HAPS is their long endurance operating capability. This has been demonstrated multiple times and already during Airbus Zephyrs maiden flight, which lasted almost 26 days at a consistently achieved altitude of > 60,000 ft. with peak altitudes of > 74,000 ft. Targeted mission durations are up to 60 days. LTA HAPS missions are projected to last for hundreds of days in the future. The operational speed of the vehicles is rather low with maximum air speeds in the range of 20 to 25 m/s. [16]

An important attribute of HAPS worth emphasizing is their limited payload. Zephyrs maximum payload is 5kg and is expected to be increased to 12 kg. [9] The fixed-wing concept in general may offer feasibility up to 30-40 kg of payload. Standard LTA HAPS offer the advantage of relatively higher payloads of 250 kg and more in case of Stratobus. [10] The volume of these HAPS can exceed 100,000 m^3, with lengths of up to 150m and diameters of over 30m. The use of LTA vehicles for payloads under 200 kg is not convenient or economical (see Fig. 1). [17] Combined with the limitation of the fixed-wing concept, a void of payload capabilities can be identified, which may be filled by hybrid concepts in the future. [18]

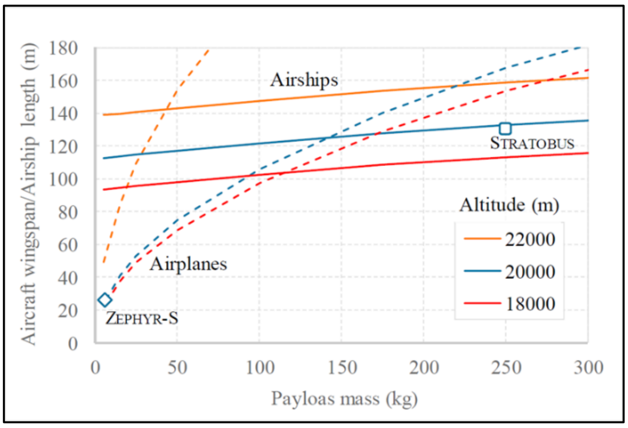

FIG 1. Platform sizes required for different payloads and flight levels *[17] [19]*

Different plug and play payloads such as high-resolution earth observation equipment, LiDAR, SAR, Air Quality measurement equipment and LTE Comms shall make best use of the limited payload capability. In general, the scope of operations can be described with the three words “see, sense and connect”, which applies to both civil and military/state use cases. [9]

The integration of HAPS operations in airspace < FL660 can be challenging in congested airspaces like continental Europe. Ascent and descent of Stratobus for example take 2 and 6 hours respectively. (It would ascent during night-time and the airship/UAS is designed to remain up to one year in the stratosphere, therefore the overall traffic impact should be minimal). Solar powered HTA HAPS however take off in the early morning, presumably leading to a higher traffic impact. In combination with the limited manoeuvrability and wind sensitivity, especially for LTA HAPS, large time-segregated and lowly dense airspaces for a notable 4D window are needed in order to transition to and from the HA. [10]

Balloons are another tool for simple and efficient flights in the stratosphere. Super Pressure Balloons as a category of balloons are most likely to be compared to HAPS. Maximum altitudes can reach 20 km whilst carrying up to 25 kg of payload. The flight durations are more than 3 months. [20] The best-known representative was probably Googles Project Loon which ceased operations in early 2021. Additionally, high payloads up to 1100 kg can be carried with Zero Pressure Balloons. Altitudes reach up to 40 km, while flight durations range only up to 40 hours. [20]

3.2. Sub-orbital flights

One of the new breeds of HAO which attracts the most attention lately are sub-orbital flights (especially A-to-A flights). Aside the major difference in the vehicle's thermal protection with the associated weight and the range covered, the obvious difference between A-to-A and A-to-B flights is the different location for take-off/launch and landing for the latter operation, while both can be realised using multiple vehicle concepts regarding take-off/launch and landing. It is important to note, that A-to-A flights' initial primary purpose of making adventure tourism to space possible, leads to a supply driven market, while A-to-B flights would directly compete with current air travel. [21] A-to-B hypersonic flights are expected to evolve, if ever, from A-to-A sub-orbital flights in the long term. [22] Given expected advancements and maturing of the sub-orbital technology, the market of a sub-orbital point-to-point transportation system (A-to-B) is similar to current flight routes between major hubs. In general, only a very limited number of routes, linking cities like New York, Los Angeles, London and Tokyo are suitable for A-to-B sub-orbital flights. A sustainable market, though small due to high ticket prices, would target the “time-poor, cash-rich” public. [5] [21] The commercial market for supersonic transport (which are also subsumed as A-to-B sub-orbital flights) could revive earlier with companies like Boom currently developing supersonic passenger aircraft. Supersonic aircraft with expected service ceilings of around 60,000 ft. would operate near the lower boundary of the HA.

Spaceflight experience (space tourism) is the first application for commercial sub-orbital operations, offering up to five minutes of microgravity. The launch profiles range from vertical take-off and landing to horizontally launched winged vehicles. [23] The best-known examples are Virgin Galactic, which is developing SpaceShipTwo (air-launched and horizontally gliding landing; Next iteration called SpaceShip III was announced in early 2021) and Blue Origins New Shepard (VTOL). [24] The UK expects a demand of 120 participants per year when commercial operations launch, increasing up to 400+ per year in year 10 of operation. [7] A global forecasted for worldwide commercial space experience flights states around 400 participants in Year 1 of commercial operation. [23]

3.3. Orbital launchers and from-orbit flights

Along with a limited number of scientific stratospheric balloons, some high-performance military aircraft or sounding rockets, orbital rocket launches were for decades the main operations interfering with HA. The number of orbital launches per year is growing – due to the emergence of commercial launch providers like SpaceX – and is expected to dramatically expand in the near term. Drivers of this development are several new companies in the nanosatellite and small satellite business, some of which are planning mega-constellations with hundreds or thousands of satellites. [25] Smaller and cheaper launch options complementing the lighter payloads are sought-after, opening possibilities for new providers including aero-launchers and vertical multi-stage micro-launchers.

Examples for orbital air-launchers are Virgin Orbit using a Boeing 747-400 or Dassault DANEO using a Dassault Falcon 2000S. Capabilities range up to payloads of 500 kg (Virgin Orbit) and 50 kg (DANEO) respectively into Low Earth Orbit (LEO) and are therefore suited to meet the rising demand for small satellite deployment. Aero-launches using balloons as carrier vehicle are another concept. Using a Zero Pressure Balloon like “Bloostar”, which would carry the rocket up to around 25 km altitude (soaring above 99% of the air) were separation and launch would occur. This concept is stated to be the most cost-effective and eco-friendly launch system. [26]

Space transportation vehicles are categorized as either Expandable Launch Vehicles (ELV) or Reusable Launch vehicles (RLV). RLV are increasingly common due to their economic advantages. [27] Vertical launches are the main mode of launching vehicles, with the majority of the global commercial launcher projects following this approach too. In Europe, especially the UK, Italy, Germany, Norway and Sweden are targeting for orbital rocket launches in the short to medium term.

3.4. Infrastructure

Dedicated infrastructure is heavily dependent on the design of the air- or spacecraft. A spacecraft like SpaceShipTwo for example with its unpowered gliding during re-entry and landing is expected to cause interruptions on a congested commercial airport to regular air traffic. Certain types of operations therefore demand separate spaceport infrastructure, whereas other spacecraft operations with powered take-off and landing profiles could possibly use existing and modified commercial airports. [5] Technological innovations could enable transportation using vehicles that are comparable to existing aircraft. This would pave the way to “aerospaceports” – similarly to existing airports with added high altitude or sub-orbital operations respectively, with required runway lengths of 3000 m or more. [28] [7] [29] A scenario for Changi International Airport in Singapore evaluated how a spaceplane (both jet engine and rocket engine powered) could be integrated into the daily operations of a major airport. A dedicated space flight zone for the rocket propulsion and gliding re-entry flight phases would be established. [30] The need for segregated airspace is furthermore emphasised across multiple sources. [7] [29]

Dedicated space- and so called “stratoports”, which are under development or under consideration, are mostly located in remote locations. This must be factored in when assessing the benefits of point-to-point suborbital passenger or cargo transport. [5] For A-to-A (commercial) spaceflight offerings, the location of the launch site could be a differentiating factor in terms of customer experience, but does not impact on the logistics or cost of the operation itself. [22] A remote location is also beneficial for HAPS launch sites. [31] In this regard, suitable locations for stratoports are often characterized by a remote geographical location and uncongested or segregated airspaces. [32] [33] [34]

As of 2019, there were 16 launch sites in the United States with orbital and/or sub-orbital launch capabilities. [35] Within 4 years the number increased by 6 with a further 5 sites proposed. During operations at these sites, either launch or re-entry, the airspace near the spaceport will be closed due to use of Special Use Airspace (SUA) and/or Temporary Flight Restrictions (TFR) by the FAA. There are no defined standards for minimum separation distances between spacecraft and aircraft. [28] Size of airspace restrictions are determined as part of a vehicle related individual safety assessment.

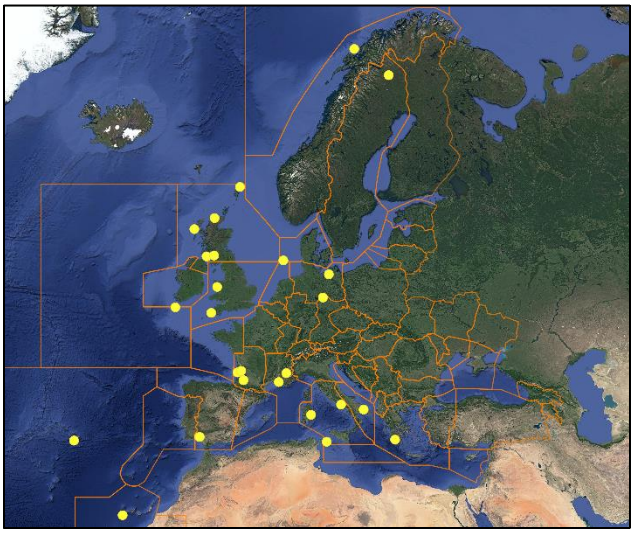

FIG 2. Proposed HAO related sites in the ECAC Area

Globally, it can be concluded that suitable launch sites are available on all continents with more under development. [35] Studies emphasize the need for both vertical and horizontal launch capabilities for a spaceport in order to be economically viable. It is to be noted that the geographical requirements for a launch site for vertical launches and sub-orbital spaceplane operations are different, because sub-orbital flights are independently feasible from the latitude of the launch site. Reaching certain orbits on the other hand is dependent on the geographical location. [7]

4. OPERATIONAL CONCEPTS

4.1. Airspace Management

One of the essential paradigms is the free access of vehicles to the Airspace (including HA). Access to airspace must be equitable for vehicles transiting airspace and operating at altitude. According to the FAA, operators cannot optimize their own operations at the expense of other operations. This shall apply regardless of performance restrictions of vehicles, though operators minimize the impacts of their operations the greatest extend possible. [1] Operational safety must be ensured at all times. Sharing of information on planned missions will be mandatory as well as meeting certain planning requirements and maintaining situational awareness at all times. [36] Experience and lessons learned from UTM can be used and incorporated due to various similarities: New stakeholders/users, new vehicle types, a wide range of vehicle capabilities, new (different levels of) services and a high degree of digitalisation and automation. A step-wise approach is needed in order to achieve full integration. [37]

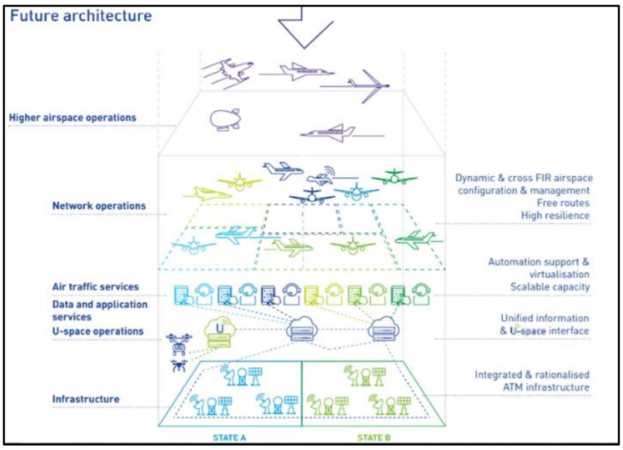

FIG 3. SESAR vision – Future ATM architecture *[38]*

An approach similar to the use of Functional Airspace Blocks (FABs) has been mentioned as a possible integrated implementation structure for adapting an existing concept of managing airspaces. Large harmonised airspace volumes may be established covering stratospheric altitudes, regardless of state boundaries, creating a supranational structure meeting the needs of global operations.

HA's two boundaries – on the lower end to the controlled Upper Airspaces and the upper end to outer space – demand interfaces to both ATM as well as STM services. The data provision which is needed for the interfaces with STM and ATM could be facilitated by System-Wide Information Management (SWIM) based services. Existing data exchange formats like AIXM or FIXM could be adapted in order to ensure conflict free transit and re-entry operations as well as conflict free trajectory planning. Merging ATM & STM principles does not require new mandates per se, but could allow operations with limited tactical intervention following a strengthened strategic separation approach. [39] [40] The need for a civil-military interface should be mentioned, with military operations today being one of the few routine operations within the limits of the HA.

A major challenge for the organisation of operations in the HA is the diversity of operational types, uses and mission profiles. Types can be differentiated in transit, persistent and point-to-point uses. [41] Further, the operational speeds range between (very-)low speed balloons or HAPS and hypersonic sub-orbital or orbital vehicles. Within each category, the types of vehicles are diverse too as described.

A model solution for a concept of HAO will rely on concepts like strategic trajectory de-confliction with exchange, maintenance and use of consistent aircraft trajectories as well as flight information for collaborative decision-making. [13] The potential application of non-HA rules to spacecraft transiting HA, the integration of sub-orbital operations or other HAO like HAPS will be difficult through traditional ATM means. In the short to medium term, accommodation of operations may on be possible using segregated airspaces for ascend and descend. In general, two options may be used in order to facilitate such segregated volumes: Bespoke areas of segregated airspace or temporary restricted areas. [7] [39]

4.2. Strategic Separation

Strategic separation refers to the approach, where coordinated conflict free planning of all pre-planned and in-flight operations shall assure separation through all flight phases from take-off/launch to landing. Vehicles follow their preferred flight trajectories while trying to eliminate the need for tactical interventions. Efficient management of airspace is needed as well as a structure to cope with the strategic control approach. [36] [42] Rather than setting fixed separation minima, separation will be predicated on vehicle performance-based criteria referred to as separation envelopes that take into consideration vehicle capabilities and performance. [1] The present concept of traffic management forms a multi-level approach to safety and separation assurance. These levels include: 1) Strategic Conflict Management, 2) Separation Provision (tactical), and 3) Collision Avoidance (last resort). Strategic trajectory deconfliction is considered to be the primary mechanism for managing traffic HAO in contrast to the conventional emphasis on tactical separation. Most vehicles will be unmanned with limited equipage due to weight sensitivity and feature limited manoeuvrability. Tactical and last resort collision avoidance can therefore not be relied on in the context of HA, leading to few options other than the strategic approach. [40]

4.3. Cooperative Management

Cooperative Management is suggested based on the conflict free route planning supplemented by tactical monitoring. The decision making within cooperatively managed airspace will be based on common accepted operational rules and the provision of situational awareness and decision support. Such a community-based concept, implemented in a proper manner, would rely on interfaces with both STM and ATM, because ascending, descending as well as transitioning vehicles through airspace must be accommodated as well. [36] The Collaborative Traffic Management in the Stratosphere (CTMS) concept initiated by Loon and Airbus is worth mentioning in this regard. [43] In the context of balloon and unmanned aircraft operations, the FAA states that in Upper Class E (term for HA in the United States), ANSP separation services are not desired, appropriate or available, thus a community-based, cooperative management of operations system will be established, guided by rules set by the regulator. This cooperative separation is achieved via shared intent, awareness, de-confliction of operations, conformance monitoring, technologies supporting decision making and de-confliction and the establishment of procedural rules of the road. [1]

4.4. Trajectory-Based Operations

Due to uncertainties of vehicle positions over time, so called 4D operating zones may be used which determine where a certain vehicle may operate. Based on performance and mission, the 4D shape and its volume may change during operation. [36] This concept is based on the 4D trajectories approach being researched both within SESAR and NextGen.

5. SUITABILITY OF CURRENT CNS TECHNOLOGY

ATM technology is still centred around the human input and decision making. Automated systems supporting the human control have been introduced gradually during the last decades. Human decision making is nevertheless still relied on to great extent, posing both challenges and opportunities for HAO. With its mostly unmanned and automated operations, technologies are applied, which have already been used extensively for UAS. The three main components/elements of ATM are communication, navigation and surveillance. Given the evolutionary process from equipment-based to performance-based operations (PBO), suitable metrics for performance-based communications, navigation and surveillance (PBC, PBN, PBS) need to be introduced. [44]

Above FL600, the airspace may serve as a test bed for new CNS technologies, which in the longer term could create opportunities to facilitate the integration in the airspace below. GNSS based navigation is seen as the primary navigation system of the future and will constitute, due to limitations of conventional navigation aids at these altitudes, probably the only viable option for the HA. It is to be noted, that separation standards in general are based on positioning relative to one another, not on absolute position.

Full integration of STM and ATM should be considered the ultimate goal for surveillance and tracking. In this regard, it is proposed, that all vehicles including spaceplanes shall be equipped with ADS-B and GNSS to ensure a safe integration. [45] SWIM is the core element of the ATM system designed both in SESAR and NextGen. For full integration of STM and ATM (and the traffic management of the Higher Airspace), SWIM is expected to be an essential element. Data transmission between space tracking networks and aviation surveillance is currently assessed to be a challenge, but will be needed for integrated operational re-entry procedures.

5.1. Communication

The main form of air-to-ground communication is the use of VHF (and HF over remote or oceanic areas) voice transmission, which is foreseeable to continue in the future. Data link is utilised and will be even more widespread in the future, eventually replacing voice communications as the primary communication means in the long term. Due to the implementation under various ATM projects worldwide, there are multiple Data Link standards which are not interoperable. Voice communications will still be provided for tactical interventions and non-routine communications. [46] In case of unmanned vehicles (which are the vast majority of HA vehicles), ground-to-ground communications will be utilised. [47] The environment of Higher Airspace with both airspace and outer space users and new non-traditional operators may pose challenges due to different policies for communication and especially regarding the frequency band designation. [47]

In addition to the aspects of operational integration regarding communication, especially HAPS can enable new means of communication service provision in the Higher Airspace. Complimentary to satellites and terrestrial connectivity options, HAPS could enable creating a "multi-modal" network, acting similar to the present ground radio network as well as functioning as a relay. The main advantages are their cost effectiveness and low latency compared to satellites. HAPS coverage could range from providing fixed broadband in both low density and high-density regions, low latency data backhaul to 4G/5G deployment. [48] [49] Emulation of cellular networks with HAPS further opens possible applications for air-to-ground, air-to-air and air-to-satellite communication scenarios. Airborne communication nodes (as a form of airborne LTE base stations) could provide a communication radius > 30 km, with omnidirectional transmission and high data rates > 1 Mbps. [50] These applications could potentially be used for HATM purposes considering, that the denser the HAPS traffic, the more complex are the trajectories and thus the separation needs.

5.2. Navigation

Conventional ground-based navigation has been based on facilities like DME or VOR, with traffic navigating from point to point along the infrastructure. It is recognised within the aviation community, that ground-based technologies are no more suitable further optimizing routes and trajectories and will be more and more replaced. More flexible and direct routings are provided using the concept of Performance Based Navigation (PBN), which is being introduced. Rather than defining specific sensor equipage, PBN sets navigation performance requirements which are intended for global use. Global Navigation Satellite System (GNSS) represents the transition from the mentioned conventional ground-based navigation aids to satellite-based navigation. The higher accuracy and standardized positioning and time information overcome the limitations of conventional navigation aids, which make GNSS the ideal navigation infrastructure to enable the benefits of PBN. [46]

Separation standards have evolved and separation can be reduced under certain conditions (for example RVSM operations) by utilising more advanced and proven technologies, which at the moment does not extend to the HA though. Military separation standards above FL600, which are the only established standards that exist for these altitudes, date back to times before GPS existed and therefore are partly based on estimations about radar limitations and degraded navigational precision (5,000 ft vertical, 10 miles lateral separation). [47] During flight tests, advanced GPS processors have demonstrated a NACp of 9 (95% Horizontal Accuracy Bound of < 30m) at altitudes > 60,000 ft. Additionally, its high vertical accuracy indicates a significant potential of GNSS for HA. [47]

5.3. Surveillance

According to ICAO, aeronautical surveillance systems provide the position and other related information to air traffic management and/or other users. Surveillance systems in general can be classified into three categories, depending on how the signals are received and processed: The Primary Surveillance Radar (PSR) is the only independent non-cooperative surveillance system. It is currently supplemented by the Secondary Surveillance Radar (SSR) which is categorised as independent cooperative. Dependent cooperative surveillance is the third category, with Automatic Dependent Surveillance – Broadcast (ADS-B) as the most common example. Independent or dependent refers to how the position is measured: Dependent means on-board determination, whereas independent refers to ground determination. Cooperative or non-cooperative refers to the aircraft equipment, which is required for the surveillance (cooperative) or not required (non-cooperative). [46]

The limit for current aviation surveillance such as PSR is at around 60,000 ft. [45] For example, ADS-B barometric altimeters have demonstrated inaccuracies of 10,000 ft. at 100,000 ft. above MSL. Further, the accuracy of barometric altimeters diminishes at high rates of climb or descend.

GNSS based systems are an alternative for altitude reporting in the HA. The value of GPS altimetry & attitude information complementing barometric information should therefore be recognised. Because ADS-B transmits both GPS and barometric altitude information, acceptable altimetry error validation is possible in order to apply separation standards. It is important to ensure that the quality of the data from each vehicle is comparable. [47] Interoperability and cooperative coordination will rely on comparable relative altitude information. In addition, new sensors for surveillance and tracking for space objects and vehicles are being developed. These new capabilities and improvements of self-reliance may be explored in HAO. [51]

6. CONCLUSIONS

A variety of new operations in the HA are imminent. The most well-known examples are HAPS, sub-orbital flights, supersonic flights as well as orbital launch operations and from-orbit flights. Traffic numbers are forecasted to rise for all types of operations at least in the medium term, though forecasts are vague at this point, where technology readiness is still predominantly low. The supporting ground infrastructure for both vertical and horizontal take-offs and landings is expected accordingly to increase. While announced/planned launch facilities are most likely located in remote areas, integrated concepts at existing airports are a possibility in the more distant future.

Given the highly automated operations, strategic deconfliction and trajectory planning are going to play a critical role. Consistently mentioned and universally accepted in this regard are the concepts "strategic separation", "cooperative management" (which could also be addressed with regards to tactical separation, which may be another layer for managing HAO) and "trajectory-based operations". The first two concepts are for example mentioned in the already published FAA Upper Class E Concept of Operations (ConOps). The European Concept of Higher Airspace Operations (ECHO) project, which is currently developing a ConOps for HAO in Europe, relies on the same principles, including fully implemented TBO in the long term.

Nonetheless, at least in the foreseeable future, temporary segregated airspaces will be needed due to the absence of separation management capabilities for nominal and contingency procedures both for transitioning through the controlled airspace and in the HA itself.

The next generation of ATM (e.g. as projected and targeted at in SESAR & NextGen) will be an environment, which then seamlessly incorporates HAO. Satellite-based navigation, performance-based operations as well as connected network-based information sharing will form the basis for future operations. An important aspect of a HA traffic management concept of operations should be its interfacing with both ATM and STM. Unanimously agreed is the need for SWIM-based services in order to assure system-wide on-time information provision, situational awareness and decision-making support.

Conventional CNS technologies face various limitations with regard to HAO application. Above 60,000 ft., barometric altimeters and ground-based navigation aids become inaccurate or unavailable. Satellite-based technology offers higher accuracy and availability for HAO. Widespread implementation and adoption of satellite-based services is the path followed by the industry. A mandatory equipage with GNSS and ADS-B may be considered (including space vehicles with regard to the integration of space traffic).

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