

The NearSpace Interface between Air and Space Traffic Management

Sven Kaltenhäuser^{a*}, Ruth Stilwell^b

^a *Deutsches Zentrum für Luft- und Raumfahrt e.V. (German Aerospace Center, DLR), Lilienthalplatz 7, 38108 Braunschweig, Germany, sven.kaltenhaeuser@dlr.de*

^b *Aerospace Policy Solutions, LLC, 1835 Hallandale Beach Blvd, Suite 265, Hallandale Beach, FL 33009, USA., ruth.stilwell@gmail.com*

* Corresponding Author

Abstract

NearSpace describes the region between the airspace commonly used by airliners and the beginning of space. It is the region where launching and re-entering commercial space vehicles pass through to and from space, where suborbital flights happen, debris breakups occur and concepts for ultrafast passenger transportation and stationary high altitude platforms plan to fly. NearSpace is no longer an exclusive transition zone but an area which sees a significant increase in operations. It extends the interface region between Air Traffic Management (ATM) and Space Traffic Management (STM), which are already required to interact in order to accustom an increased amount of space vehicles during their flights through regular airspace. The diversity of operational types within the NearSpace region poses a challenge with regard to ensuring the safety of operation at all times. The mission profiles and technical requirements for the vehicles used in this environment will make it difficult to rely on established standards and established cooperative processes. New but nonetheless reliable and interoperable means of communication and surveillance will be needed. This paper will present requirements to and related concepts for an extended traffic management for the NearSpace region, taking into account the challenges of ATM and STM interfacing, roles and responsibilities as well as suggested Air and Space Traffic Services.

Keywords: NearSpace, Commercial Space Transportation, Space Traffic Management, Air Traffic Management

Acronyms/Abbreviations

Air Navigation Service Provider (ANSP)
Air Traffic Control (ATC),
Automatic Dependent Surveillance - Broadcast (ADS-B)
Flight Information Region (FIR)
High Altitude Platform (HAP)
International Civil Aviation Organization (ICAO)
International Telecommunications Union (ITU)
NearSpace Operation Management System (NOMS)
Space Traffic Management (STM)*
System Wide Information Management (SWIM)
Unmanned Aerial Vehicle (UAV)
Unmanned Traffic Management (UTM)

1. Introduction

From the beginning of aviation, the high altitude region has been considered a vast unoccupied and unused void. As rockets started to cut through those altitudes on their way into space and military high altitude reconnaissance aircraft sneaked above the regulated volumes of airspace, its population increased through the second half of the last century. Yet, most

* Space launch and re-entry operations are managed to prevent collisions between space vehicles and aircraft, however, once operating in space, space traffic monitoring is the more precise term.

vehicles were controlled by state entities and the amount of traffic in this area remained rather small.

Nowadays, airspace above an altitude of 20 km is still a relatively unoccupied region, but the number of operations in this regions have picked up again, now under different circumstances. Many users are civil commercial entities. The speed regime those operations cover is vast, from station keeping up to hypersonic speeds of Mach 25. All those vehicles have to pass through regular airspace on their way up - and some on their way back down again. And some even scorch towards space and enter another vast but nonetheless quite occupied region above earth. By now, flying in this region remained rather uncontrolled and unmanaged. With changes in its operational use, the former void between air and space has to draw increased attention.

2. Challenges of the NearSpace region

A legal definition has not been adopted, however, the Karman line at 100km is generally regarded as the common definition for the boundary of space [1][2]. Aviation operators may refer to this region as high altitude airspace, while space operators generally use the term NearSpace. The challenge in managing the

NearSpace region, from FL660 (20km) to FL3300 (100km) (Fig. 1) is not congestion, but rather diversity of operational types. This is distinct from the challenges states have encountered in both air and space traffic management. Each domain has a primary focus on safety, however, for space, congestion and debris drive the policy agenda, while for aviation, increasing capacity and efficiency are the drivers. It is important to recognize that even with increasing demand for access to NearSpace, the altitudes will remain relatively uncongested for the immediate to near future. However, while the airspace may see low density traffic overall, there may be specific areas that see significant competition between users. There are several different providers developing high altitude platforms for delivering either telecommunications or earth sensing services that may compete for the same markets. Airspace policy needs to consider both safety and equity issues to allow for operations in unsegregated airspace.

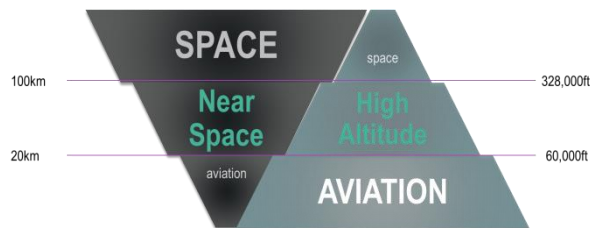


Fig. 1. Definition of the NearSpace altitude segment

In addition to direct market competition, there is competition between the users that dwell in the airspace for extended periods and those that seek to transit the area quickly. This precludes the use of a “hands off” approach using uncontrolled airspace if states seek to enable the high altitude industry. Users of the NearSpace region can generally be divided into three categories:

- Transit users – those operations that transit the airspace vertically, including space launch and re-entry operations.
- Persistent users – those users for which the airspace is the destination from which services will be provided to the Earth, this includes high altitude long endurance unmanned aircraft
- Point to point – those users that traverse the airspace while providing transportation between two points on the Earth.

This region shares certain characteristics with orbital operations, including that many operations are long endurance and unmanned. However, it also shares many characteristics with traditional air traffic, including that aircraft are controllable, subject to state regulation and debris is not a primary risk [3]. These elements, unique

to the NearSpace region, provide an opportunity to develop a new regime that could serve as the transition between air and space traffic management.

Conditions that allow for a new concept in this airspace include:

- Aircraft utilizing this airspace will have met the requirements to transit controlled airspace. This allows for the provision of services without new mandates.
- The airspace is free from obstructions or terrain.
- Airspace above FL 660 is currently uncongested, allowing for the use of large separation standards as safety mitigation. This follows the model used for oceanic airspace; where technology standards to increase capacity through reduced separation, were added as airspace demand increased.
- Aircraft operating in this airspace are closely monitored by the ground operator with an infrastructure designed to ensure aircraft conform to planned routes and altitudes to ensure consistent service delivery. A cooperative relationship between the operators and Air Navigation Service Providers (ANSP) can capitalize on the tracking information used by these systems.
- For operators above FL660, shared information on position, altitude, and trajectory can be used for collision avoidance purposes and for planning conflict-free routes, rather than rely on the detection of conflicting traffic from the aircraft.

The opportunity exists, however some states recognize a regulatory ambiguity that may preclude progress in this area. Most states identify their Flight Information regions with a vertical limit of “unlimited” however, we know from the Outer Space Treaty and a generation of Space Law, that there is a vertical limit above which no claim of sovereignty can be made. This limit is undefined. In the lower portion of the NearSpace region, from FL660 to FL1000, it is difficult to support an argument that the Outer Space Treaty would apply as manned aircraft have operated at these altitudes for decades without claim that it is astronautics. Recognizing the aviation operations in this segment of NearSpace as subject to the provisions of the Convention on International Civil Aviation facilitates progress in enabling operations. As new entrants seek access to the NearSpace region above FL1000 (30km) the question of vertical limit for the Convention on International Civil Aviation may need to be resolved.

3. NearSpace traffic management requirements and how to address them

3.1. Ensure safe operations at all times

The key requirement for managing traffic in NearSpace is to ensure the safety of operation at all times. In essence it means to ensure safe separation between all participating vehicles. This task corresponds with Air Traffic Control (ATC) for airspace regions below FL660. However, considering the larger speed differences in high altitude airspace, the requirements for traffic control vary considerably. Tactical control becomes relatively ineffective, as specifically slow vehicles (e.g. High Altitude Platform (HAP) aircraft operating at speeds of approx. 20 m/s or balloons travelling at the velocity of the wind) cannot effectively directed away from vehicles traveling at supersonic or even hypersonic speeds (depending on altitude and flight profile). For most of these vehicles, their trajectory can only be adapted in limited ways during flight execution. Therefore maintaining separation is becoming a more strategic than tactical effort.

3.2. Plan operations to be conflict free

Ensuring separation on a strategic level means planning operation ahead in time to remain conflict free during their execution. Considering the different types of operation in the NearSpace region, as discussed in chapter 2, flights cannot be planned without consideration of other traffic, as is commonly done for regular air traffic. Planning has to incorporate short duration/high speed flights (e.g. rocket launch) with inherent time uncertainties (launch window) as well as long duration flights (24/7-type of operation) covering a certain relevant area of interest. For strategic planning of a conflict-free operation, therefore, a principle can be applied, where a route and schedule is approved by an ANSP as free of conflict and augmented with tactical monitoring. This is a departure from the manner in which flight plans are accepted and approved in traditional airspace. In lower airspace, a flight plan that conforms to requirements for operating in that airspace is accepted without regard to traffic conflicts. However, an aircraft is not allowed to execute the flight plan until an ATC clearance is issued. This is the essence of tactical air traffic control. Under a strategic air traffic control concept, the approval of the flight plan would constitute the approval to operate in the airspace. This step provides the operator with mission assurance that is needed for long term planning.

In modeling this airspace to determine that routes are conflict free, the uncertainty of the aircraft position over time must be considered. This may require that the route is modeled as an operating zone, rather than an aircraft position. An operating zone does not have to be seen as a static volume of space. It can be defined as a

four dimensional shape and volume, and may vary based upon the performance characteristics of the aircraft. Similarities can be seen to planning of Unmanned Aerial Vehicle (UAV) flights, as it is part of several Unmanned Traffic Management (UTM) concepts.

The desired time and location of operation, together with all other relevant parameters of each vehicle, has to be submitted to and managed by an entity responsible for planning, negotiating and ensuring a conflict free allocation of flight plans. This entity can be an organization (like an existing or yet to be determined ANSP) and may make use of a dedicated NearSpace Operation Management System (NOMS).

Planning of operation also has to take into account the transfer through and back to airspace below FL660. This process ideally should go hand in hand and be fully interoperable. It has to cover the interaction between both regions, providing an integrated planning of hazard areas through airspace and NearSpace when those are required. For space vehicles planned to be inserted into Earth orbit or high suborbital trajectories, interfacing with STM has to be provided as well, ensuring a conflict free trajectory clear of interference with other space objects.

3.3. Allocate appropriate operating zones

The concept of 4D operating zones allows for a combination of trajectory based and performance based traffic management. The operating zone has to be seen as a function of airspace planning and modeling. It can be remodeled as conditions require. The size of an operating zone initially is determined by performance criteria associated with the vehicle type and its planned mission. It takes into account its type of operation, its planned trajectory pattern and its uncertainty in predicting its position (based on different operational aspects). As a function of time, the operating zone of a vehicle can change its position and size, for example due to changes in meteo conditions or a planned transfer flight of a HAP to a new area of interest with different trajectory pattern.

Changes over time can be constructed ahead as part of the flight planning process before launch or takeoff in association with the vehicles mission planning. Other changes will occur during operation (especially for long duration flights), induced by external factors (weather, equipment degradation, ...) or changes into the mission. Other changes might be initiated as a measure to de-conflict the operating zones of two vehicles as part of strategic traffic control. It is essential for the NearSpace Management to allow for these changes in planning and during operation. It has to facilitate a negotiating

process in case of conflicting interests between operators, allowing for equal accessibility of NearSpace while considering regulations and rules for operation, especially with respect to possible limitations associated with geographical and national regions.

3.4. Monitor operated flights

Monitoring of flight execution can utilize to a major part ground operator infrastructure, which is used to guide and control the vehicle along its designed mission trajectory. Monitoring may include not only the commonly used vehicle state vector but as well status data and further flight planning information. Appropriate distribution mechanisms shall be used for data provision to the NOMS. Use of established services, like exchange of flight information related to the Flight Object using the blue SWIM Technical Infrastructure Profile, currently under definition within SESAR [4], allows for interoperability with existing ATM tools and processes.

The monitoring task focuses on the operating vehicles proceeding along their route and schedule clearances. It ensures that all vehicles remain operating free of conflicts. Changes to designated routes and related operating zones will be checked against current planning for the related time of operation. Inflight modifications and requested ad hoc changes of routes will also be coordinated by the operators in charge using the NOMS.

The monitoring and control principle can be compared to current approaches of flight centric air traffic management and control. While this concept development focuses on tactical en-route ATC, especially for low complexity upper airspace, it already incorporates many of the monitoring and control principles described for NearSpace traffic management [5]. It is designed for the controller to look ahead in time and detect and resolve possible conflicts with other aircrafts. The concept is based on assigning the responsibility of guiding individual vehicles through large sized airspaces. As such it is by design creating the possibility to have dedicated controllers for managing flights with very specific characteristics. The air traffic controller is supported by assistance systems and specifically designed situation displays which supports conflict detection and resolution. In previous work, this control principle has already been suggested to be used in handling of space vehicle operation within upper airspace and for NearSpace control [6]. Its vehicle centric approach and design to plan ahead operation free of conflicts allows a relatively straight forward adaptation to NearSpace monitoring tasks and as an operator interface for the NOMS.

3.5. Ensure Surveillance

For surveillance, a combination of different sources for data acquisition must be used to provide a comprehensive representation of the traffic situation in NearSpace. Radar may be used to detect and track vehicle operating over regions with radar coverage. Secondary radar can provide enhanced information including identification, altitude etc. for transponders equipped vehicles. ADS-B can be used as cooperative means of surveillance, supported by satellite based ADS-B reception to cover also remote or oceanic operational regions without any radar coverage. It has to be taken into account that ADS-B based surveillance data depends on the accuracy of available on-board data. Tracking information assessed by the vehicle operator or space surveillance entities can further enhance the surveillance picture or close the gap for vehicles without ADS-B or other aviation transponder systems (mostly space systems) [7].

The multiple sources of surveillance have to be accessed, the data to be collected and analyzed. Appropriate data fusion capabilities have to be provided to generate a consistent traffic situation out of the different named sources. The resulting traffic situation has to be provided to the traffic monitoring entity in charge of NearSpace traffic management.

All these processes are time critical. Therefore, secure and performant data distribution services are an important enabler for the described concept. As referred to in 3.4, SWIM based services are suggested to be used to distribute related flight information data. SWIM is a core element of the ATM system designed as well in SESAR as in NextGen. Although its implementation varies slightly between Europe and the US, interoperability for time critical provision of space flight related data has been demonstrated [8]. The general principle of a SWIM based flight information exchange, covering data aggregation, fusion and distribution, is shown in Fig. 2.

3.6. Supply interfaces to STM and ATM below FL660

Planning of trajectories to NearSpace on transit to controlled airspace below FL660 has to be coordinated and should consider flight planning requirements of both domains [9]. By using data exchange formats associated with the commonly introduced SWIM services, flight planning and status information can be shared even under time critical constraints, as described in 3.4 and 3.5. As planning and monitoring of operations in NearSpace might require certain modifications to existing formats (e.g. for FIXM, the Flight Information Exchange Message), those have to be introduced in a way that allows for system wide interoperability.

For flights planned as vertical transit through NearSpace, e.g. space launch and reentry operations, interfacing with STM is needed as well. To ensure a conflict free trajectory clear of interference with other space objects during the planning phase and to update on the position and status specifically for re-entering vehicles, appropriate mechanisms for on-time transfer of flight information have to be established. Incorporation into the interoperable runtime infrastructure of SWIM again is suggested.

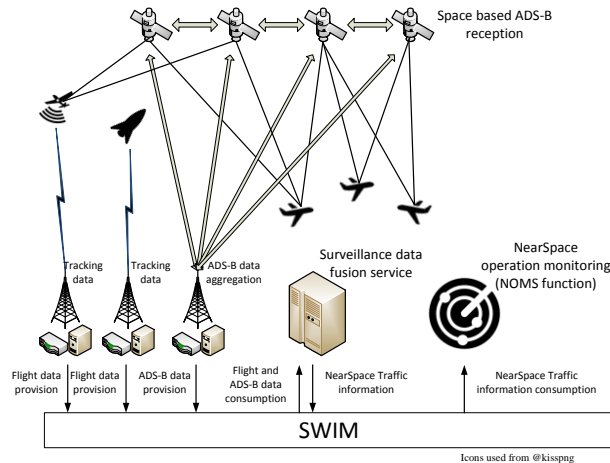


Fig. 2. SWIM based surveillance data provision

4. Commonalities between ATM and STM

There are distinct differences between the operational concepts of Air Traffic Management (ATM) and Space Traffic Monitoring (STM). Issues of sovereignty, regulation and law create two distinct domains. However, the fundamental concern of each is common, to avoid collisions. Each domain, aviation and space, is subject to the standards of an international organization, through the United Nations specialized agencies of the International Civil Aviation Organization (ICAO) and International Telecommunications Union (ITU), respectively. For NearSpace operators seeking to provide services to the ground from the airspace, both regimes will be relevant.

Examining the mandate of each body reveals clear commonalities. ITU's orbit and spectrum allocation principles serve as a foundation for STM, they are:

- To avoid harmful interference
- To ensure efficient, rational and cost-effective utilization radio-frequency spectrum and satellite-orbit resources
- To develop procedures that facilitate access to the resources
- To establish global standards and associated material to assure the necessary required performance, interoperability and quality

For aviation ICAO's Air Traffic Management principles are:

- To prevent collisions between aircraft
- To expedite and maintain an orderly flow of air traffic
- To provide advice and information useful for the safe and efficient conduct of flights
- To establish global standards and recommended practices in support of a safe, efficient, secure, economically sustainable and environmentally responsible civil aviation sector

Merging the principles of both domains serve as the basis for principles for the safe, efficient, rational and cost effective utilization of the NearSpace region. These principles are needed whether or not a state chooses to provide air traffic services above 20km. These principles would be to:

- Avoid harmful interference
- Prevent collisions between operators in the NearSpace region
- To provide advice and information useful for the safe and efficient conduct of flights
- To develop procedures that facilitate access to the resources
- To expedite and maintain an orderly flow of air traffic
- To establish global performance, interoperability and quality to provide a safe, efficient, secure, economically sustainable operating environment from 20km to 100km.

This approach can illustrate how the management of the NearSpace region can serve as bridge between ATM and STM, particularly from the perspective of a regulatory regime. ATM is built upon the premise that a single authority is responsible for each given volume of airspace. This authority is based on sovereignty for the airspace over a territory and territorial waters. For international (high-seas) airspace, the airspace is delegated by the ICAO Council to an individual state for the provision air traffic services. There is no similar concept for operations in space, which has no claims of sovereignty and does not have an international treaty that would empower a body to delegate responsibility for the provision of STM to a given state or states.

For the NearSpace region, most states have asserted that while ATM services may not be provided, the airspace itself is within the state's Flight Information Region (FIR). In reporting the vertical limits of their FIRs to ICAO, the majority of contracting states cite "unlimited" as the vertical limit. This indicates that while air traffic services may not be provided, there is an interest in maintaining regulatory authority over the

NearSpace region. As a consequence, the principles discussed above could provide a framework for the regulation of the airspace to ensure safe operation, while allowing the flexibility of operators to manage flights without direct intervention by air traffic control. This concept of cooperatively managed airspace, using a strategic separation model that relies on shared information, can serve as a bridge to a space traffic management model.

The NearSpace region does not have the debris risk that is a primary concern for space operations. This is a significant difference in the operational implementation. However, from the standpoint of operational architecture and regulatory authority, the NearSpace model is instructive as it allows for the transition from single control authority to a cooperatively managed commons. The concept of cooperatively managed airspace depends upon shared information of sufficient quality to allow operators to avoid collision and to remain clear of protected airspace. This requires the actions discussed in chapter 3, to plan conflict free operations, monitor operated flights, and ensure surveillance which align with the STM principles of orbital assignment, satellite monitoring, and space situational awareness. The advantage for the NearSpace region is that concept of sovereignty can be applied to require compliance.

For space operations regulatory compliance is derived from the oversight responsibilities of the state of launch not based on the operating environment. As a result, in space operations, different space vehicles could be subject to different regulatory standards while operating in the same region. For NearSpace, the authority stems from control of the airspace and is applied to all operations within. This allows for the development of a model of cooperatively managed airspace without the legal ambiguity that is encountered in the space domain. Once established and accepted, the cooperative approach relying on common standards, could be exportable to the orbital regime.

6. Summary and Conclusions

The major challenge to manage operation in the NearSpace region is the diversity of operational types and mission profiles. Three distinctly different types of users have been categorized: users on their way into or back from space (transit), operating over a fixed location (persistent), or traveling through NearSpace from one point of the earth to another (point to point).

To ensure safe operations at all times, the principle of strategic separation has been elaborated further. The free of conflict criteria have to be met during the

planning process for the requested route and schedule of a vehicle. Uncertainties in vehicle position over time based upon its performance characteristics are considered by associating each route by an operating zone, which can be defined as a four dimensional shape and volume. Tactical monitoring augments the strategic separation process, ensures compliance with the previous planning and supports the implementation of updates for the operating zones during flight. A NearSpace Operation Management System is suggested for processing the planning information, calculating operating zones and supporting the monitoring process during operation. Exchange of planning and monitoring information as well as coordination with planning and control facilities of ATM and STM can be facilitated by the implementation of SWIM related services, ensuring interoperability and use of established standards and data exchange formats. To acquire a consistent picture of the NearSpace traffic situation, a multi-source surveillance approach is suggested, utilizing a cooperative relationship between the operators and ANSP by sharing available tracking information. In addition, use of standardized cooperative transponder technologies is recommended for as many vehicles as possible, utilizing the improved surveillance capabilities supported by space based ADS-B.

Provision of services for NearSpace does not necessarily require new mandates. Nevertheless, certain regulatory ambiguities apply, especially with respect to the often undefined limits of airspace and the beginning of space according to the Outer Space Treaty. By merging the defining organizational principles of STM and ATM and applying them to NearSpace operations, a framework for the regulation of the airspace to ensure safe operation can be provided, while allowing the flexibility of operators to manage flights without tactical intervention by air traffic control.

Acknowledgements

Ruth Stilwell would like to acknowledge the Space Policy Institute at George Washington University for its support of this research.

References

- [1] Bhavya L., Nightingale, E., Where is Space? And Why Does That Matter?, Space Traffic Management Conference, Dayton Beach Campus, Florida, 5 November 2014.
- [2] National Environmental Satellite, Data, and Information Service (NESDIS), Where is space?, 22 February 2016
<https://www.nesdis.noaa.gov/content/where-space> (accessed 16.09.18).

- [3] Stilwell, Ruth E., Blurring the Lines: The Overlapping Interests of High Altitude Unmanned Aircraft, Commercial Space, and Aviation Policy, 2nd Annual Space Traffic Management Conference, Dayton Beach Campus, Florida, 12–13 November 2015
- [4] Commission Implementing Regulation (EU) No 716/2014 of 27 June 2014, on the establishment of the Pilot Common Project supporting the implementation of the European Air Traffic Management Master Plan, Annex 5.1.6.
- [5] Birkmeier, B., Schmid, J., Schmitt, A. R., Korn, B., Change of controller tasks in a sectorless ATM concept - first results, 2012 Integrated Communications, Navigation and Surveillance Conference, Herndon, VA, 2012, pp. I6-1-I6-22. doi: 10.1109/ICNSurv.2012.6218414.
- [6] Kaltenhäuser, Sven, A concept for improved integration of Space Vehicle Operation into ATM, 33rd Space Symposium, 2017, 3 - 6 April, Colorado Springs, CO, USA.
- [7] Stilwell, Ruth E., Demidovich, Nickolas, The bridge to space: CNS technology for high altitude operations, Integrated Communications, Navigation and Surveillance Conference (ICNS), 2017. IEEE, 2017.
- [8] Morlang F, Ferrand J, Seker R. Why a Future Commercial Spacecraft must be able to SWIM. 8th International Association for the Advancement of Space Safety Conference, Melbourne and Florida, May 2016.
- [9] Kaltenhäuser Sven et al., Facilitating Sustainable Commercial Space Transportation Through an Efficient Integration into Air Traffic Management, New Space Journal, August 2017.