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COOPERATIVE STRATEGIC DECONFLICTION FOR THE HIGHER AIRSPACE USERS

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Abstract. *The evolution of needs in terms of services for telecommunication, data collection, transportation, and even space tourism pushed the industry to explore and start to operate in the higher airspace. New airspace users and types of operations are therefore emerging in this layer of airspace between 20 to 100km altitude above mean sea level (MSL). The first initiatives from the industry already demonstrate the usage of a large diversity of vehicles, from unmanned balloons, airships, and solar planes capable of persistent flight, collectively known as High Altitude Platform Systems (HAPS), to super- and hyper-sonic aircraft, trans-atmospheric and suborbital vehicles*

The objective of this paper is to analyze and model these new types of operations and their associated constraints to suggest a way allowing the higher airspace users to cooperatively operate based on strategic deconfliction solutions. Subsequently, each user should be able to accomplish their flight and offer their services safely and efficiently.

1 INTRODUCTION

The Higher Airspace region is located between the airspace normally used by aircraft and the beginning of space. Higher airspace is no longer an exclusive transition zone, but an area where operations will be significantly expanded as a result of the emergence of a completely new aviation domain, business, technical opportunities and more [1]. Higher Airspace Operations include the operation of vehicles that fly in the higher air space, vehicles that transit the higher airspace to space, and vehicles that return from space. Besides vehicles, also different sources of debris will be considered. Their operational characteristics are very diverse, ranging from stationary balloons to hypersonic aircraft and space launches. Moreover, many characteristics are still unknown. This also applies to the frequency and distribution of the operations. Increasingly new airspace users and operations are emerging in this volume of airspace. The diversity of vehicles is high ranging: from unmanned balloons, airships and solar planes capable of persistent flight, collectively known as high-altitude-pseudo satellites (HAPS) to super and hyper-sonic aircraft and trans-atmospheric and suborbital vehicles. Commercial and State space operations are also transiting through the higher airspace for launches and re-entries. The expansion of operations in this stratospheric layer, which was conventionally used solely for transition purposes, brings along new challenges and risks due to the diverse nature of operations taking place in this volume of airspace [2]. Moreover, the emergence of new entrants into the conventional airspace with variant technical and fleet characteristics, thanks to the development of new technologies, has added upon the complexity of the traffic management in an integrated way amongst conventional airspace, U-space, higher airspace, and outer airspace. Hence innovative enablers are needed for a safe and orderly manner of Higher Airspace Operations in the near term and future. Such enablers can be provided by research entities with a focus on modeling different types of such operations [2].

This paper's objective is to suggest a potential cooperative strategic deconfliction for HAO. It will provide a background description of the HAO based on the ongoing initiatives in Europe and the United States. Then a description of what is the current analysis of the aircraft modeling is performed. A suggestion of their possible categorization and their relevant trajectory prediction for simulation to use follows. A first approach to what could be the cooperative strategic deconfliction consideration is presented.

2 BACKGROUND

While operations in the Higher Airspace have historically been limited due to the challenges faced by conventional fixed wing aircraft in reduced atmospheric density, new technologies have led (and will lead) to an increased number of vehicles that can operate in such conditions. There is a wide range of technological solutions leading to various shapes and types of vehicles, ranging from balloons, airships, sophisticated long endurance vehicles to new kinds of supersonic/hypersonic aircraft or spaceplanes [3].

Traditionally, orbital rocket launches were one of the few operations touching or crossing the Higher Airspace. The number of orbital launches per year is growing again – due to the emergence of commercial launch providers like SpaceX – and is expected to dramatically expand in the near term. The drivers of this development are several new companies in the nanosatellite and small satellite business which are planning mega-constellations [4].

Spaceflight experience (space tourism) is foreseen to be the first application for commercial spaceplane operations. The best-known launch provider is Virgin Galactic, which is developing SpaceShipTwo in order to become world's first commercial spaceline (The new iteration named SpaceShip III was presented in early 2021) [5]. The UK expects a demand of 120 participants per year when operations start, increasing up to 400+ per year in year 10 of operation [6]. The worldwide demand for commercial space experience flights is forecasted with around 400 participants in Year 1 in the baseline scenario by The Tauri Group [7].

High Altitude Platform systems (HAPS) represent a field-tested development in the Higher Airspace with a diverse application from earth observation, surveillance, telecommunication to navigation [8]. Whilst sharing key characteristics like long endurance flight times and operating altitudes in Higher Airspace, generally, they can be distanced based on two categories of "Heavier than air" and "Lighter than air" [9]. Hybrid platforms have been developed in the last years [10] [11] [12]. Although amongst 12 promising projects launched in the time frame between the early 2000s and the early 2010s, 7 were closed by 2016, in the meantime, the number increased, with Airbus' Zephyr and Thales' Stratobus being the only active projects of this "initial" group. Alongside the opportunities brought by the promising approach of hybrid platforms, new challenges are identified for the higher airspace operations varying from the integration with ATM and to the regulatory framework for certification to the confliction avoidance techniques, required for a safe operation for all types of vehicles with different characteristics.

3 VEHICLE MODELLING

To model vehicles operating in or crossing Higher Airspace, the type of movements and purpose of operations should be considered. Therefore, it is necessary to know diverse types of operations performed today and the ones to be expected to be performed in the future as well as the purpose of these operations, their payload, and characteristics of movements. The initial analysis is based on the type of operations that will be detailed in the following parts to well cover the scope of the modeling we need to describe the technical and fleet characteristics associated to the operations taking place in the Higher Airspace.

3.1 Flight types:

3.1.1 Suborbital flights (A-to-A & A-to-B)

The first well-known category of operations is suborbital flights including A-to-A and A-to-B flights that differ based on take-off and landing for the latter operation and share multiple possible vehicle concepts for both takeoff and landing. In other words, A-to-A flights target space tourism while A-to-B flights are expected to evolve from A-to-A suborbital flights in long term to compete with present air travel [13] [14].

The launch profiles for the reusable vehicles can possibly range between vertical takeoff and landing and horizontally launched winged vehicles [15].

A mission profile for a vehicle, either taking off and landing horizontally, or aero-launched and landing horizontally, can be described as below: [6] [16]

- Horizontal takeoff with engines operating in turbojet mode from a runway followed by subsonic ascent to altitudes between 5 and 10 km or takeoff carried by a carrier aircraft
- (Separation from carrying aircraft.) Acceleration through the transonic speed range and climbing using combined cycle engine mode or rocket engines depending on vehicle type
- Hypersonic cruise (for either transcontinental A-to-B or suborbital parabolic A-to-A flights) using high specific impulse ramjet engine mode or rocket engines depending on vehicle type, gilding descent and landing or powered landing depending on vehicle type
- The total flight duration is usually less than 2 hours

3.1.2 High Altitude Platform System flights

HAPS are unmanned aircraft positioned at around 65000ft (20km) altitude in the stratosphere. Initially, this technology was meant to complement terrestrial and satellite-based communication networks. Later on, other possible uses like remote sensing, earth observation, and surveillance for military and civilian applications emerged [17].

As mentioned earlier, concepts for HAPS are distinguishable in “heavier than air” and “lighter than air” vehicles, and hybrid vehicles using both the approaches (light and heavy). The technology readiness level (TRL) is considered to be higher for the “heavier-than-air” category, whilst being lower for “lighter-than-air” and for hybrid vehicles. Key enabling technologies mentioned are batteries, solar cells and (lightweight) materials [12]. Due to weight constraints, the power consumption is critical especially during nighttime. Staying at high altitudes is therefore at least challenging (or even not possible), depending on latitude and season [18]. Rigorous station-keeping requirements for certain types of operations can limit their payload capabilities due to the higher energy consumption [19]. Heavier-than-air HAPS offer better maneuverability and are better resilient to winds [20]. Representatives of both HAPS concepts claim good station-keeping capabilities [20] [21].

A unique characteristic of HAPS is their long endurance operating capability. Targeted mission durations are up to 60 days. Lighter-than-air HAPS missions could last hundreds of days in the future [1].

Another important characteristic is the limited payload. Fixed-wing may offer good feasibility up to a payload of 30 -40 kg. Standard Lighter-than-air HAPS offer the advantage of relatively higher payloads up to also over 200 kg. The use of LTA vehicles for payload under 100 kg is generally not convenient, whereas the limit of fixed- wing leads to a reduction of capabilities in the range of 30-100 kg, which can be covered by the hybrid vehicles [22].

The integration of HAPS operations in airspace < FL660 can be challenging in congested airspaces like continental Europe. In combination with limited maneuverability and wind sensitivity, especially for lighter-than-air HAPS, large segregated airspaces for a notable time window could be needed in order to transition to and from the Higher Airspace [21] .

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 [23]. The most well-known representative was probably Googles Project Loon which ceased operations in early 2021. High payloads up to 1100 kg can be carried with Zero Pressure Balloons. Altitudes can reach up to 40 km, while flight durations are only up to 40 hours [23].

3.1.3 Supersonic and hypersonic flights

Supersonic aircraft with expected service ceilings of around 60,000 ft. (20km) is expected to operate near the lower boundary of the Higher Airspace to operate point to point flights while Hypersonic flight is a flight through the atmosphere below about 300,000 ft. (90 km) at speeds ranging between Mach 5-10 [24].

The high cost of meeting the environmental restrictions on sonic booms, inefficient fuel consumption, and other factors had limited the usage of such operations in the military domain. For the extension of flights of this sort to the commercial and business segments of the aviation sector, there are technical areas where ongoing work should be continued and new focused research initiated to enable operational deployment of an environmentally acceptable, economically viable commercial aircraft capable of sustained supersonic flight, including a flight over land, at speeds up to approximately Mach 2 in the next 25 years or less [25] [26].

3.1.4 Aero-launched (orbital and suborbital) flights

A carrier aircraft being the launch platform for either an orbital or a suborbital vehicle explains the concept of an aero launched flight. Capabilities range up to payloads of 500 kg (Virgin Orbit) and 50 kg (DANEO) respectively into Low Earth Orbit and are therefore suited to meet the rising demand for small satellite deployment. Separation of vehicles and the rocket launch occurs at around 35,000 ft in limited restricted airspace. As an example virgin Galactic separates its SpaceShipTwo at 50,000 ft [5] [27].

Aero-launches using balloons as carrier vehicles are another concept mentioned. Using a Zero Pressure Balloon, in this case “Bloostar” could be carried at around 25 km altitude (soaring above 99% of the air) were separation and rocket launch would occur. This system is stated to be the most cost-effective and eco-friendly launch system ever [28].

3.1.5 From orbit flights

Space transportation vehicles are categorized as either Expandable Launch Vehicles (ELV) or Reusable Launch vehicles (RLV). RLV are increasingly common, mainly due to their economic advantages [29]. Vertical launches are the current main method of launching vehicles. Reusable spaceplanes could offer similar capabilities regarding (small) satellite launches in the future. Lower costs for horizontal launches are expected for this type of operation [6].

ATM-relevant categories of space vehicle operations are launch and de-orbiting operations. Launch operations using reusable first stages like SpaceX' Falcon 9 result in an additional Higher Airspace flight trajectory for the returning first stage [30]. Controlled re-entry from orbit can be differentiated by ballistic (e.g. capsules) or horizontally landing vehicles (e.g. spaceplanes). Especially vertical landing spacecraft cannot be considered active players in any de-confliction or collision avoidance [31]. Uncontrolled re-entry from orbit of ELV or parts thereof, either undergo re-entry over remote area or burn up on re-entry with determined or probabilistic re-entry location information [32] .Unlike current airspace segregation methods which restrict large airspaces statically and conservatively, in the future, 4D envelopes based on individual probabilistic of nominal spacecraft conditions both during launch and re-entry could enforce only the closure of airspace that is at risk at a given time (based on a maximum acceptable risk) [31] .

3.2 Operation types

From a broader view, we can have the below breakdown of the vehicles enclosing the above-mentioned categories as follows [1]:

- **Breakout group 1: High Speed Vehicles/Operations** (aero launch and A to A suborbital)
- **Breakout group 2: Low Speed Vehicles/Operations** (HAPS)
- **Breakout group 3: Global and Very High-Speed Vehicles/Operations** (A to B suborbital and super/hypersonic)
- **Breakout group 4: From Orbit, vertical launcher**

4 TRAJECTORY PREDICTION

Our approach is to focus on the higher airspace above FL600, so the trajectories to model and simulate will be from the entry point in the Higher Airspace to the exit point from the Higher Airspace. The operations, trajectories below FL600 will be covered by the conventional Air Traffic Management simulation and tools.

For the trajectory prediction in the HAO, we should address different approaches according to the type of operations presented above:

- **For group 1; High-Speed Vehicles/Operations and group 3:** Global and Very High-Speed Vehicles/Operations (A to B suborbital and super/hypersonic): the trajectory prediction mechanism will be based on aircraft flying parameters, similar to what is done for the aircraft operating below FL600, but it is needed to add their specificities in term of speed, climb and descend rates. Furthermore, the launch point could already be in the higher airspace in case of aero launch.
- **For group 2; Low-Speed Vehicles/Operations (HAPS):** these vehicles will focus on volumes of operations with a specific period of activities
- **For group 4; From Orbit, vertical launcher**: we define 4D envelopes based on individual probabilistic of nominal vehicle conditions both during launch and re-entry. That gives volumes of operation conducting to restricted airspace for a given time period for all other groups.

5 COOPERATIVE STRATEGIC DECONFLICTION

The diversity of the types of operations and the variety of vehicles in the higher airspace brings new challenges in terms of the risk of collision. The conflict detection in the tactical phase, during the operations, is constrained by the available means to detect the vehicle and avoid collisions and on the fact that the airspace is shared by vehicles with extreme velocity and maneuverability differences. In fact, tactical conflict resolution between a rocket and a balloon does not make sense. To reduce the risk of potential conflicts, they should be analyzed during the strategic phase, many hours before the operations. In that case, according to the type of vehicles and the type of operations, predefined trajectories could be drafted, and the risk of collision could be assessed. Trajectory conformance or accurate prediction is a stringent requirement for de-confliction management. The other advantage of this approach is the suggestion to be given to the airspace users different de-confliction solutions. They could then negotiate the solution to put in place according to their own operational concerns.

The conflict detection in the strategic phase should be based on an accurate trajectory prediction and based on the constraints coming from the type of operations. Some specific areas could be considered as more critical in terms of risk of collision, one main example is the areas used for the take-off and landing of vehicles operating in the higher airspace. These volumes of the airspace should be managed by some restrictions to avoid disruption within the air operations below FL600. Some other examples could be areas where stratospheric balloons are operating.

5.1 Use cases and trajectory prediction

The use cases of operations in the higher airspace are not yet completely described, they are in discussion between the airspace users, Eurocontrol, and other partners within the ECHO project funded by SESAR JU for defining the concept of operations in the higher airspace [1]. An approach has been presented on this topic by MITRE in March 2021 based on the technical paper presented at ATCA (Air Traffic Control Association) in December 2020 [33] [34].

The Mitre Analysis highlighted the specificities of operations in the Higher Airspace as following:

- Wide range of vehicle performances that vary in time.
- Missions which last over a year, others a few minutes.
- Wide range of mission objectives, preferences, and constraints
- Growing uncertainty of intents in future

From another perspective, the vehicles operating in the higher airspace could be split into two categories [2]:

- Vehicles with non-deterministic intent (probabilistic), those vehicles with very low maneuverability and speed fall within this category (balloon, aircraft with large wingspan).
- Vehicles with deterministic intent for which the trajectory could be computed with a relatively high confidence rate for the predicted trajectory to remain within a tube of prescribed radius along the true flight path.

For the non-deterministic category, our approach will be to identify their specific volumes of operations in a given time. So, the trajectory prediction will be reduced to the zone of operations in time. For the deterministic aircraft, the trajectory prediction mechanism will be based on the vehicle flying parameters, similar to what is done for those operators flying below FL600.

5.2 Dynamic Airspace Management

For the Higher Airspace operations, it is important to consider some specific restrictions for crossing the levels used by the conventional airspace operators below the FL600. Several initiatives have started to identify spaceports that will be used for the take-off and landing of some of the vehicles that are meant to operate within the Higher Airspace e.g. US space tourism venture Virgin Galactic is planning to send people into space via Italy’s future Grottaglie Spaceport [13] [14] [35].

In our approach we will consider specifying:

- Specific restricted areas with defined activities period above the spaceports to reduce the risks of collision.
- Specific restricted areas of operations with activity periods for the non-deterministic vehicles
- Specific restricted areas for special operations (military, surveillance…others).

A mechanism should be put in place to dynamically optimize the usage of the airspace according to the various constraints of the operations.

5.3 Cooperative deconfliction

Our approach for the cooperative strategic deconfliction mechanism is to combine the dynamic airspace management and the planned trajectories deconfliction. The dynamic airspace management will take into account the constraints of operations associated with the schedule and provide possible solutions that could be approved or amended by the airspace users. We can considerer an iterative process between the suggested airspace allocation by operations and the feedback of request amendment by airspace users.

The process consists of the following sequence:

- Each user provides the type of operations and the associated special and temporal constraints
- An optimization to be performed taking into account all the constraints and potential overlaps to be presented to the concerned airspace users.
- A negotiation process to solve the conflicts and overlaps. The final suggested solution is then presented to all the airspace users for improvements. If the suggested solution is not approved by all, the process leads to a restart of the negotiation process between the concerned airspace users.

The deconfliction will be based on the optimization of the airspace usage combined with the calculation of possible conflicts for the deterministic vehicle depending on their planned trajectory. Several solutions could be suggested based on defined criteria allowing their classification according to the operational concerns. The airspace users could then negotiate between themselves the proposed solutions to put in place according to their own concerns and priorities.

5.4 Collaborative steps of strategic deconfliction

What is presented hereafter is one of the possible scenarios that could be followed to reduce the risk of conflict at the strategic level.
The strategic deconfliction should follow steps according to the constraints associated with each group of operations.

- **First step; Group 4:**

  The deconfliction mechanism should take into account the most important constraint induced by group 4 since the means of controlling their operation is limited. Therefore, the means to reduce the risk of collisions within group 4 is also bounded.

- **Second step; Group 2:**

  The actors belonging to group 2 should submit the volumes and time frames concerned by their operations in advance. Thereafter, negotiation amongst them avoids overlaps of volumes on the same period of time. They should also take into account the constraints coming from group 4 (Step 1).

- **Third step; Group 1 and 4:**

  The trajectories should consider the constraints of group 4 and group 2 (Steps 1 and 2).

A negotiation between the actors belonging to group 1 and 4 takes place to avoid the potential conflicts on the time frame of the operation (easier to put in place) of operation and then on the variation of trajectories.

- **Fourth step:**

  There are cases where some of the operations of group 1 and 4 could not be performed due to the constraints of group 2 (Step 2), in that case, a negotiation should be done between the actors of group 2 and the actors of group 1 and 4 in order to avoid overlaps of volumes of operation in a given time.

6 CONCLUSIONS

The definition of the concept of operations (ConOps) in Higher Airspace Operations field is in progress in Europe and the United States. An integrated traffic management approach and subsequently new negotiation and collaboration schemes are required once the demand and traffic volumes increase. This paper will be a reference to develop new contributions in this domain. The objective is to set up a safe and efficient de-confliction management system for all sorts of HA users including operators and service providers enabling them to confidently operate and implement their services in an interactive manner. We suggested specifically one of the possible solutions allowing the higher airspace users to cooperatively perform strategic de-confliction mechanisms from a high point of view. Our approach allows us to describe, analyze and suggest possible models for various types of operations and their associated constraints in the Higher Airspace (HA). Future work should be done based on more realistic parameters e.g. traffic volumes, composition, geographical distribution, vehicle performances, etc. to be able to characterize reference traffic situations and detail more about negotiation and collaboration processes. This shall be addressed by setting up a simulation with modelization of demand and identifying specific use cases in collaboration with the future Higher Airspace users. Thereafter, we can validate and improve our suggestion for the cooperative strategic deconfliction in the future Higher Airspace.

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