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Framework for Evaluating Traffic Management Services in Higher Airspace

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Introduction

There is a vast realm of airspace that remains unexplored, save for a handful of scientific and national security missions. It is rife with extremes, where flights can reach multi-Mach speeds or stay aloft for months as they slowly circumnavigate the globe. This region lies roughly between 52,000 and 160,000 feet and is referred to as higher airspace in this paper.

Recent breakthroughs in technology have set the stage for routine commercial operations in this realm. Companies are investing in ways to harness its potential for a wide range of commercial applications. Until recently, few have contemplated how this assortment of operations will coexist where the air is thin and manned operations are likely to be the exception, not the rule.

Today's air traffic management (ATM) system was designed for legacy aircraft, not unmanned and lighter-than-air operations. As a result, existing flight rules which govern aircraft behavior, are likely to be ill-suited to these non-traditional operations. Just as the current system has adapted to meet user needs, so too will adaptations be needed to safely and equitably serve the needs of these new users.

Thus, an assessment of the pros and cons associated with ATM components is needed to determine the most suitable path for addressing operational needs in higher airspace. This paper presents a framework for evaluating ATM services in higher airspace based on the International Civil Aviation Organization's (ICAO) Global Air Traffic Management Operational Concept (GATMOC), which enumerates user expectations and ATM components for 2025 and beyond.[1] It provides an understanding of ATM services relevant to higher airspace, viewed through the prism of user expectations along with a discussion of when services beyond what are currently available may be warranted.

Higher Airspace Environment

For the purposes of this paper, higher airspace begins where passenger transport traffic ends, and ends where atmospheric density can no longer sustain lift through aerodynamics or buoyancy. As mentioned previously, this region is roughly between 52,000 and 160,000 feet. Operations that rely on aerodynamic lift rarely exceed 100,000 feet, while operations that rely on buoyancy generally top out at 140,000 feet, except for some research balloons.[2] This region is well below the Karman line (~330,000 feet), and thus still considered "airspace".

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[1] The GATMOC presents the civil aviation community's mid-term vision for an integrated, harmonized, and globally interoperable air navigation system.

[2] Of the operations that rely on lift, unmanned free balloons can go the highest. The current record is well below 200,000 feet.

The lower boundary is consistent with the Federal Aviation Administration’s (FAA) JO7110.65’s definition of Jet Routes as not exceeding Flight Level (FL) 450.[3] Also, FAA Advisory Circular guidance on high altitude operations does not address altitudes above FL510 [1] [2].

Higher airspace, generally associated with the stratosphere (see Figure 1), differs from the troposphere below in two key areas:

- Higher airspace is considered “above the weather.” High winds associated with the jet stream top out around 50,000 feet; the thunderstorms stop around 60,000 feet.
- According to the U.S. Naval Flight Surgeon’s manual [3], “from a physiological viewpoint space begins when 50,000 feet is reached since supplemental 100 percent oxygen no longer protects man from hypoxia.”

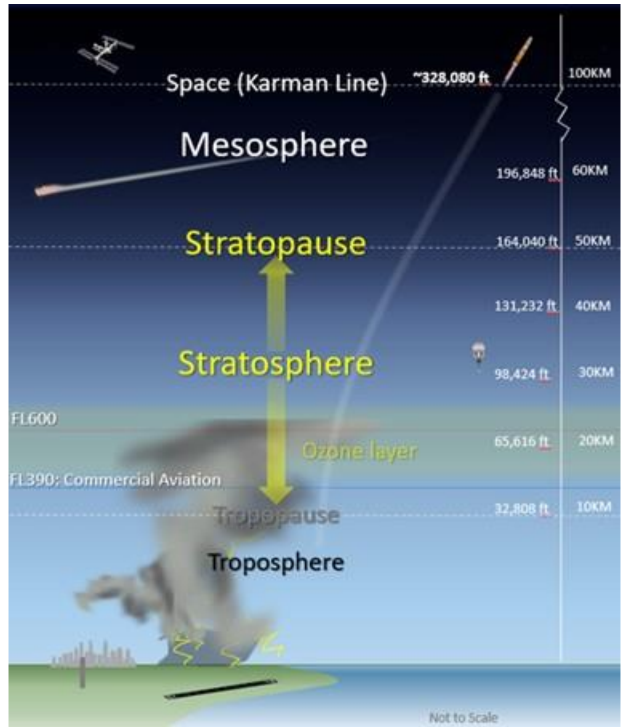

Figure 1. Atmospheric Layers

Anticipated Operations in Higher Airspace

There are two broad categories of commercial operations that can access this region: 1) operations that conduct their mission in higher airspace, and 2) operations that rapidly transit higher airspace en route to their mission.[4] The focus of this paper is on the former, since they are expected to dwell in higher airspace, and therefore require a range of traffic management services. Transiting operations will spend little time in this region on the way to their final destination, typically using segregated airspace.[5] The needs of these transiting operations remain the same throughout their entire trajectory and are not unique to higher airspace.

Vehicles with wings, rotors, and those that use lighter-than-air gases, rely on air for lift. As altitude increases, the air thins and so does the number of viable operations. Only a handful of specialized vehicle types can operate with ease in higher airspace.

The five categories of vehicles most likely to operate in this region include: unmanned balloons (e.g., sounding, super pressure and zero pressure), manned balloons (e.g., space tourism), unmanned aircraft, manned aircraft (e.g., supersonic and hypersonic) and unmanned airships. General operational characteristics of these vehicle types are captured in Table 1, and Figure 2 classifies these diversely performing operations by speed and trajectory.

[3] FAA JO 7400.2, Procedures for Handling Airspace Matters, also defines Jet Routes as being between FL180 and FL450.

[4] Amateur, hobbyist, research and defense related operations, while peripherally considered, are not the focus of this analysis.

[5] These operations include orbital and suborbital spacecraft, amateur rockets, and air launched rockets. Vehicles returning to earth from orbit also transit this airspace; some are controlled reentries (deorbit) and some are not (decay).

Table 1. Performance of Commercial Vehicles Anticipated to Dwell in Higher Airspace

Operation Type	Speed	Duration	Cruise Altitude (feet)
Unmanned Balloons (Super and Zero Pressure)	Low	Hours - Months	50,000 to 75,000
Manned Balloons (Space Tourism)	Low	Hours	100,000
Long Endurance Unmanned Aircraft	Low	Days - Months	60,000 to 85,000
Supersonic Transport Aircraft (Manned)	Very High	Hours	55,000 to 75,000
Unmanned Airships	Low	Days	55,000 to 70,000

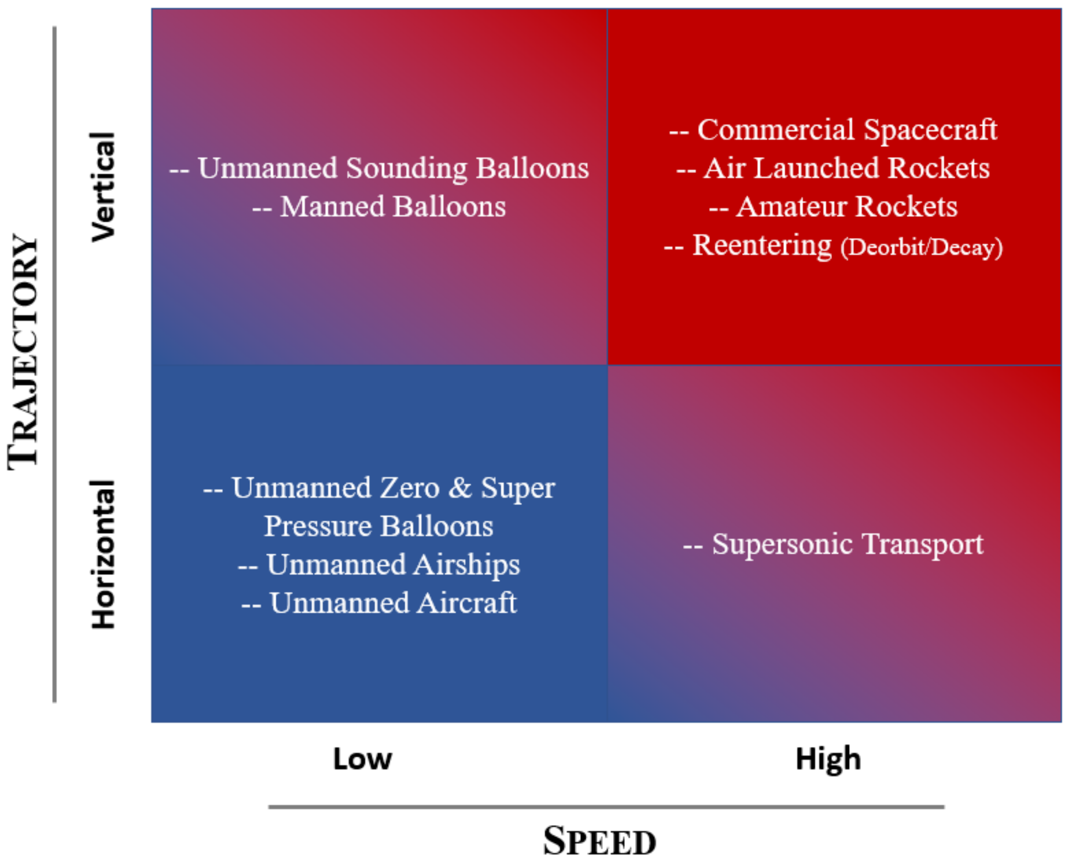

Figure 0. Commercial Vehicle Types Included in each Performance Category

Few operations in higher airspace are expected to maintain a steady altitude on mission. Most low-speed horizontal trajectory vehicles ascend in altitude with the heat of the day and descend at night. Some platforms use different altitudes for transiting as opposed to station keeping. Even high-speed horizontal trajectory flights will slowly ascend as fuel is burned. High level analysis indicates that the altitude range between FL550 and FL750 is expected to experience the highest demand.

Operations in higher airspace will likely be concentrated in specific geographic locations due to their business needs, operational limitations and/or environmental reasons. While the overall anticipated number of operations is low, most of these operations will remain in higher airspace for extended periods of time. This has significant ATM services implications, as current services are geared toward legacy traffic operations which are greater in number, but considerably shorter in duration.

The following is a list of characteristics unique to commercial operations in higher airspace:

- Long duration operations (typically months) are highly sensitive to weight and tend to rely on solar power.
- The thinner the atmosphere, the more difficult it becomes for operations that rely on lift to maneuver.
- Super and hypersonic aircraft have narrow viable speed ranges (also known as the "coffin corner") and large turning radii.
- Operations that rely on buoyancy have limited control and maneuverability at all altitudes, including higher airspace, unless an engine is present (e.g., airships).

Anticipated Service Implications

The low atmospheric density characteristic of higher airspace and the unique vehicular performance adaptations for coping with it, pose challenges for an air traffic management system built to accommodate a relatively homogenous fleet of maneuverable and responsive aircraft. However, while some operational characteristics may make air traffic management more challenging, others may actually make it easier. The following categorizes features associated with higher airspace and its anticipated operations by their expected impact on ATM:

- Positives
    - The lack of convective weather and jet stream increase operational predictability.
    - The preponderance of unmanned operations would result in less severe collision outcomes.
    - Technologically advanced operators are likely to be able to coordinate well with other operators.
- Negatives:
    - Weight-sensitive vehicles, with limited onboard equipment and power, will limit options for ATM integration.
    - Handling off-nominal situations with unmanned operations may be more complex.
    - New airspace needs associated with constellations of loitering vehicles will challenge established norms.
    - The inability to rely on tactical or last-resort collision avoidance will require deconfliction in advance (strategic planning).
    - Single-use and novel vehicles challenge standard safety practices associated with airworthiness and equipment certification that enable integration.

User Expectations

The most successful service models are informed by user expectations. Fortunately, ICAO has outlined a set of civil aviation user expectations. They can be found in Appendix B of Document 9854, *Global Air Traffic Management* [4]. Not all elements are of equal relevance to the higher airspace community, as they were developed with legacy operations in mind. Table 2 contains ICAO's description (in italics) with a brief discussion of each expectation's applicability to the higher airspace environment. An additional element, not a part of ICAO's original list, but specific to the higher airspace community is included in the last row of the table.

Table 2. ICAO User Expectations and Higher Airspace Application

ICAO User Expectations	ICAO Definition	Higher Airspace Adaptation
Safety	*Safety is the highest priority in aviation, and ATM plays an important part in ensuring overall aviation safety.*	The concept of safety may need to be reimagined when interactions only involve unmanned vehicles.[6]
Global Interoperability	*The ATM system should be based on global standards and uniform principles to ensure the technical and operational interoperability of ATM systems and facilitate homogeneous and non-discriminatory global and regional traffic flows.*	An important factor since operators intend to have missions that span the globe.
Flexibility	*Flexibility addresses the ability of all airspace users to modify flight trajectories dynamically and adjust departure and arrival times, thereby permitting them to exploit operational opportunities as they occur.*	Some users will require this more than others, such as those who are reliant on wind for propulsion or are highly sensitive to wind speed. Mission needs are also likely to require flexibility.
Access and Equity	*A global ATM system should provide an operating environment that ensures that all airspace users have right of access to the ATM resources needed to meet their specific operational requirements and that the shared use of airspace by different users can be achieved safely.*	One of the most difficult requirements to meet given the heterogeneous mix of missions and vehicle performance. It will be particularly important for those operations that transit regions occupied by constellations of on-station vehicles.
Security	*Security refers to the protection against threats that stem from intentional acts (e.g., terrorism) or unintentional acts (e.g., human error, natural disaster) affecting aircraft, people or installations on the ground.*	This is an important concern, given that this region will largely be inhabited by unmanned vehicles; cybersecurity and spectrum security will be vital but not unique to higher airspace.
Cost-Effectiveness	*The ATM system should be cost-effective, while balancing the varied interests of the ATM community.*	The current system (which usually relies on fuel taxes and overflight fees) is not aligned well with the mission lengths or power sources in higher airspace.

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[6] A recent National Academies of Science press release (June 11, 2018) about its prepublication report on *Assessing the Risks of Integrating Unmanned Aircraft Systems (UAS) into the National Airspace System* [5] stated that, "FAA Should Change Its Safety Risk Assessment Approach for Drones to Effectively Integrate Them Into the Nation's Airspace."

ICAO User Expectations	ICAO Definition	Higher Airspace Adaptation
Predictability	*Predictability refers to the ability of airspace users and ATM service providers to provide consistent and dependable levels of performance.*	Trajectories of new vehicles are expected to become more predictable over time. However, the broad range of trajectories is likely to persist.
Capacity	*The global ATM system should exploit the inherent capacity to meet airspace user demands at peak times and locations while minimizing restrictions on traffic flow.*	Airspace capacity is unlikely to be a concern in the near to mid-term due to low traffic levels and natural geographic segregation. Operators who use more than one vehicle per mission, typically networked with their nearby vehicles, may experience capacity constraints.
Participation by the ATM Community	*The ATM community should have a continuous involvement in the planning, implementation and operation of the system to ensure that the evolution of the global ATM system meets the expectations of the community.*	The user community is not anticipated to be large, so this should not be challenging, and could prove to be effective for collaborative strategic deconfliction.
Efficiency	*Efficiency addresses the operational and economic cost-effectiveness of gate-to-gate flight operations from a single-flight perspective.*	Transport operations are likely to value this more than operations that provide other services.
Environment	*The ATM system should contribute to the protection of the environment by considering noise, gaseous emissions and other environmental issues in the implementation and operation of the global ATM system.*	This is not a focus area for operators, as most vehicles with horizontal trajectories in higher airspace are environmentally friendly, with some notable exceptions (sonic booms from Mach travel).
Additional Requirements to Consider (not ICAO)	**Portability** – The system can be accessed from multiple locations on the ground and uses technology and hardware that are readily available to key system users.	

Safety is listed first because the expectation of safe passage is fundamental to the system. New commercial operators and vehicle types are particularly susceptible to repercussions when safety incidents occur.[7]

Safety, quantified as risk, is a continuum. Not all operations have the same level of risk tolerance or aversion. More risk is tolerated when operations are less likely to result in casualties or injuries (e.g., unmanned operations) in the air or on the ground. More risk is also tolerated when transport is conducted for private purposes rather than for hire. This continuum is a fundamental concept that will be invoked when discussing needs and service levels related to ATM components in the next section.

The first column of Table 2 lists the system attributes that all users value in principle and the third column suggests which attributes are most relevant to the higher airspace community. While there may be general agreement among the higher airspace community, getting all stakeholders to agree to a common set of values may be challenging given the diverse mission

[7] A recent example from surface transportation involves the introduction of autonomous vehicles. A fatal accident made national news when a self-driving Uber car killed a pedestrian [6]. However, the other, approximately 6,000 pedestrian fatalities in 2017, involving manned vehicles rarely, if ever, make national headlines [7].

needs of the operators. Even users of today's ATM system rarely share the same values (e.g., general aviation, cargo, and passenger operations have different priorities).

Adding to the challenge, many system attributes are interdependent and an emphasis in one area can reduce performance in another area. For example:

- A secure system may restrict access, have less flexibility and forego interoperability.
- Access and equity may be restricted to ensure safety.
- Increased flexibility may come at the expense of system efficiency and capacity.

To be useful, expectations must be prioritized so that necessary tradeoffs will be guided by what matters most. ICAO recognizes this in its Manual on Global Performance of the Air Navigation System (Document 9883), which advocates a balanced approach in Part I Appendix B, Section 4.1 [8].

Higher airspace user expectations have been prioritized in Table 3. They represent an average of individual rankings derived from two sources:

- Rankings provided directly from several operators. We received rankings from three different vehicle categories.
- A compilation of priorities ascertained from discussions with operators, public statements made by industry representatives on conference panels, and during Aerospace Industry Association meetings.

Expectations were ranked using one of three values: high, medium and low. Priorities may change over time; the prioritization of user expectations in Table 3 represents a mid-term (ten years out) outlook.

Safety, global interoperability, access and equity, and flexibility ranked the highest, with safety being a unanimous priority. Having stated that, users operating unmanned vehicles in higher airspace may have a higher safety risk tolerance than manned operations. Global interoperability is crucial to many of the business models and also minimizes conflicting vehicle design and equipage requirements. Access and equity will be critical given the diversity in missions and vehicle performance. Finally, flexibility will be crucial since many of these operations do not plan to follow the traditional transport model (people and cargo) but will need to regularly alter their flight plans to respond to winds and business needs.

Table 3. Prioritization of Higher Airspace User Expectations

User Expectation	Averaged Priority*
Safety	1
Global Interoperability	2
Flexibility	4
Access and Equity	4
Security	5
Cost-Effectiveness	5
Predictability	5
Capacity	5
Participation by the ATM Community	7
Efficiency	7
Environment[8]	8

* Range is from 1 to 9

Traffic Management in Higher Airspace

Air traffic management services have evolved to serve legacy operations below 52,000 feet.[9] As a result, these services are not as well-suited to serve the unique vehicles and missions planned for higher airspace. This section provides an overview of how current ATM services could be adapted to the higher airspace environment.

The seven traffic management components identified by ICAO's GATMOC were used to frame the evaluation. For those components relevant to higher airspace, varying levels of service are identified along with qualitative triggers for additional services.

Adapting Traffic Management to Meet the Challenges of Higher Airspace

The traffic management implications referred to earlier suggest that it would be ineffective to rely heavily on tactical separation provision and last resort collision avoidance in higher airspace. Tactical separation rests largely on a vehicle's ability to deconflict trajectories via maneuvering. Most vehicles in higher airspace will have a limited range of maneuverability. Last resort collision avoidance relies on the operator's situational awareness (visually or though technological aids akin to Traffic Collision Avoidance System) to see (or detect) and avoid. The majority of higher airspace operations will not have an onboard pilot and will need to limit equipage (due to weight sensitivity), leaving few, if any, feasible options for last resort collision avoidance.

This leaves strategic trajectory deconfliction as the primary mechanism for managing traffic in higher airspace. Given the relatively low number of operations anticipated through the mid-term, there should be enough airspace capacity to safely accommodate operational demands, while still

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[8] This ranking is more likely a reflection of vehicles that already incorporate environmentally friendly features, as opposed to a reflection of value or importance.

[9] According to the ICAO GATMOC Air Traffic Management is defined as "the dynamic, integrated management of air traffic and airspace – safely, economically, and efficiently – through the provision of facilities and seamless services in collaboration with all parties."

offering mission flexibility. The lack of convective weather in higher airspace increases predictability and allows for more accurate trajectory estimates.

To this end, operators could indicate their "intent to fly" and "request" airspace surrounding a 4-D trajectory in advance, as long as it does not conflict with other trajectories. This would be similar in effect to implementing a Temporary Flight Restriction (TFR), an altitude reservation (ALTRV) or activating another type of Special Activity Airspace (SAA) but more dynamic in nature. The amount of airspace reserved would vary with the certainty and timing associated with a given operation's trajectory. Trajectory separation requirements would be determined by assessing the performance of the interacting operations (i.e. speed, maneuverability, equipage, communication latency, etc.). Initially, distances would be substantially buffered in time and space. But as operational experience accrues, and technology improves, the buffers could be reduced. The advantage in this stratum of atmosphere is there are fewer operators that would need to avoid this temporary airspace activation. This activation could be more time sensitive based on the launch parameters/planned departure time for this same reason. Figure 3 illustrates notional airspace needs and buffers. The black buffer reflects the minimum vehicle performance buffer, whereas the green line reflects a trajectory and speed-based buffer relative to other operations. Procedural separation would be used during off-nominal events, enhanced by technology and automated position reporting to confirm route conformance.[10] For operations that do not know their full intended trajectory or timing prior to their mission start (because some missions last for months), an initial trajectory (flight plan) would be required, but amendments could be allowed in areas where no other operations would be adversely affected.[11]

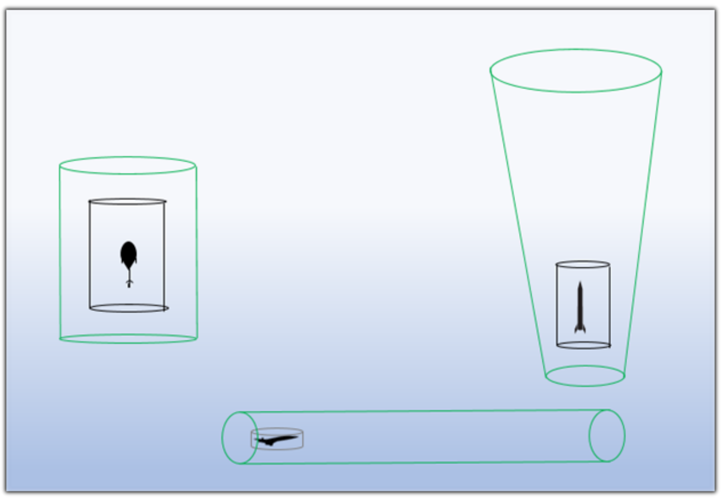

Figure 3. Notional 4-D Trajectory Airspace Buffers

Applicability of ICAO's Traffic Management Components

ICAO's air traffic management operational concept describes the services that will be required to operate the global air traffic system up to and beyond 2025. As noted earlier, ICAO identified seven interdependent system components that make up the GATMOC of the future. Together these components describe how ATM will act directly on the flight trajectory of a manned or

[10] Procedural separation could be used because it meets operational requirements, and relative to other methods, it is easy to implement and does not require a large investment in supporting infrastructure.

[11] This is similar to current traffic management practices, whereby placeholders are entered 24 hours in advance into the Aggregated Demand List. A series of triggers update the flights intent, such as the filing of a flight plan.

unmanned vehicle during all phases of flight, and the interaction of that flight trajectory with any hazard.

By emphasizing global ATM components and services, ICAO avoids complications associated with boundaries (political and/or airspace). This approach facilitates the evolution of an integrated, harmonized and globally interoperable system. The ICAO GATMOC defines the following system components:

1. Conflict Management
2. Airspace Organization and Management*
3. ATM Service Delivery Management
4. Airspace User Operations
5. Demand and Capacity Balancing*
6. Traffic Synchronization*
7. Aerodrome Operations

* Indicates components that ICAO considers an integral part of conventional Strategic Conflict Management, but that relationship does not necessarily hold for higher airspace

The scope of this paper is limited to operational needs in higher airspace, and therefore does not include transiting to or from that region. As a result, aerodrome operations are considered out of scope and are not addressed.

The remainder of this subsection elaborates on each of the individual components, outlining what services already exist in higher airspace and what may be needed in the future. When applicable, the associated level of service is identified, as well as qualitative triggers for when those components would be needed.

Conflict Management

Applicability*:* This is a core requirement of any traffic management system. ICAO's conflict management component is made up of layers, which together form a multi-level approach to safety and separation assurance. The layers include: 1) Strategic Conflict Management, 2) Separation Provision (tactical), and 3) Collision Avoidance (last resort).

For the reasons provided earlier, tactical and last resort collision avoidance cannot be relied upon in the higher airspace environment. Instead, to the extent possible, separation assurance should be determined strategically to prevent encounters between vehicles. This does not preclude the need for a viable secondary collision avoidance mechanism in the case that the primary mechanism fails.

ICAO's vision of strategic conflict management (made up of three other components: airspace organization and management, demand and capacity balancing, and traffic synchronization) does not quite align with the expected environment and will need to be tailored to the higher airspace region. The applicability of the three associated strategic components is addressed in subsequent sections.

Current Level of Service: In the U.S., the three levels of conflict management are procedurally addressed in the following ways:

1. Strategic Conflict Management – Typically handled on an ad hoc basis, usually via airspace management tools, to separate commercial space launch and reentry or other

hazardous operations from other vehicles. In the past, specialized routing was used to support supersonic flight across the Atlantic Ocean.

2. Separation Provision – Generally IFR traffic are handled on a first come, first served basis, with some exceptions provided in FAA JO 7110.65 2-1-4 (Operational Priority). In addition, JO 7110.65 offers IFR separation criteria applicable to higher airspace aircraft including: vertical (4-5-1), lateral (5-5-4) and airspace (9-3-2).
3. Collision Avoidance – Title 14 Code of Federal Regulations Part 91.113 requires vehicles with superior maneuverability to take evasive action.[12]

Triggers for Additional Service: Acceptable level of collision risk plays a large role in determining the degree of conflict management services. As the variables that impact collision risk change over time (e.g., trajectory predictability, number of operations, presence of manned operations), the appropriateness of the conflict management system should be reviewed.[13]

In the future, automation may offer a way to provide conflict management services to particularly challenging areas of the NAS. For example, higher airspace and near ground level airspace are two areas which could eventually benefit from automation. It may also help supplement conventional air traffic control, as traffic complexity and levels continue to increase. In the far term it is possible that advanced automation could fulfill all roles.

Airspace Organization and Management

Applicability: Airspace organization and management is expected to play a vital role in safely managing the anticipated operational diversity and ensuring global interoperability in higher airspace.

Current Level of Service: Segregating high-speed vertical operations from other operations, using SAA, is currently the tool of choice that will likely see continued, if not increased use. Ideally, as more experience is gained with vehicle operations, the amount of airspace blocked will be reduced in both size and duration.

Triggers for Additional Service: A preliminary risk assessment performed by MITRE indicates that the near-term (2025) risk of a collision in higher airspace is extremely unlikely [9]. However, as traffic density increases, and supersonic and/or hypersonic manned flight begin to take place overland, changes to airspace classification and the addition of structure (via charted high-altitude routes) may be warranted. Supersonics pose two challenges that airspace structure and management could potentially mitigate, their extreme speed compared to other operations, and the increased risk due to the presence of human life.

Any airspace classification change (which could involve an existing or a new airspace class) would need to complement conflict management service levels (discussed in the previous section). The addition of airspace structure could be used to minimize the comingling of high and low speed horizontal operations, offering predictable routes or corridors for manned traffic (to reduce collision risk), that balloons and other slow-moving operations would avoid when activated. An example of organized flow management might look like the North Atlantic Organized Track System and the Pacific Organized Track System where routes are developed

[12] This has equity implications as well, as less maneuverable vehicles such as UFBs can take advantage of this hierarchy to prioritize their use of the airspace.

[13] Service providers like the FAA have begun to proactively identify safety risk. A formal methodology, Safety Risk Management, exists to evaluate airspace changes.

and published daily via Notice to Airmen (NOTAM). They are located to take advantage of winds while maintaining lateral separation between the tracks to minimize conflicts and complexity, and to maximize capacity and efficiency. For higher airspace purposes they may be fixed in location, but only activated when needed via a NOTAM. For example, because the Concorde flew above the jet stream, only two tracks were created for it (one eastbound and one westbound), thereby eliminating the daily need to optimize for wind.

New airspace tools may also be needed to more flexibly and dynamically handle the hazard areas below some operations, particularly those associated with launch and reentry activity (e.g., activate protective corridors established for the launch duration and then deactivate them once the airspace volume is no longer required). The airspace deactivation could also be done in sections or layers after the vehicle transitions through them to minimize the impact to nonparticipating aircraft and/or other vehicles.

Airspace User Operations

Applicability: The diversity of vehicles and missions expected in higher airspace make this ATM component particularly relevant. The ability to safely accommodate different vehicle capabilities and planning horizons will be crucial to any higher airspace ATM system. Of the attributes ICAO associates with this component, perhaps the most salient is the "limited ability of some vehicles to dynamically change trajectory." In higher airspace, limited tactical maneuverability will be the rule rather than the exception.

Current Level of Service: In the U.S., the FAA is in the process of better understanding the operational needs of new entrants. Multiple Aviation Rulemaking Committees have been formed including Unmanned Aircraft System (UAS) in Controlled Airspace, Part 101, and Airspace Access Priorities. Equipage requirements vary depending on how vehicles are regulated. This currently creates an inconsistent environment for delivering ATM services.

Vehicle licensing and airworthiness certification are frequently used to ensure compatibility with ATM operations. In situations where there is no standardized path for new or novel vehicle types, proponents must obtain special permission/exemptions to waive regulatory compliance, and a corresponding certificate of authorization. This process can be cumbersome and costly depending on the safety data required of the proponent.

Triggers for Additional Service: Once at altitude, the higher airspace community will face minimal integration concerns, as they will be among the first commercial operators to routinely operate in this airspace.[14] Instead, the focus will be on how the system can safely accommodate extremes in performance (e.g., an unmanned free balloon and a supersonic business jet). New services and/or procedures will be triggered as risk increases, which will generally coincide with manned flights and incompatible vehicle performance characteristics.

ATM Service Delivery Management

Applicability: Increased reliance on strategic conflict management for collision prevention will amplify the importance of the situational awareness and collaborative decision-making aspects of this component.

[14] As is true for the legacy NAS, measures will need to be taken to ensure that civil operations pose minimal impact to defense related missions.

Current Level of Service: Under the FAA's Aeronautical Information Management Modernization Program (AIMM), the Aeronautical Common Services (ACS) capability serves as the single trusted source for Aeronautical Information, including SAA information. The real-time availability of SAA status and schedule information is currently under development. Planned functionality includes SAA legal descriptions and TFR/ALTRV NOTAM information [10]. The ACS uses the System Wide Information Management (SWIM) services to disseminate SAA data, allowing NAS users the opportunity to view the dimensions and active status of all SAA in the NAS. The data contained within these systems could potentially be used for scheduling and strategic deconfliction in the higher altitude stratum.

Triggers for Additional Service: As traffic density and diversity increases, the need to coordinate traffic trajectories will increase. In the near term, collaboration tools for space operations, such as the Information Sharing Capability, could be expanded to serve the higher airspace community. In the mid-term, operations could signal intent through trajectory-based operations (TBO) as part of the strategic conflict management process. This will be especially relevant for long duration missions where strategic conflict management occurs when a vehicle is already on mission in higher airspace.

Demand and Capacity Balancing

Applicability: Demand is unlikely to routinely exceed higher airspace capacity in the near to mid-term. Notwithstanding, temporary constraints may arise in busy corridors. For example, the region between Florida and Puerto Rico, regularly hosts commercial space launches, Department of Defense (DoD) operations and high-altitude balloons. In the future, this busy international corridor may also see supersonic and airship activity.

Current Level of Service: Due to the rare and impromptu nature of imbalances, this is largely an ad hoc process that is not handled consistently across the NAS. At present, airspace capacity shortages are most associated with SAA that is being used for commercial space launch. To alleviate capacity shortages, the Air Traffic Organization (ATO) has developed guidelines, based on five different mission categories, to help determine the level to which SAA use can disrupt the activities of other airspace users. Airspace use associated with commercial launch and reentry (including tourism) ranks the lowest.

Should ongoing mission operations need to be strategically deconflicted, a priority scheme similar to the ATO guidelines is likely to be employed, whereby DoD operations take precedence over commercial operations. However, DoD missions may also choose to deconflict, assuming they have advanced knowledge of the commercial operator's intent.

Triggers for Additional Service: In the next ten years competition for the same airspace should rarely occur because operator's missions and vehicle characteristics will naturally segregate the operations. For example:

- Fast moving horizontal trajectories of super and hypersonic aircraft operations will generally be found over international waters as these operations aim to reduce travel time between continents (this also minimizes noise impact[15]).

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[15] Commercial operations traveling over Mach 1 are currently prohibited overland in the U.S., per 14 Code of Federal Regulations Part 91.817.

- Fast moving vertical trajectories associated with commercial space operations will occur in coastal regions over international waters and from inland spaceports within developed economies.
- Slower moving and station-keeping telecommunication vehicles using unmanned aircraft, airships and balloons will be concentrated over developing economies near populated regions.

There may eventually come a time when vehicles' airspace needs routinely conflict. Given the relatively small number of operators, it would be preferable for the users to collaboratively develop procedures, in partnership with service providers, to balance capacity and demand.[16] The concept would be similar to what the collaborative decision making (CDM) community has done with ground delay programs and en route flow constrained areas.

Traffic Synchronization

Applicability: This component has limited relevance in higher airspace because the tactical sequencing and spacing to maintain an orderly flow of traffic is unlikely to be needed in the near to mid-term given the absence of structured routes and congested airspace. Even if the need arose, many vehicles would not be able to maneuver well enough for it to be effective.

Current Level of Service*:* Traffic synchronization is not routinely needed to manage operations in higher airspace today. If and when the need arises, it is handled manually.

Triggers for Additional Service: In the near to mid-term, it is unlikely that higher airspace will become so congested as to require routine traffic synchronization. It is possible that points of ingress and egress into higher airspace (akin to choke points) could become constrained requiring a method for synchronization or scheduling.

Summary

In Table 4, we present ATM components through the lens of the user community, synthesizing the analyses from the previous sections. User expectations are grouped in descending order of priority and shaded based on the priority level (described earlier). The traffic management components are also ordered, starting with the most important based on applicability to higher airspace. The table offers a relative ordering, with the upper left-hand corner boxes representing the key expectations and most relevant traffic management components. Conversely, the lower right-hand corner, represents less pressing expectations, and less germane traffic management components.

Note that for the most part, the lowest priority expectations intersect with the least applicable traffic management components. Whereas, the highest priority expectations are generally aligned with the most essential traffic management components.

[16] The impact on legacy traffic below and DoD operations must also be factored into requirements.

Table 4. Global ATM Components and Prioritized User Expectations

Traffic Management Component *(ranked by descending importance)* / **User Expectations**	**Safety**	**Global Interoperability**	**Flexibility**	**Access & Equity**	**Security**	**Cost-Effectiveness**	**Predictability**	**Capacity**	**Participation by ATM Community**	**Efficiency**	**Environment**
	High Priority			**Medium Priority**					**Low Priority**		
Conflict Management	●			•							
Airspace Organization and Management	●	●	•	●			●	●			●
Airspace User Operations	●	●	●	●		•	●				
ATM Service Delivery Management	●				●	●			●		
Demand and Capacity Balancing				●			●	●	•	●	
Traffic Synchronization								●		●	

● Primarily contributes to meeting user expectation

• Secondarily contributes to meeting user expectation

Concluding Remarks

For this analysis, an existing ICAO framework was leveraged as a way to systematically evaluate and prioritize traffic management components. It is important to note that this study is not advocating a particular solution or concept, but rather exploring options to determine what traffic management components would be of most value as needs in this region evolve.

This work focused on nominal operations, however both nominal and off-nominal operations will need to be considered once a concept of operations is established, and a safety case will be needed to support it. A more nuanced approach to off-nominal operations may be needed as not all off-nominal situations will pose a risk to humans in the air or on the ground.

In the meantime, much can be done on an operational level to improve access and situational awareness in the immediate future. Work should be undertaken to enable operations in the near term by leveraging operator use cases, existing research, and existing capabilities.

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