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Integrating Orbital Carrying Capacity into International Policy Constructs: Leveraging best practices from aviation's risk-based norms

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Abstract

This paper proposes modeling an orbital altitude-based "LEO Class" based on aviation's Airspace Class approach that considers traffic volume and complexity in establishing entry requirements for particular airspace volumes. Orbital capacity, like airspace capacity, should consider the characteristics, behavior, and capabilities of objects operating at particular altitudes coupled with the precision and accuracy of space situational awareness. Carrying capacity at its core is a safety metric, improvements in collision avoidance capability, including SSA and maneuverability, can increase the carrying capacity of a specific orbit, but may be constrained by the least capable actors.

For aviation, the requirement to accommodate various airframe types, from experimental home-built aircraft to advanced airliners, operating in airspace ranging from low density to highly congested, led to the existing international framework for aviation safety, using a well-organized set of airspace classes. The aviation framework of Airspace Class establishes performance standards for entry into a specific airspace volume by considering the complexity, congestion, and risk in the airspace volume itself. Higher airspace classes have higher entry requirements to mitigate collision risks while airspace volumes with lower collision risk remain accessible to lessor equipped operators through lower entry requirements. Airspace Class is clearly defined and transparently disseminated, allowing operators to self-select operating zones according to their willingness and ability to fulfill entrance criteria. Orbital altitude-based approaches, defining LEO Classes using Airspace Class as a model, complement ongoing efforts, like the Space Sustainability Rating (SSR), and provide a necessary incentive structure to accelerate acceptance and codification of norms of behavior in space. This proposal suggests implementing higher safety requirements for altitudes where resident missions are paramount, and mishaps have more significant consequences.

In this scenario, “consequence” encompasses the immediate risk to generate debris, the potential for collision with operational missions, and the long-lasting nature of this collision threat. Debris persistence is a distinctive aspect of space safety compared to aviation. A combined LEO “Airspace” protocol and tools like the SSR framework may contribute to better defining the essential safety requirements and incentivizing responsible behavior. Modeling an existing globally harmonized approach can provide a path to achieve safe space sustainability goals.

While norms of responsible behavior must encompass equitable access for established and nascent space actors, adopting a uniform framework that applies to all orbital paths may result in the establishment of inadequately low performance thresholds in congested orbits which affects risk, or excessively stringent criteria in sparsely utilized orbits which inhibit experimental endeavors and innovation. An orbital classification system mitigates these risks by creating clearly defined requirements for specific orbital ranges rather than attempting to develop one standard that applies to all orbits.

Keywords: Keywords: orbital classification, LEO Class, space situational awareness, carrying capacity, collision avoidance, space sustainability.

1. Introduction

As low earth orbit (LEO) continues to become more and more complex, the need for a robust and adaptive framework to manage orbital traffic is becoming increasingly critical. This paper proposes adopting an orbital altitude-based "LEO Class" system modeled after the aviation industry's Airspace Class approach to address this necessity. The Airspace Class system in aviation effectively manages traffic volume and complexity by establishing specific entry requirements for different airspace volumes. Similarly, an orbital classification system can enhance space safety and sustainability by tailoring requirements to the unique characteristics and capabilities of objects operating at various altitudes.

Carrying capacity is central to aviation and space operations, serving as a fundamental safety metric. In the context of LEO, carrying capacity is influenced by collision avoidance capabilities, space situational awareness (SSA), and the maneuverability of space objects. Incorporating these factors into an altitude-based classification system that optimizes the use of orbital space and maintains safety by minimizing collision risks is possible.

In the aviation sector, the need to accommodate a wide range of aircraft, from experimental home-built planes to sophisticated commercial airliners, led to the development of a comprehensive international framework for airspace safety. This framework, which includes various Airspace Classes, sets performance standards for entry into specific airspace volumes based on the complexity, congestion, and risk associated with those volumes. Higher airspace classes require stricter entry requirements to mitigate collision risks, while lower classes remain accessible to less equipped operators.

Applying this approach to LEO, we propose the creation of LEO Classes that define performance standards for different orbital altitudes. This system would complement existing initiatives, such as the Space Sustainability Rating (SSR), by providing a clear incentive structure for adopting and codifying responsible behavior in space. Higher safety requirements may be necessary for altitudes where the consequences of mishaps are more significant, encompassing debris generation, collision potential with operational missions, and the persistence of collision threats. The development of risk models necessary to determine airspace class will require the contribution of experts and broad community engagement, this framework can serve to facilitate the development of standards to be made available to states in exercising their authorization and supervision functions.

In contrast to aviation, where debris typically poses a short-term hazard, space debris remains a long-lasting threat, necessitating a unique approach to space safety. While ensuring equitable access to space for both established and emerging actors is essential, a single framework for all orbital paths may lead to overly lenient performance thresholds in congested orbits, increasing risk. Conversely, excessively stringent criteria in sparsely utilized orbits excludes many non-commercial users, including academia, and can hinder innovation. An orbital classification system addresses these concerns by establishing precise, altitude-specific requirements for entry, fostering a safer and more efficient space environment.

Existing literature contains some generic definitions of orbital carrying capacity that center around the principle of a definable, measurable, metric of the volume of space objects (including satellites and debris) that can safely orbit the Earth without increasing the likelihood of collisions past an acceptable level of risk [1] others define it in terms of the the maximum expected population of satellites that is sustainable [2]. Some arguments focus on the finite nature of congested orbits [3]. The most relevant defintion of orbital capacity for this paper comes from an opinion article by Lifson and Linares who state, "Orbital capacity is not a number of satellites, but rather a set of bounds on where, how, and how densely satellites make use of orbital volume**.** Multiple factors, not a straightforward number of satellites, limit orbit use and delineate the set of possible futures with allowable consequences." [4] This paper argues that orbital carrying capacity is more akin to the carrying capacity of airspace volumes, where the capacity of a given volume of airspace is increased by improved required performance of communication, navigation, and surveillance and that performance requirements are established based on risk metrics. The well-established and internationally harmonized airspace classification system can provide a conceptual model for congested orbital regimes based on safety metrics (Fig. 1)**.**

This model presents a possible structure for organizing our approach to orbital capacity and developing adoptable norms of behavior for low Earth orbit. As a starting framework it can provide structure to organize stakeholders and experts around areas of common concern, or communities of interest, to further refine and develop the approach into one that supports the unique characteristics and demands of the space community.

Like airspace, the physical volume of an orbital regime is finite, but the capability of an object and the characteristics of objects occupying that orbit affects the carrying capacity. A risk-based orbital classification framework that defines entry requirements and surveillance capability can serve to increase the carrying capacity of high demand orbits. This classification approach uses the model used in international aviation for airspace classification that has safely increased the carrying capacity of high demand airspace. Airspace complexity is largely driven by commercial demand, where entry requirements are highest in areas where aircraft operate at high speeds, where visibility may be limited, and in the vicinity of major airports. For orbital class, the metrics may consider the number of satellites present, overall mass on orbit, constellation size, and persistent debris.

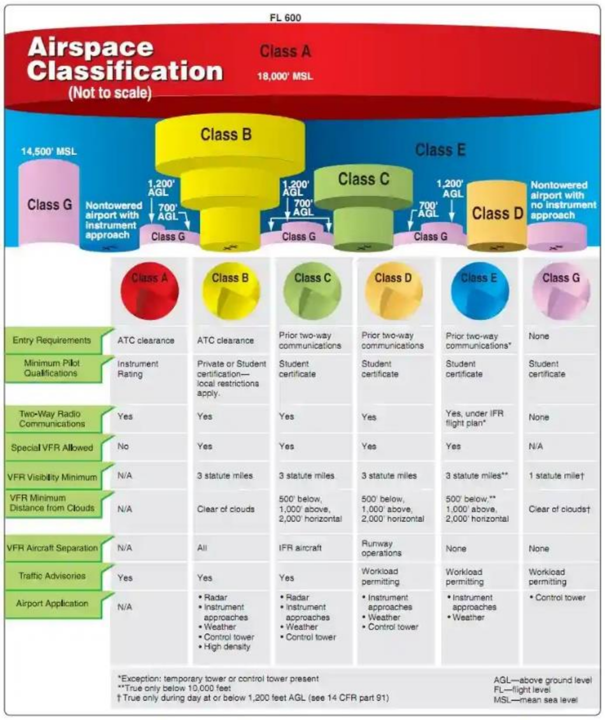

Fig. 1: US airspace classification chart (source: Federal Aviation Administration)

This graphical presentation of a notional orbital classification model (Fig. 2) considers the range of conditions in LEO and presents a construct that is further described in Appendix B.

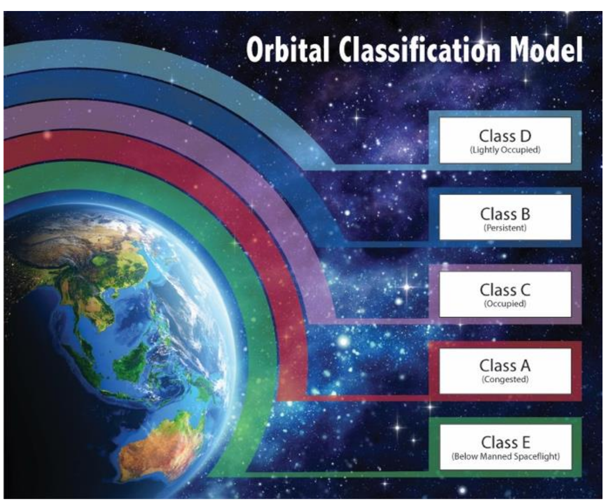

Fig. 2: Illustration of Notional Orbital Classification Model

2. Background on Aviation's Risk Based Airspace Classification

Approaches that advocate for creating limits on orbital access require an assumption that there is not only a desire to limit access, but that a globally respected norm to respect access restrictions is attainable and enforceable. This limitation has been recognized by international bodies in other discussions; for example, the Secretary General of the International Telecommunications Union (ITU) stated that voluntary commitments and guidelines to mitigate the threat of orbital debris is not sufficient [5]. This would require a mature regulatory state that does not yet exist in the space domain. However, even in the aviation domain, where a mature regulatory state exists, the efficient use of airspace has long been a priority; efficiency seeks to increase capacity rather than restrict access.

2.1. Mature regulatory state

The modern modeling approach for airspace capacity management (Fig. 3) has evolved over time, as demand increased, is further along the international regulatory path than the global space community, and includes controls that are not available in space traffic management. However, the approach used by the aviation community may be instructive. The model offered in figure 3 is widely adopted by civil aviation authorities around the world to determine the capacity of a specific volume of airspace. The capacity influencing factors are the variable inputs that can be altered to increase system performance.

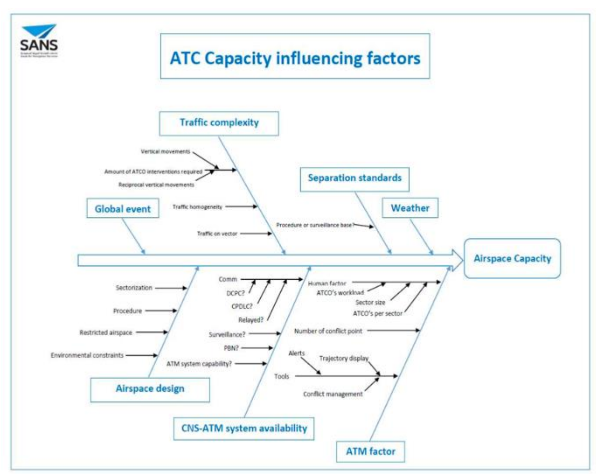

Fig. 3: Factors affecting airspace capacity (source: Saudi Air Navigation Services from ICAO documents)

This type of analysis is used to establish the capacity for defined airspace volumes and serves to identify trigger points for the implementation of traffic flow management initiatives that limit the number of aircraft entering a given airspace volume. This represents a very mature state and requires regulatory authority to restrict traffic. The orbital domain is not at this stage and efforts to implement capacity restrictions on a global basis are unlikely. However, it is useful to examine the early steps to organize airspace to increase safety and capacity to determine where aviation models may be useful to guide the thinking in the space community moving forward.

2.2. Globally Harmonized

A significant advantage of the orbital class approach is that it mirrors one that is globally harmonized and developed within an international framework. Each of the 192 contracting states to the International Civil Aviation Organization (ICAO), the UN specialized agency for aviation, has adopted the airspace classification standard but retains sovereign authority over where each class is applied within their borders. The useful parallel for the space community lies not in the level of services provided, but in the entry requirements established to operate within each airspace class. The adoption of the current classification standard harmonized State based classification models to ensure a common understanding of requirements for international operations. The preceding classification constructs were built on similar principles but lacked common terminology and included minor variations in requirements. Adopting a common classification standard served to improve transparency and provided associated safety benefits. These entry requirements apply equally to airspace users, with the exception of limited state operations operating under the construct of due regard, are not considered in conflict with the concept of freedom of access.

2.3. Airspace Classification

Airspace classification served as an initial step in organizing airspace from a safety perspective. The higher probability and consequence of collision varies by airspace density and user type. In order to manage the variable safety risk, aviation has adopted a set of globally harmonized airspace classes that set clear entry and equipment requirements based on airspace class, where the higher class of airspace has the more restrictive entry requirements (Fig. 1). This approach does not deny access to the airspace, rather it permits access to all operators who meet the safety-based entry requirements. The classification of a particular volume of airspace can change based on new operational demands and considers: the level of service available, safety relevant incidents, traffic volume, traffic concentration, traffic mix, and unique or particular operations [6].

Within a given airspace class, additional communications, navigation, and equipment requirements may be established to safely allow greater concentrations of traffic in high demand areas. While airspace class is delineated based on controlled and uncontrolled, the principle of agreed upon entry requirements based on orbital risk can be considered absent a controlling entity. The concept of entry requirement allows States to use the regulatory tools of launch approval and continuing supervision to ensure that operators are appropriately equipped and capable to meet the requirements of their anticipated mission orbit.

Rather than a model centered around airports, the orbital domain is distinguished by altitudes with variable density and risk factors. In addition to evaluating the current state, this approach considers how future activity may affect the classification of a particular orbit, which may be a consideration in long term planning for mission approvals and diplomatic discussions.

2.4. Surveillance and airspace capacity

For aviation, airspace capacity is constrained by the separation standard. The separation standard is the required distance between two aircraft to ensure safe operations. This standard is based on the precision of position information, defined by the performance of the two-way communications, surveillance infrastructure, and airborne navigation precision, for space operations this concept would be the characterization of the risk tolerance in a conjunction assessment.

The North Atlantic Organized Track System is an important reference model for the space community. In addition to being the most congested oceanic airspace in the world [7], it is international and high seas airspace, subject to the principles of freedom of overflight and is not subject to claims of sovereignty. In addition, the airspace is not under radar coverage, but improvements in the capability of aircraft operating in the airspace has allowed for the reduction of separation distances over time, based on clearly articulated performance standards [8]. Access to specific and desirable tracks is predicated on meeting performance standards.

The introduction of surveillance in an airspace volume produces the most significant increase in airspace capacity as it improves the quality and precision of aircraft position information. Either radar or Automatic Dependent Surveillance – Broadcast (ADS-B) can allow the separation standard on a route to reduce from 120nm to 5nm, increasing both airspace capacity and efficiency.

This has clear parallels to the orbital regime and how improved SSA capabilities can improve risk modeling. Uncertainty of the location of other satellites or debris does not change the absolute risk of collision but does increase the error ellipse in calculating the probability of collision, a factor in the decision to execute an avoidance maneuver. More accurate information on the position and intent of other satellites and debris can affect the behavior of individual operators and provide a basis for the introduction of entry requirements for operators based on the risk characteristics of the specific altitudes. The process of adopting a common classification standard will take time, however, staged implementation reflecting the safety and capacity interests may provide a way forward by identifying emerging norms in particular orbits.

While there is no controlling entity that restricts access, a risk based orbital classification used to develop standards for maneuverability and debris generating behavior may provide a path toward globally recognized and ultimately harmonized standards within the orbital domain. An increase in effective and implemented standards could lead to an increase in orbital carrying capacity but can also serve to identify higher risk orbits that may support operator self-selection to lower risk orbits. This behavior is already emerging as evidenced by the advanced collision avoidance capabilities deployed onboard satellites in large constellations.

3. The Changing Orbital Domain

Broadly considering orbits in the categories of Low Earth Orbit (LEO), Medium Earth Orbit (MEO), and Geosynchronous Orbit (GEO) does not provide sufficient granularity for an effective classification system. The debris distribution in LEO [9] illustrates that a risk-based classification regime would support different categories of orbital classification within the LEO range (Fig 4).

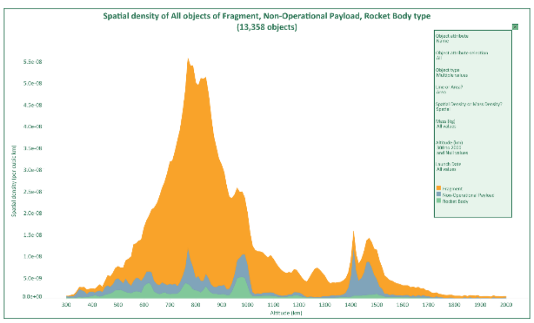

Fig. 4: Debris distribution in LEO (source: LeoLabs LeoCat Tool)

In addition to the growing and persistent problem of space debris, the last decade has seen an unprecedented number of satellites launched into Earth's orbit (Fig. 5) [10]. This increase in number is almost entirely attributable to the introduction of large constellations. The number of satellites alone is not an adequate measure of orbital risk. It is important to factor the size, mass, maneuverability, and lifespan of the satellites in a particular orbit.

[*] A larger representation of figure 6 is available in Appendix C.

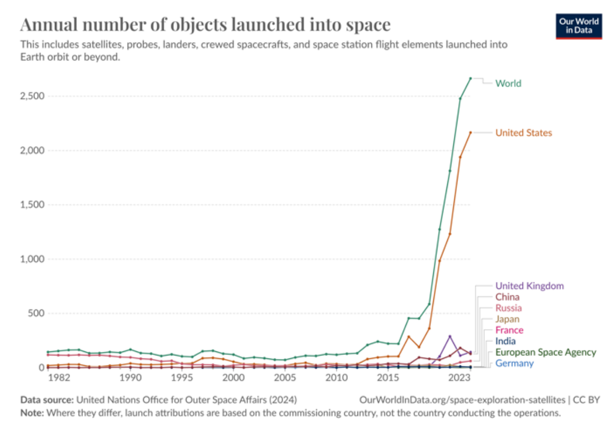

Fig. 5: Annual objects launched into space (source: Our World in Data)

While the thesis of this paper is that certain regions of earth orbit could be characterized as having different levels of requirements to operate in each region, low Earth orbit (LEO) is already almost striated into "neighborhoods" as depicted in Figure 6. These neighborhoods are largely differentiated by the concentration of object types (i.e., fragments, operational payloads, and intact derelicts).

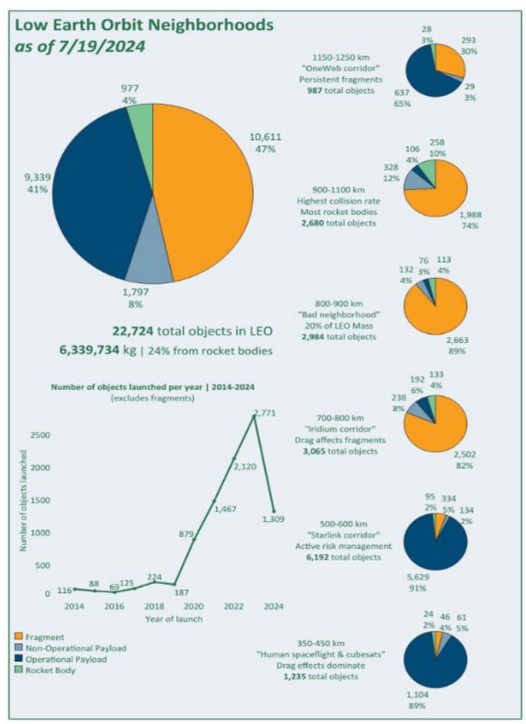

Fig. 6. LEO is already segmented into "neighborhoods" based on demographics of certain 100 km altitude bins (Source: LeoLabs LeoCat tool)[*]

The “neighborhoods” from lowest altitude to highest are epitomized by:

- Human spaceflight and CubeSats neighborhood has two large space stations and hundreds of non-maneuverable but operational CubeSats – atmospheric drag rapidly removes fragments and intact hardware;
- The Starlink corridor is characterized by the largest density of operational spacecraft but these satellites are exceptional at mitigating collision risk between each other and the resident space object population – atmospheric drag cleanses this region of derelict debris (both fragments and intact hardware) fairly quickly;
- The iridium corridor has one major operational constellation but a significant amount of fragmentation debris from previous breakup events – drag does little to remove fragmentation debris from this region;
- The region from 800 to 900 km is considered the “bad neighborhood” due to both the large number of debris and massive objects residing in this region;
- The altitude bin from 900 to 1000 km has the greatest spatial density of intact derelict objects (i.e., rocket bodies and non-operational spacecraft) leading the greatest collision rate among massive derelicts in LEO; and
- The OneWeb corridor is a “notch” in spatial density of orbital debris that OneWeb and several other future constellations are looking to deploy – this region is low risk for now but any fragmentation event here would have the remnants linger for centuries.

Operational spacecraft must be able to avoid derelict objects and other operational spacecraft already deposited in certain regions either by previous missions or due to orbital decay from higher altitudes. A risk-based orbital classification considers both the debris risk and the ability of the operational satellite to avoid the collision risk. The issue of maneuverability is key to orbital capacity modeling and, therefore, to any cogent classification framework. While risk may change over time, thresholds should be established to ensure standards to manage risk at all altitudes, remembering that many of the objects released in LEO will eventually migrate through lower altitudes as their orbits contract on their way to reentry. As a result, there is a hierarchy of compounding effects in LEO that does not exist in the aviation safety use case. Table 1 details the parameters that might be relevant for the space version of the airspace classes grouped by orbit and object characteristics that are either absolute or relative.

Table 1. Parameters that need to be considered for airspace classes for space applications are related to both the orbital regime and spacecraft operating in a region.

	Orbit	Object
Absolute	Altitude (i.e., persistence)	Mass and AMR Maneuverability (yes/no)
Relative	Spatial density of derelict objects Spatial density of operational objects	Maneuverability (ΔV and responsiveness) Risk tolerance (probability of collision (PC) threshold for maneuver and PC goal for maneuver)

4. Notional Orbital Classification Framework

Before drafting a proposed framework of “LEO[†] airspace” classes, as illustrated in Appendix B, it is instructive to examine several use cases that drive this development:

- Operational spacecraft have a greater duty to conduct responsible, safe space operations when they deploy to altitudes that have a significant number of operational spacecraft already using that region and when the remnants of any derelict deposition have a greater orbital lifetime (i.e., low area to mass ratio and high altitudes).
- There has been a migration to lower altitudes by many of the newly deployed constellations probably largely based on the goal of being naturally compliant to the 25-year rule for post mission disposal (PMD). Recent moves to reduce the PMD threshold by the FCC[‡] may encourage constellations to move to even lower altitudes (i.e., below 500 km vs. below 625 km).
- Operational spacecraft must be able to avoid derelict objects already deposited in certain regions either by previous missions or due to orbital decay from higher altitudes. The issue of maneuverability is key to orbital capacity modeling and, therefore, to any cogent airspace classes framework. The table in Appendix A describes a framework for maneuverability motivated and initiated by David

[†] *This paper focuses on LEO scenarios for simplicity. The concepts proposed apply equally well to all orbits.*

Goldstein of SpaceX in his support to Starlink constellation operations.

The table in Appendix A highlights the issue of maneuverability, however the spectrum of maneuverability highlights the flaw in a simple binary status for maneuverability (i.e., yes or no). This model also includes the ability to accept conjunction data messages either manually or autonomously. A system may have de-orbit capability without autonomous ingestion of CDMs, however, lack of maneuverability capability provides an indicator that the system may not execute post mission disposal (PMD) reliably. The maneuverability levels are further differentiated by total ΔV and responsiveness in Table 2.

Table 2: Maneuverability metrics for operational spacecraft

Maneuverability Metrics for Operational Spacecraft			Responsiveness		
			Low > 3 days	Med 1-3 days	High < 1 days
Total ΔV per year of operations	High	> 10 m/s			4,5
	Med	1-10 m/s		3	
	Low	< 1 m/s	2		
	Non e	---	1		

In addition to maneuverability, a spacecraft operator must also characterize its intent to minimize collision risk; the capability to maneuver away from a high-PC conjunction is not sufficient to characterize its intent to minimize collision risk. This risk tolerance has two major components:

- PC threshold that will trigger a risk reduction maneuver (RRM), and
- The PC goal to which the conjunction's PC is abated to by the RRM.

Table 3 provides a proposed hierarchy of risk tolerance families that reflect the range of current risk tolerance levels for operational spacecraft. It should be noted that Starlink's very public adherence to the most stringent requirements (i.e., #5 in Table 2) has resulted in many more RRMs per satellite than other operators. This larger number of RRMs has been erroneously correlated to a higher risk profile while, to the contrary, reflects the commitment of SpaceX to the highest space safety standards. The risk tolerance levels are also incorporated into the draft airspace schema summarized in Appendix B.

Table 3: Collision Risk Tolerance

Collision Risk Tolerance Criteria		PC to Trigger RRM		
		1E-4	1E-5	1E-6
"Abate to" PC	1E-5	Very High 1		
	1E-6	High 2	Moderate 3	
	1E-7	Moderate 3	Low 4	Very Low 5

Collision risk tolerance is a critical component of an operator's ability to safely operate in a congested environment, maneuverability is not sufficient. A higher tolerance to risk is worse and receives a lower score.

As we begin to examine the variables and engage the expert stakeholder community, we will seek to apply specific classes to defined altitudes that have a given demographic. This demographic will change over time so the resolution of how often a certain region of space changes its "orbital class" and the altitude expanse of each of these regions will all have to be considered carefully. This allows the community to identify how an implementation of the LEO orbital class model could emerge by matching the classes to the orbits based on the current state (Fig. 7). Characterizing maneuverability and assigning a performance level, as illustrated in Appendix A, provides clarity in assigning an entry requirement based on ability to maneuver as illustrated in Appendix B. Raising the performance requirement to operate in a specified orbit increases the carrying capacity. However, the risk tolerance for operators is equally as important and can be reflected in both its proposed operational concept of operations but must also be validated by actual performance on-orbit. This validation process is largely performed by regulatory agencies for satellites licensed through the US's Federal Communications Commission (FCC), however, it is unclear how the actual risk tolerance behavior on-orbit is assessed for many of the existing constellations; this is especially problematic for satellites operated by countries that are not very public with the satellite's capabilities, risk reduction procedures, or end of life plans.

Other factors can also be considered when assigning an orbital class, including those external to the operator, like quality of SSA data and available conjunction detection and alerting services. The characteristics developed in the Space Sustainability Rating (SSR) may be instructive in developing entry requirements while the orbital classification may support an incentive structure to encourage its adoption [11].

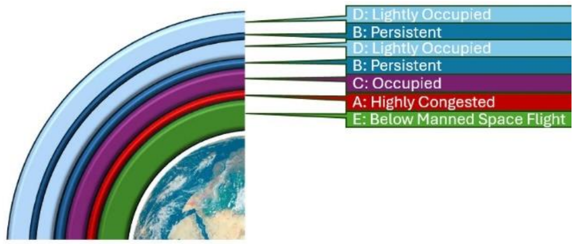

Fig. 7: Notional implementation of Orbital Class Framework

5. Benefits to other Activities

The potential benefits of an orbital classification regime are not limited to controlling the carrying capacity for specific orbital regions. The construct provides a framework to facilitate the capturing of emergent behaviors and developing norms in the context of a safety discussion. Recognizing the shared interest in space safety and sustainability, the orbital classification approach allows for the development of performance standards that are targeted to increase safety and capacity where needed, without the introduction requirements in lower density orbits that may restrict access or impose unnecessary burdens.

5.1. Economic incentives

Entry requirements based on orbital class allows the industry to quantify the benefits (access to preferred orbits) of investment in higher levels of maneuverability. The transparency of the approach and the ability to forecast changes to class based on planned activity provides operators to anticipate requirements in the design phase. Conversely, some operators may choose to lower operational costs by self-selecting an orbit with a lower entry requirement, alleviating demand on higher category orbits. Further, this construct may also motivate operators to change their risk tolerance over time as the orbital debris environment worsens or other factors promote a safer operating environment. This phenomenon has occurred for the operations of the Starlink V1 constellation at ~550 km. The original risk tolerance combination of react to events with PC > 5E-5 and abate the risk to 1E-6 was updated to one where Starlink now performs RRMs when the PC exceeds 1E-6 and then they abate the risk to 1E-7. This change was completely voluntary; this may have been motivated by the quality of the SSA data they were receiving, a corporate goal of more reliable operations, and/or a focus on leading by example on the push for space sustainability principles to minimize the potential for debris-generating events.

5.2. Information sharing ecosystems

Greater information sharing, particularly about planned maneuvers and orbit raising can improve the SSA of all operators. The value of data sharing is recognized as an essential tool for space sustainability as reflected in the weight given to it in the SSR [12]. Despite the community interest in expanding information sharing, the process has been slow. Concerns about proprietary and classified data as well as national or regional autonomy complicates discussions of information sharing. The need for shared information in more congested orbits may be higher than in orbits with less demand. Entry requirements may include participation in relevant information sharing regimes. A particular orbital class could constitute a de facto community of interest where certain higher levels of information sharing is confined to the orbital class and all parties, by virtue of selecting that operational orbit, have agreed to participate at least at the level established for the class. This may serve to overcome some to the perceived barriers to information sharing.

5.3. Regulatory Activities

This proposal does not propose which regulatory actions are needed or how each State should pursue a regulatory framework. It suggests that a common framework that ties entry requirements to a transparent, community developed, risk-based characterization of specific orbital altitudes supports the regulatory process. Like aviation, a common framework allows individual States to rely on common factors when authorizing and supervising space activities. Agreement between dominant space faring nations can serve to assure that operators in shared orbits are meeting a common standard. Emerging space faring nations benefit from established and transparent norms in developing their approval processes. A classification approach serves to move from an ad-hoc approach to approval to greater standardization that can provide a measure of regulatory certainty and build efficiency within the regulatory process.

6. Diplomatic considerations

Efforts to codify norms for responsible behavior in space are persistent in the space community driven by a shared interest in improving safety. A framework modeled on an approach that has been globally adopted in a similarly competitive environment dealing with similarly discordant geopolitical barriers may be instructive for orbital capacity. Recall the definition of orbital capacity as championed in this paper is “not a number of satellites, but rather a set of bounds on where, how, and how densely satellites make use of orbital volume.”

The aviation focus on safety as the basis for entry requirements is accepted as conforming with the concepts of freedom of navigation, including over the high seas. The space community has an opportunity to build upon that which is already familiar. Further, by focusing on airspace capacity as a design model, this paper has explained that in comparison with ICAO airspace classification, airspace is demarcated according to uncontrolled and controlled space, and in principle the concept of agreed upon entry requirements based on orbital risk could be evaluated without a controlling regulatory entity.

Orbital capacity is also influenced by legislative and governance factors. Chief amongst them is the central pillar of international outer space law: The 1967 UN Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space (OST) is the seminal document for outer space law. The OST is a leading document that prohibits national claims of sovereignty, establishment of military bases and weapons, or placement of weapons of mass destruction in orbit or on celestial bodies. Another major treaty implicated in increasing orbital capacity is the Liability Convention of 1972. This convention is an agreement for States to accept liability for any damages caused by their space objects.

Having an entity serve as a champion for change is also a key component of codifying norms for responsible behavior in space. Change champions can help promote growth in developing and implementing standards, which in turn could potentially lead to an increase in orbital carrying capacity. At the time of this writing, there is no leading entity equipped with the authority to propound enforceable standards around maneuverability and debris generating behavior. This could potentially be an opportunity for multilateral entities like the International Standards Organization, or other standards making bodies, to convene global experts to advance a desired safety protocol. Standards and diplomatic considerations pair together as standards can serve a critical enabling function for creating cohesion in developing schemas for orbital paths for spacefaring and aspiring spacefaring nations. Further, the process of standard creation, implementation, and oversight builds upon communication and cooperation in space. Lastly, standards can help protect equitable access to space for established and nascent space actors.

As this paper has argued, a combined LEO “Airspace” protocol could contribute to improving identifying the essential safety requirements that the SSR strives to uphold by advancing protocols of responsible behavior in space.

6. Conclusions

Developing a framework for orbital classification can provide an opportunity to convene experts and other stakeholders in a multidisciplinary approach to consider appropriate methodologies to evaluate orbital risk as a tool to establish requirements that may help to manage carrying capacity at various orbits. Understanding and capturing norms that have emerged organically, particularly in highly congested orbits, can serve to accelerate progress in creating standards and international agreements. The operational community has already begun to increase maneuver capability, reduce collision risk tolerance, and enhance space situational awareness in the interest in protecting their own assets. Individual regulatory regimes may find opportunities to support these efforts using structures that incentivize either investing in greater capabilities or self-selecting less congested operational orbits.

Identifying where risk varies between orbital altitudes to define and apply a specific orbital class will require input requires input from experts, stakeholders, and policy makers and can serve as first step in moving towards the development of standards that can be applied. As the space object population grows, it is necessary for there to be a flexible, responsive framework to modify operational requirements as the collision risk background changes.

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Appendix A:

Maneuverability is a key aspect of defining orbital capacity and potential “LEO airspace” classes.

Level	Name	Change Attitude (to reduce collision cross-section)	Manual Ingestion of CDMs	Differential Drag (change attitude to increase drag very low ΔV and very low responsiveness)	Cold Gas or Degraded Full Propulsive (e.g., CP or EP) Maneuverability (low ΔV and moderate responsiveness)	Full Propulsive (EP or CP) Capability (high ΔV and very responsive)	Autonomous Planning and execution of Collision Avoidance Maneuvers	De-Orbit Capability	CA Maneuver Impact on PC
0	Non-maneuverable								N/A
1	Only Attitudinal Maneuverability	X	X						Low
2	Non-Propulsive Maneuverability	X	X	X					Low
3	Partial Propulsive Maneuverability	X	X		X				Med
4	Full Propulsive Maneuverability	X	X			X		X	High
5	Full Propulsive Autonomous Maneuverability	X	X				X	X	High

EP: electric propulsion and CP: chemical propulsion

Appendix B

Notional LEO Classification System

Draft LEO classification system depends on altitude, constellation present, derelict background, and maneuverability / risk tolerance required.

<table>
<tr><th rowspan="2">Class</th><th colspan="3">Altitude (Persistence)</th><th colspan="3">Constellation Size Present</th><th colspan="3">Debris Background Level (i.e., spatial density, objects/km^3)</th><th colspan="6">Maneuverability Required</th><th colspan="5">Collision Risk Tolerance</th></tr>
<tr><th>Low <400km</th><th>Med 400 to 650km</th><th>High >650km</th><th>Low >10</th><th>Med >100</th><th>High >1000</th><th>Low <1E-9</th><th>Med 1E-9 to 1E-8</th><th>High >1E-8</th><th>0</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th></tr>
<tr><td>A
Congested</td><td colspan="3">X</td><td></td><td></td><td>X</td><td colspan="3">X</td><td></td><td></td><td></td><td></td><td></td><td>X</td><td></td><td></td><td></td><td></td><td>X</td></tr>
<tr><td>B
Persistent</td><td></td><td colspan="2">X</td><td colspan="2">X</td><td></td><td></td><td colspan="2">X</td><td></td><td></td><td></td><td></td><td>X</td><td>X</td><td></td><td></td><td></td><td>X</td><td>X</td></tr>
<tr><td>C
Occupied</td><td></td><td>X</td><td></td><td colspan="2">X</td><td></td><td></td><td colspan="2">X</td><td></td><td></td><td></td><td>X</td><td>X</td><td></td><td></td><td></td><td>X</td><td>X</td><td></td></tr>
<tr><td>D
Lightly Occupied</td><td colspan="2">X</td><td></td><td colspan="2">X</td><td></td><td colspan="2">X</td><td></td><td></td><td>X</td><td>X</td><td></td><td></td><td></td><td></td><td>X</td><td>X</td><td></td><td></td></tr>
<tr><td>E
Below Manned Spaceflight</td><td>X</td><td></td><td></td><td>X</td><td></td><td></td><td>X</td><td></td><td></td><td>X</td><td></td><td></td><td></td><td></td><td></td><td>X</td><td></td><td></td><td></td><td></td></tr>
</table>

Appendix C

Low Earth "Neighborhoods"