Applying Lessons Learned from FAA Drone Regulation to Space Traffic Management

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1 Introduction

The growing use of space in the modern age drives an increased need for conscientious utilization of space resources. In particular, there is a heightening awareness of the presence of orbital debris in the space environment, and of the necessity for space traffic management (STM) in order to mitigate risks to infrastructure. A primary challenge in this effort is the lack of precedent and capabilities for maintaining the space environment. Space is frequently misperceived as a frontier where Earth-based analogies do not apply. Contrary to expectations, however, we need not entirely reinvent the wheel when it comes to STM policy-making.

There is precedent for an STM-like system in another aerospace regime: in recent years, the FAA has begun integrating unmanned aerial systems into the National Airspace System (UAS-NAS integration) — an environment where unmanned vehicles need to cooperatively navigate in a safe, autonomous, and non-disruptive manner, just as in Earth orbit. Studying this effort will shed light on best practices and possible points of failure for the implementation of STM. This paper highlights select measures and policies that either could apply directly to STM or otherwise guide its overarching principles.

2 Comparing the Environments

2.1 Daily Fraction of the Environment Traversed by its Operators

Intuitively, the space and aerospace environments might appear too dissimilar for any productive comparison, let alone a comparison about traffic management specifically. As a rebuttal to that notion, consider the following rudimentary analysis. Daily traversed volume is perhaps one of simplest heuristics that correlates with collision likelihood for arbitrary volumes with random object distribution, and for these two regimes, the daily traversed volume as a fraction of the overall volume of the environment is roughly only a factor of 300 off. Put another way, imagine air traffic control was shut down for a day, but all planes continued to fly — this is the situation that Low Earth Orbit experiences year-on-year with regards to spacecraft traffic. This calculation is physically correct assuming that (a) object size and speed are not correlated, and (b) the objects are randomly distributed and have random velocities — obviously neither are strictly true for either Earth orbit or the National Airspace System (NAS), but this analysis provides a meaningful basic heuristic for comparing each environment.

> Low Earth Orbit is a 10^{20} cubic meter volume containing over 30,000 objects larger than 10 centimeters in diameter and likely on the order of 1,000,000 objects in the range of 1-10 centimeters in diameter[1] — much of which are clustered at specific orbital altitudes, and all of which travel at speeds around 7-8 km/s. Assuming the former category of objects is on average 20 cm in diameter and the latter is 2 cm in diameter, these objects traverse $2 \cdot 10^{-7}\%$ of the volume per day.[2]
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> The U.S. NAS is a 10^{17} cubic meter volume[2] which oversees 45,000 flights and millions of passengers per day,[3] with highly concentrated regions of high-volume traffic (airports, airways, populated regions, etc.). Traffic

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[1] ESA, "Space Debris by the Numbers".

[2] See Appendix for the detailed calculations.

[3] FAA, "Air Traffic by the Numbers".

generally experiences speeds ranging from 25 m/s to 300 m/s, and traverses $6 \cdot 10^{-5}\%$ of the volume per day, assuming the typical vehicle has a cross-sectional area of 10 m^2 and travels at 100 m/s.[2]

So, indeed, these two regions are more similar than one might expect. The following sections will further compare the relevant operational and policy environments between the two volumes, and will justify where FAA policy-making lessons may or may not also apply to STM.

2.2 National Airspace System Operational and Policy Environment

The U.S. national airspace system is a relatively tightly-controlled environment. Most commercial operations take place under Instrument Flight Rules (IFR) as part of a centralized command-and-control system in which air traffic control instructs aircraft navigation directly and grants permission for altered navigation upon request.[4] The remaining traffic either operates under a somewhat relaxed command-and-control system as part of Visual Flight Rules (VFR) or is outside of controlled airspace entirely and does not have contact with air traffic control.

The introduction of drones to this environment somewhat parallels the operation of spacecraft in Low Earth Orbit. Not more than a few years ago, rules regarding operating drones within the national airspace system were relatively scant — namely, as recently as 2012, all operations within controlled airspace were illegal except on a case-by-case basis.[5] There is great utility in operating drones within the NAS — desired current and future operations include applications such as transportation of people and shipments, infrastructure inspection, emergency monitoring and response, and amateur/hobby use[6] — but unlike in orbit, no such applications are possible in national airspace in the absence of a safe method of integration.

The FAA has responded to this need by taking separate steps to integrate amateur/small-scale and commercial/large-scale operation, since the risks posed by each category depend on how they utilize the airspace. For the former category, dubbed Part 107, sufficiently small UAVs are essentially given complete freedom but may only operate outside of controlled airspace except under case-by-case exemptions in certain scenarios.[7] (It is worthwhile to note that UAVs over 250 grams require further registration and remote identification tags). Commercial operations directly utilizing controlled airspace are a different matter, and are the primary subject of the UAS-NAS integration effort

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[4] FAA, "Instrument Procedures Handbook".

[5] Rotor Drone Pro, "Rules & Regulations: A history of drone laws in the United States".

[6] Business Insider, "Drone technology uses and applications".

[7] FAA, "Fact Sheet — Small Unmanned Aircraft Systems (UAS) Regulations (Part 107)".

which began in 2011.[8] Currently the FAA requires Certificates of Authorization (COAs) on a case-by-case basis for any flight within controlled airspace. The UAS-NAS integration effort is undertaking demonstrations to ensure that flights within controlled airspace can be conducted in a safe manner; upon the safe and successful completion of these demonstrations, the FAA is expected to methodically work towards a more expansive and permanent policy solution. In the meantime, the FAA has set up a system to grant expedited COA approvals for emergency response operations, and continues to grant COAs on a case-by-case basis.[9]

2.3 Earth Orbit Operational and Policy Environment

Earth orbit has frequently been characterized as “the Wild West”: not only is it a frontier for exploration and innovation, but it is also one in which laws and norms of behavior are essentially non-existent. While much work on STM is currently underway, particularly with regards to building the capabilities for Space Domain Awareness (SDA) and data-sharing organizations, present STM policies have meager impact on actual on-orbit operations.[10] The most noteworthy policies are the Space Policy Directive-3 which designates the Office of Space Commerce within the Department of Commerce as the civil agency responsible for SDA and STM,[11] but which has yet to produce effectual on-orbit operational policies, and the oft-quoted “25 year rule” (the primary component of a series of optional mitigation guidelines put forth by the U.S. Government)[12] which states LEO satellites should be deorbited within 25 years following the end of their operational lifetime.

Satellite operators can be cleaved into two broad categories in terms of their utilization of Earth orbit. Some, primarily GEO operators with their own expensive and exquisite infrastructure, go above and beyond to collaborate and ensure their orbital regimes are hazard-free; these operators take measures to keep orbital bands free by shifting their satellites to graveyard orbits at the end of their lifetime, and avoid collisions via collaborative data-sharing agreements. On the other side, there are operators who follow the minimum guidelines for operational safety, primarily within Low Earth Orbit, where policies, behavioral norms, and industry standards are under-cultivated.

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[8] NASA, “NASA Armstrong Fact Sheet: Unmanned Aircraft Systems Integration in the National Airspace System”.

[9] FAA System Operations Support Center (SOSC), “How To: Get Approval in an Emergency”.

[10] International Academy of Astronautics, “Space Traffic Management: Towards a roadmap for implementation”.

[11] Presidential Memoranda, “Space Policy Directive-3, National Space Traffic Management Policy”.

[12] NASA JSC, “U.S. Government Orbital Debris Mitigation Standard Practices, November 2019 Update”.

There are a variety of caveats worth noting in relating Earth orbit and the national airspace system. First, a hierarchical command-and-control system similar to air traffic control is unrealistic for STM, because current SSA lacks sufficient quality to enable such operations, and because only a fraction of man-made space objects are maneuverable anyways. Although mandated collision avoidance maneuvers in certain situations may be a possibility far down the line, they are not yet a significant factor for STM. Secondly, air traffic control has national basis and regulation, and it is simply at the geographical boundaries of countries that national air traffic control systems must interface. Space has no such geographical separation of spacecraft, so nationally-based STM will face cooperative challenges with other spacecraft which may be following an entirely different set of rules, or none at all. An international system is favored. Thirdly, the definitions of safety in air and space differ. "Air safety" concerns all air vehicles, because human lives — pilots, passengers, and people on the ground alike — are at risk. On the other hand, the implicit working definition of "space safety" in the industry so far is simply the preservation of space assets to the extent corresponding to their monetary or strategic value.

Nevertheless, there are clear parallels between the national airspace system and space traffic management. In this analogy, proactive users of Earth orbit might be compared to existing human-piloted aircraft, and the less safety-inclined users might be compared to UAVs. Where the FAA worked to ensure UAVs could safely and non-disruptively operate in the national airspace system, so too can policies and methods be implemented to ensure satellite operators can safely utilize Earth orbit. The following section will detail specific strategies and policies the FAA undertook in their integration effort, and will elaborate on how corresponding strategies in the space environment may be effective as well.

3 Lessons Learned

3.1 Direct Regulations on Operators

In the aeronautical world, UAVs are only required to participate in the FAA's Air Traffic Management system to an extent corresponding to the risk they pose to human lives, human assets, and the operation of other aircraft. For this purpose the FAA created regulatory tiers which categorize aircraft depending on factors such as the aircraft's type of operations, the location and altitude of its flight path, and the size and equipment of the vehicle. Small amateur UAVs that operate away from airports and below the airspace floor are restricted to uncontrolled airspace, but have the most operational freedom. Large commercial UAVs flying at typical manned aircraft altitudes in controlled airspace are regulated and controlled the most strictly, but have the ability to enter most controlled airspace classes with prior approval from the FAA.

A similar system of regulatory tiers based on category of operations would benefit the space environment as well. Regulatory tiers should capture the risk spacecraft pose to other spacecraft and the overall risk of contributing to space debris. A number of factors would have to be considered, including orbital regime of the spacecraft (e.g. LEO, MEO, GEO), size/mass of the spacecraft, on-board collision avoidance capabilities, end-of-life deorbit plans, amount and location of debris produced by a possible collision, and estimated likelihood of collision over the spacecraft's entire lifespan. Factors that do not involve conducting calculations or studies are preferred in order to maintain simple and rapid classification — satellite manufacturers should know from the outset of the design process which category a proposed design would fall under, just as drone manufacturers have clear demarcations for their relevant regulations based on drone size and operational regions. Simple classification methods will help make certification and checkout processes faster and less expensive.

The FAA grants COAs — case-by-case authorizations — for individual UAV flights within the NAS. Such a system could certainly be implemented for STM as well; the FAA already conducts individual launch approvals for all U.S.-launched spacecraft,[13] and this process could extend to include STM-based authorizations. Such authorizations would ideally take into account whether sufficient STM-related measures have been taken or are planned by the spacecraft operators. Regulators would be wise to give consideration to the type of operation as well, just as amateur and commercial drone operations are regulated separately. For example, a different level of STM compliance ability may be reasonably expected from a university-created science mission than from a commercial telecommunications megaconstellation. For launches that require expedited approvals, a separate process could be set up for approvals for particular emergency scenarios.

3.2 Alternative Means to Incentivize and Ensure Compliance

Low compliance and difficulty of enforcing rules involving small non-commercial UAVs were significant challenges faced by the FAA faced early on, and to a lesser extent, continues to face today. Amateur UAV operators (particularly those new to the hobby) are often either uneducated on the "rules of the road" entirely or otherwise frequently disregard common safety protocols in favor of maintaining their own operational freedom. Notably, illegal amateur UAV operations in 2018 at England's Gatwick Airport caused a level of disruption to flights at the airport on par with the 2010 eruptions of the Eyjafjallajökull volcano in Iceland.[14] There are a variety of reasons for the lack of broad compliance in UAV rules among amateur operators, but it generally comes down to a lack of exposure to the norms and safety culture of the flight community.

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[13] FAA, "Safety Approvals for Commercial Launch Operations".

[14] BBC News: "Gatwick Airport: Drones Ground Flights".

These types of violations have counterparts in spaceflight as well. While established and experienced operators tend to go beyond legal requirements when it comes to STM — many operators in geostationary orbit, for example, are part of the independently-established Space Data Association which conducts traffic management as a subscription service[15] — new and inexperienced operators in Low Earth Orbit tend to display low levels of self-initiative when it comes to traffic management and orbital debris mitigation. Also of note is the March 2019 Indian ASAT test, which was a technical success but a space sustainability failure.[16] Perhaps more exposure to the safety culture in the spaceflight community could prevent situations like these, which may otherwise begin to set a precedent for new users of space and for the spaceflight communities of developing countries.

In handling the amateur UAV issue, the FAA took two paths of action. The first was to sidestep operators and instead negotiate with UAV manufacturers directly to come up with regulatory and technology solutions to the non-compliance issue. As a result of these efforts, several UAV manufacturers now intentionally impose geofencing on their products to prevent operators from flying into controlled airspace — DJI, for example, deployed their "FlySafe" geofencing and safety-related user information system in 2015.[17] The FAA also requires remote ID beacons on large drones to ensure their locations are broadcast to manned aircraft.[18]

The other course of action involved beginning to offer a certification course to amateur operators who wished to gain knowledge of relevant UAV rules. This certification (Part 107) allows hobbyists to conduct small-scale commercial operations, and informs them on the processes they can take to obtain clearances into airspaces normally unavailable to them.[19] Therefore the course incentivizes operators to educate themselves about UAV regulations independently. The certification itself is something of a "badge of honor" to such operators, which further incentivizes new users to obtain such a certification.

3.2.1 Regulations on Manufacturers

STM regulations or incentives could be imposed in a similar manner to the FAA's method of sidestepping UAV operators. Instead of governing satellite operators with direct rules concerning their operations, regulations could instead be introduced to satellite manufacturers or launch providers. Manufacturers

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[15] Space Data Association, "Participants".

[16] Space News, "India ASAT debris spotted above 2,200 kilometers, will remain a year or more in orbit".

[17] DJI, "DJI Introduces New Geofencing System for its Drones".

[18] FAA, "UAS Remote Identification Overview".

[19] FAA, "Become a Drone Pilot".

could install independent on-board GPS receivers to provide satellite positional information. Launch providers could require users to obtain STM services prior to launch, to share ephemerides/maneuver information, or to ensure end-of-life deorbit of their satellite. An advantage of this approach is that U.S. launch providers already must obtain FAA certification and approval of launches, which provides a straightforward route for implementation of additional policies that promote STM compliance. Additionally, the number of satellite manufacturers and launch providers is far fewer than the number of satellite operators, so coordinating with and catching all parties involved is simplified. Fewer rogue actors would slip through without making appropriate plans for STM or orbital debris mitigation.

3.2.2 Norms of Behavior

A key component for success of the drone-airspace integration effort is that drone operators themselves place utmost importance on acting safely and non-disruptively. While established commercial drone operators understand this factor and go to great lengths to certify their airframes and execute flight demonstrations, novice drone operators are often uneducated on the “rules of the road” and disregard common safety protocols in favor of maintaining freedom. The FAA went to extra lengths to ensure these operators specifically were informed and compliant. The same is true for satellite operators in the space domain: while established users adhere to and even expand industry best standards, newer users of space frequently disregard guidelines to lessen costs, and additional efforts should be focused on them.

The prominent under-addressed challenge for STM in this regard is fostering a strong safety culture among users of space. While rules in place to enforce safety among operators are necessary, far more important is the willingness of industry to adopt norms of excellence that go above and beyond those rules. In all industries, accidents are likely to ensue when companies only adhere to minimum standards. Sustained success only comes from entities choosing for themselves to behave safely and with integrity.

A culture of safety cannot arise from a vacuum. Instead, it is learned institutionally and acquired over time as companies begin to adopt behavior that prioritizes safety and sustainability. Therefore, in order to best establish a safety culture, we must choose to:

- Recruit expertise from related fields with strong safety cultures, such as air traffic control and human space exploration efforts
- Better integrate newer users of space into the existing safety-oriented community
- Hold entities publicly accountable for STM-related failures, and promote those that engage in best practices

These efforts will best enable a community-driven rather than a solely rule-driven STM architecture. Some such efforts to establish norms and incentivize proactive and conscientious behavior are already underway — for example, the Space Sustainability Rating under development by the World Economic Forum aims to enable transparency and promote operator-led initiatives to improve operational safety.[20] These efforts should be further embraced as STM grows.

3.3 Risks from Slow Certification Processes

For all the success of the UAV-airspace integration effort, there are some pitfalls that should be noted and avoided for STM — after all, lessons should be learned not just from that which was done well, but also that which perhaps could have been done better. The FAA has understandably taken conservative precautions with commercial UAVs that operate directly in controlled airspace because those are the vehicles that pose the most risk to humans and are likely to disrupt normal airspace operations if they were to fail. However, these precautions have, on occasion, created excess boundaries for the industry — instead of UAV detect-and-avoid technology being the limiting factor in the advancement of the industry, the bottleneck is more commonly in the certification and approval process, which can take months and years, even when the technology is already established. These processes require significant investment from industry, preventing all but highly established companies from participating. FAA policy has therefore lagged behind technology in this area due to inflexibility and slow adaptation.

Although existing and near-term future authority regarding STM is unlikely to have the ability to create a similar bottleneck in the industry, it is important to consider the effects STM will have, in particular the burden it places on individual companies with slow and expensive certification or regulatory processes.

4 Conclusion

This document has proposed a select few policies and strategies the FAA undertook in integrating UAVs into national airspace that could be successfully implemented in the STM policy environment as well. While some work has already been conducted regarding utilizing technical lessons from the UAS-NAS integration effort for STM,[21,22] in particular, regarding large-scale autonomous operations and data-sharing, such efforts are relatively unexplored on the policy side of the effort. It is expected that many further policy insights could be derived from further inspection into the similarities between the policy environments of the National Airspace System and Earth orbit.

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[20] World Economic Forum, “Space Sustainability Rating”.

[21] NASA Ames, “A Concept for Civil Space Traffic Management: Applying the NASA Unmanned Aircraft System Traffic Management Architecture to Space Traffic Management”.

[22] NASA Ames, “System Autonomy for Space Traffic Management”.

5 Appendix

This section details the calculation of daily traversed volume percentages, which are calculated as follows:

$$\text{Daily traversed volume fraction} = \frac{\text{object speed} \times \text{object cross-section} \times \text{number of objects}}{\text{total environment volume}} \tag{1}$$

Low Earth Orbit

LEO spans from roughly 400 to 1000 km altitude above the Earth's surface, which has a radius of 6378 km. Therefore the volume of LEO is given as follows:

$$\frac{4}{3}\pi\big((6378\text{ km} + 1000\text{ km})^3 - (6378\text{ km} + 400\text{ km})^3\big) = 3.78 \cdot 10^{20}\text{ m}^3 \tag{2}$$

The traversed volume of the 34,000 $\geq$10 cm objects, assuming the average diameter is 20 cm and the average speed is 7.8 km/s, is:

$$7.8\text{ km/s} \times \pi(10\text{ cm})^2 \times 34000 = 7.2 \cdot 10^{11}\text{ m}^3/\text{day} \tag{3}$$

And the traversed volume of the 1,000,000 1-10 cm objects is:

$$7.8\text{ km/s} \times \pi(1\text{ cm})^2 \times 1000000 = 2.12 \cdot 10^{11}\text{ m}^3/\text{day} \tag{4}$$

Therefore, the total daily traversed volume percentage is:

$$\frac{7.2 \cdot 10^{11}\text{ m}^3/\text{day} + 2.12 \cdot 10^{11}\text{ m}^3/\text{day}}{3.78 \cdot 10^{20}\text{ m}^3} = 2 \cdot 10^{-7}\% \tag{5}$$

National Airspace System

Controlled airspace extends across 5.3 million square miles from an altitude of 1,200 feet to 60,000 feet. Therefore its volume is given by:

$$\big(60000\text{ ft} - 1200\text{ ft}\big) \times 5300000\text{ mi}^2 = 2.46 \cdot 10^{17}\text{ m}^3 \tag{6}$$

The traversed volume of 45,000 aircraft, assuming an average speed of 100 m/s, an average cross-sectional area of 10 m^2, and an average flight time of 1 hour, is:

$$100\text{ m/s} \times 10\text{ m}^2 \times 45000 \times \frac{1\text{ hour}}{24\text{ hours}} = 7.2 \cdot 10^{11}\text{ m}^3/\text{day} = 1.62 \cdot 10^{11}\text{ m}^3/\text{day} \tag{7}$$

Therefore, the total daily traversed volume percentage is:

$$\frac{1.62 \cdot 10^{11}\text{ m}^3/\text{day}}{2.46 \cdot 10^{17}\text{ m}^3} = 6 \cdot 10^{-5}\% \tag{8}$$