GNSS AND SUSTAINABLE ACCESS TO SPACE

by

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ABSTRACT

Space-based precision navigation and timing systems (commonly referred to as Global Navigation Satellite Systems or GNSS) have and will continue to improve agile decision-making in aviation and maritime traffic management. Certainly, the use of GNSS represents one of the most relied upon space applications, as noted by its ubiquitous impact on our daily terrestrial lives (a prime example being our use of GPS on our smartphones). This positive impact is consistent with the United Nations' 2030 Sustainable Development Goals (SDGs).

However, GNSS capabilities are not fully exploited in national airspace (NAS) and may yet provide a path to integration of all airspace users, including space operators. Environmental sustainability on Earth and in space by necessity includes a stable environment of the NAS.

Current international GNSS governance provides some guidance in protecting the terrestrial, airspace and outer space environments in an effort to secure the long-term sustainability of all activities therein.

This paper discusses the historic background of GNSS, its current applications in the aviation and maritime sectors, and its inherent potential for integrating multiple users of national airspaces and beyond. The paper also examines the current international frameworks governing GNSS applications and the various discussions related to GNSS governance currently underway in international fora. The paper concludes with high-level recommendations to better utilize GNSS capabilities through increased cooperation and coordination.

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I. BACKGROUND AND HISTORY

Satellite navigation has a long history as a successful space application. The US Navy navigation satellite system Transit (the forerunner to GPS) was first approved and funded by Congress in 1958 and became operational in 1964.[1] Transit's data was released for commercial use as early as July 1967, establishing a dual-use satellite navigation policy in the United States.[2] The seventies and eighties saw the development of the US Global Positioning System (GPS) office and multiple launches to support the system.[3] An air navigation tragedy in 1983 prompted President Reagan to make GPS information available to the general public.[4]

By the nineties, early GPS was fully operational,[5] and already undergoing modernization,[6] and by the turn of the century other providers were beginning to surface in the international arena.[7] The International Committee on Global Navigation Satellite Systems, discussed in more detail below, was formed in 2005 and, reflecting the increasing numbers of GNSS providers, the Providers Forum commenced in 2007.

II. CURRENT APPLICATIONS AND RELEVANT GOVERNANCE

GNSS is currently used in maritime and aviation contexts in support of various PNT (positioning, navigation, and timing) applications[8]: it is the foundation of performance-based navigation (PBN), Automatic Dependent Surveillance Broadcast (ADS-B and ADS-C) and provides a common time reference used to synchronize systems. Specifically, ADS-B

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[1] International Committee on Global Navigation Satellite Systems, *GNSS History*, Presentation, accessed 17 Nov 2017, online: <http://www.unoosa.org/pdf/icg/2015/presentations/30.pdf> [GNSS History].

[2] Thomas Stansell *The Transit Navigation Satellite System* (USA: Magnavox, 1978) at p 10.

[3] GNSS History, *supra* note 1.

[4] Sarah Laskow, *The Plane Crash that Gave Americans GPS*, The Atlantic, 3 Nov 2014, online: <https://www.theatlantic.com/technology/archive/2014/11/the-plane-crash-that-gave-americans-gps/382204/>.

[5] The Navigation Center of Excellence, *GPS Fully Operational Statement of 1995*, US Department of Homeland Security, News Release, 17 Jul 1995, online: <https://www.navcen.uscg.gov/?pageName=global>.

[6] GNSS History, *supra* note 1.

[7] For example, China's Beidou system was providing regionally active service in 2000. Ran Chengqi, *Development of the BeiDou Navigation Satellite System*, in National Academy of Engineering, "Global Navigation Satellite Systems: Report of a Joint Workshop of the National Academy of Engineering and the Chinese Academy of Engineering" (Washington DC: The National Academies Press, 2012) at p 17.

[8] Paul Larsen, *International Regulation of Global Navigation Satellite Systems*, (2015) 80 J Air L & Com 365 at 387-88.

is a space-based surveillance technology that is used as a navigation tool by utilizing an ordinary GNSS receiver to support aviation and non-aviation applications. For the purposes of this paper, discussion will be limited to ADS-B and maximization of its usage in furtherance of domestic and international policy goals. The following is a brief and high-level overview of how ADS-B technology works.

ADS-B systems are always on (automatic), thereby eliminating the need for an operator and depend on accurate GNSS position data. When installed in an aircraft, maritime vessel or on a spacecraft, the ADS-B transponder broadcasts its identification, position, altitude, velocity, and other relevant information (as in, characteristics that amount to surveillance). The broadcast element requires no interrogation or triggering by other stations; the data is simply sent to any aircraft, ground station or other location equipped to receive it. Enhancements to ground-based systems exist which remove the need for line of sight connections, and allow data flow in situations where conventional air traffic surveillance is either impossible or impractical.[9] Furthermore, placing space-grade receivers on a satellite constellation would make "100 percent global surveillance using the same ADS-B signal that aircraft already transmit"[10] possible. Although more often discussed in relation to ADS-B usage for aviation, GNSS PNT is used by the International Space Station to meet its attitude determination requirements and to more precisely perform its spaceflight operations like rendezvous and docking, station keeping, formation flying, and GEO satellite servicing.[11]

Interference, interoperability, and interchangeability are critical issues for GNSS. Interference, or disruptions, can be intentional or unintentional, predictable or unpredictable, resulting from human activity or from natural or environmental causes, either crude or sophisticated, and widespread or localized.[12] The effect of GNSS interference can be a disruption to critical navigation and surveillance services. "Compatible constellations do not interfere with each other, and interoperable constellations gain strength from each other. Thus, interoperability is a

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9 Edward Valovage, *Enhanced ADS-B Research*, (2006) presented at 25th Digital Avionics Systems Conference, Portland, Oregon, USA.

10 Aireon, *It's Just ADS-B*, Aireon, accessed 17 Nov 2017, online <https://aireon.com/resources/its-just-ads-b/>.

11 James Miller, *Space Situational Awareness 2015: GPS Applications in Space*, NASA, Presented at Space Situational Awareness 2015 on 13 May 2015, online: < https://www.gps.gov/multimedia/presentations/2015/05/SSA/miller.pdf > at 2.

12 Deborah Lawrence, *Alternative Positioning, Navigation, and Timing (APNT)*, Presented at 13th National Space-based PNT Advisory Board on 3 Jun 2014, Federal Aviation Administration, online: <https://www.gps.gov/governance/advisory/meetings/2014-06/lawrence.pdf> at 3.

stronger condition than compatibility."[13] Interoperability and/or compatibility can be achieved through consistent system time and geodetic coordinate systems. Even more robust than an interoperable state is that of interchangeability; however, interchangeability requires a more specific set of requirements.[14] Notwithstanding the increased requirements, interchangeability makes it possible for a user to estimate latitude, longitude, altitude, and user time offset based on any four satellites from any of the cooperating constellations all of which will have a synchronized clock and operate on a common (or close to common) carrier frequency.[15]However, since ADS-B data is automatically broadcasted and can be received by any system equipped to do so, security is a significant concern. To counter such concerns, different, incremental levels of security, such as encryption technology, can be used to enhance data links and, for example, provide validation or authentication – NextGen's SWIM system utilizes this type of security.[16]

Governance of these operational complexities can be found in a multitude of places, reflecting the full panoply of legal effect. Under the United Nations Office for Outer Space Affairs, the International Committee on Global Navigation Satellite Systems (ICG) attempts to establish, at an international level, the compatibility/interoperability of GNSS systems. The ICG's structure allows for the participation of various stakeholders. The ICG Providers' Forum, established in 2007, provides the means by which to promote communication among system providers on technical issues and operational concepts such as protection of GNSS spectrum, orbital debris mitigation and orbit de-confliction.[17] Separately, the Interagency Operations Advisory Group addresses strategic issues related to inter-agency interoperability, space communications, and navigation matters. ICAO also provides some measure of international governance related to GNSS. Amendment 76 to Annex 10 of the Chicago Convention contains Standards and Recommended Practices (SARPs) related to GNSS and provides extensive guidance on the technical aspects of GNSS and its application in furtherance of international aviation safety.

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[13] Grace Wingxin Gao, *Summary of the Workshop*, in National Academy of Engineering, "Global Navigation Satellite Systems: Report of a Joint Workshop of the National Academy of Engineering and the Chinese Academy of Engineering" (Washington DC: The National Academies Press, 2012) at p 17 [Gao] at 3,

[14] *Ibid*.

[15] *Ibid*.

[16] FAA, System Wide Information Management (SWIM), Federal Aviation Administration, accessed 5 Jun 2018, online: <https://www.faa.gov/air_traffic/technology/swim/>.

[17] The original members of the International Committee on Global Navigation Satellite Systems' Providers Forum were China, India, Japan, Russia, the US and the EU. Larsen, *supra* note 8 at 402.

Annex 10 identifies and defines three types of GNSS augmentation: Aircraft Based Augmentation System, Satellite Based Augmentation System and Ground Based Augmentation System. By improving surveillance capabilities, the separation standards required between aircraft in flight can be reduced, thus increasing airspace capacity and the ability to support user-preferred trajectories. In areas where radar cannot be installed or where there are no ground stations (such as on the high seas or in remote areas), ADS-C is used. Vulnerabilities exist in the form of interference and also susceptibility to ionospheric effects (a source of natural or environmental interference).

The ICAO Council approves the Global Air Navigation Plan (GANP) triennially.[18] The GANP is a rolling 15-year strategic methodology that organizes objectives into Aviation System Block Upgrades (ASBUs) and outlines implementation issues for the Planning and Implementation Regional Groups (PIRGs).[19]ABSUs are programmatic and flexible and allow Member States to advance air navigation capabilities based upon specific operational requirements. The ultimate goal is a fully harmonized global air navigation system with global interoperability as a minimum objective. NextGen (US), SESAR (Europe), CARATS (Japan), SIRIUS (Brazil) and others (Canada, China, India, Russian Federation) all represent ongoing air navigation improvement programs falling within the GANP.[20]

The ten key air navigation policy principles are:

a) Commitment to the implementation of ICAO's strategic objectives
b) Aviation safety is the highest priority
c) Tiered approach to air navigation planning
d) Global air traffic management operational concept
e) Global air navigation priorities
f) Regional and state air navigation priorities
g) Aviation system block upgrades, modules and roadmaps
h) Use of ASBU blocks and modules
i) Cost benefit and financial issues
j) Review and evaluation of air navigation planning.[21]

The four specific performance areas are: 1) greener airports, 2) globally

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18 ICAO, *Global Air Navigation Plan 2013-2028*, International Civil Aviation Organization, Fourth Edition – 2013, online: <http://www.icao.int/publications/Documents/9750_4ed_en.pdf>, at 12 [GANP].
19 *Ibid*.
20 *Ibid* at 12.
21 *Ibid* at 17-19.

interoperable systems and data; 3) optimum capacity, and 4) flexible flights and efficient flight paths.[22] GNSS is recognized as a key element of the air navigation system that will deliver improved services and meet environmental, efficiency, and safety objectives related to these performance areas. Although not framed in terms of users of airspace per se, and while silent as to space traffic integration through national airspace, it is in these performance areas that the use of GNSS by all airspace users is most clearly justified, particularly numbers two, three, and four.

Consistent with the recognition that GNSS PNT has the potential to make systemic contributions to a global, interoperable, efficient, and flexible airspace infrastructure, its use is directly linked to several of the UN's SDGs.[23] Given that national airspaces are part of a sovereign state's infrastructure, the safe and efficient ingress and egress of space assets through these airspaces is important so that these applications can continue to improve terrestrial life for the benefit of all mankind. Additionally, airspace is a shared resource and part of the human environment that must be preserved.

SDG 9.4 suggests upgrading infrastructure and retrofitting industries.[24] Sustainability depends upon increasing the efficiency of utilizing resources by implementing clean and green technologies. Certainly, ADS-B technology fits this mandate. SDG 17.14 addresses policy coherence; the potential for global interoperability and even interchangeability furthers coherence between systems and enhances global partnerships, an express objective of SDG 17.16. The partnerships between the public sector and the private sector contemplated by SDG 17.17 are already in place for GNSS PNT. The US FAA NextGen initiative is a good example, as it involves government, industry partners, and academia.[25] Environmental standards are included in the SDG's implementation strategies; preservation of the integrity of airspace is consistent with these objectives.[26] ADS-B affords a level of situational awareness far beyond the old ground-based radar system and has greater potential than a system relying upon ground stations. It should be the

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[22] *Ibid* at 36.
[23] UN, *Sustainable Development Goals*, United Nations, accessed 23 Apr 2017, online: <https://sustainabledevelopment.un.org/sdgs>.
[24] UN, *Transforming our world: the2030 Agenda for Sustainable Development*, United Nations, accessed 17 Nov 2017, online: <https://sustainabledevelopment.un.org/post2015/transformingourworld>.
[25] FAA, *What is NexGen?*, Federal Aviation Administration, accessed 17 Nov 2017, online: <https://www.faa.gov/nextgen/what_is_nextgen/>.
[26] *Ibid*.

standard for all users of airspace and outer space.

Recent US GNSS policy exhibits precisely the type of policy coherence described in SDG 17.14. The US 2010 National Space Policy directs the US to engage with foreign providers and encourages interoperability, promotes transparency, and makes US markets available to other GNSS providers in support of industry.[27] For aviation users, the US Code of Federal Regulations discusses ADS-B equipment requirements in 14 CFR 91.225 and the operating rules for ADS-B in 14 CFR 91.227, making them extremely relevant to all airspace users.[28] The deadline for compliance is 1 January 2020. Currently, the retail cost of an ADS-B transponder ranges from ~$1,900 US to ~$5,100 US.[29] On the receiver side, because of how inexpensive and capable digital chips and memory systems are at present, it is as cheap to manage many receivers as it is to manage one.[30]

These regulations suffer from two flaws. First, consistent with existing US policy, regulations, and guidance, these regulations continue to discuss the airspace in terms of one user – the traditional aviation user flying traditional aircraft (14 CFR 91.225 reads "operate an aircraft"). A long-term view seeking to preserve airspace integrity and secure access to space ought to re-frame this, perhaps to "user of airspace". Second, as a result of the shortcomings related to the first flaw, other users of the airspace are not subject to this equipment requirement, compromising the potential efficiencies ADS-B would provide to airspace management. Simply put, ADS-B works wherever it is placed, be that on an aircraft, or on a space vehicle, or on a stratospheric balloon, or on a remotely piloted system. Since the technology follows the transponder, requiring that all vehicles in airspace use such equipment would increase the safety and efficient use of such airspace.

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[27] Executive Office of the President, *National Space Policy of the United States of America*, US Government, 28 Jun 20110, online: <https://www.nasa.gov/sites/default/files/national_space_policy_6-28-10.pdf>.

[28] The Code of Federal Regulations is the codification of rules in the United States. Government Publishing Office, *Code of Regulations, 1996 to Present*, accessed 5 Jun 2018, online: <https://www.govinfo.gov/help/cfr>.

[29] Marc C. Lee, *ADS-B Buyer's Guide 2016 Final Countdown*, Plane & Pilot Magazine, accessed 17 Nov 2017, online: <http://www.planeandpilotmag.com/article/ads-b-buyers-guide-final-countdown/>.

[30] Rita Lollock, et al., *The Interchangeability Problem: Signals, Coordinate Frames, and Time*, in National Academy of Engineering, "Global Navigation Satellite Systems: Report of a Joint Workshop of the National Academy of Engineering and the Chinese Academy of Engineering" (Washington DC: The National Academies Press, 2012) at p 79.

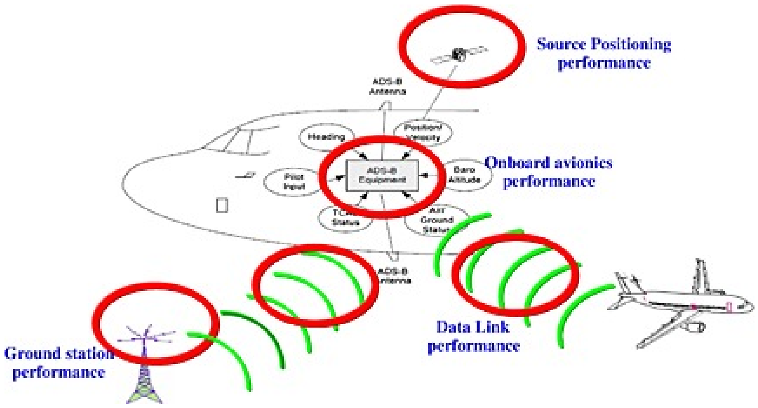

Figure 1: The transponder is the key, not the aircraft.

III. IMPLICATIONS FOR THE NAS

The requirement for ADS-B transponders on all aircraft will support increased airspace efficiency but misses the opportunity to maximize airspace efficiency in a mixed-use environment. By considering all users of the airspace, rather than restricting the planning process to aviation users, it is possible to develop strategies that can at once ensure reliable and predictable access to space users while reducing the economic and environmental consequences of displacing civil aviation to accommodate launch and recovery activities.

The FAA is granted authority over U.S. sovereign airspace through 49 USC, 40103 which states, "*The Administrator of the Federal Aviation Administration shall develop plans and policy for the use of the navigable airspace and assign by regulation or order the use of the airspace necessary to ensure the safety of aircraft and the efficient use of airspace.*"[31] While the bulk of the statutory authority granted to the FAA specifies application to aircraft, it does not specify that it is precluded from authority over other airspace users. Jurisdiction over the management of the airspace is exclusive to FAA. The inclusion of efficient use of airspace presumes that FAA has the ability to develop policies affecting other airspace users in order to fulfill this responsibility.

The FAA addresses the safety portion of its responsibility though the use of approval or denial of airspace access to non-aviation users through the use of segregated airspace. While safe, this inherently inefficient approach

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[31] US Code Title 49, Subtitle VII, Part A, Subpart I, Chapter 401, §40103.

requires nonparticipating aircraft to be routed around the segregated airspace, increasing track distance for aircraft, adjacent airspace congestion, carbon emissions, and economic costs. A move toward integrating commercial space users is desired and currently in development; Without timely and accurate position information available to air traffic control systems from all airspace users, however, integration cannot be achieved. There is a particular need for surveillance information on airspace users in the commercial space industry as current airspace allocation is based on calculations of probable risk from predictive data. Moving to a system that utilizes position information, rather than prediction, would significantly reduce airspace consumption. This approach has been successfully demonstrated in the traditional aviation community in the transition from procedural separation standards to surveillance standards. Similarly, the introduction of surveillance systems in remote and oceanic airspace reduces airspace consumption from a required one hundred lateral miles between aircraft to five, thus increasing airspace capacity twenty-fold. For the commercial space user, the surveillance infrastructure is already in place, and can be utilized for this purpose through a policy approach.

Diversity in space operations leads to comparably diverse opportunities to derive benefits from increased surveillance capabilities. For traditional vertical launch activities, the benefits may be limited to the reduction of the amount of time that airspace remains segregated, as operational personnel could reopen airspace tactically and eliminate the delay resulting from the required notification process. However, for other types of space operations, even greater efficiencies can be realized. For example, current protocol determines “aircraft hazard areas” on the basis of probability models every time a rocket stage re-enters the atmosphere; the ability to detect an expended stage prior to it reentering the atmosphere would allow for smaller hazard areas (as determined by precise GNSS information) and can also allow for tactical avoidance of the hazard itself. For reusable launch vehicles, under operator control, whether through steered parachute, or control surfaces on the vehicle, it is possible to develop tactical separation standards between aircraft and spacecraft rather than between aircraft and protected airspace.

This approach would achieve a state of full integration for these operational types and maximize airspace efficiency. Implementing the discussions about would make space vehicles fully integrated airspace users that grants the space operator with assured access to the airspace and does not disrupt existing aviation operators.

IV. CONCLUSIONS

Although accommodating the diverse interests of those using a shared airspace has always existed, it is much more prevalent in the present. Useful technologies currently exist at attractive price points that can have a profound and constructive impact on how airspace users interact. However, the implementation of such efficient integration has been delayed because of aviation's dominance over all other users of airspace. Not only is this tactic counterproductive, it is contrary to intrinsic global governance goals. The UN SDGs seek more efficient use of infrastructure, including airspace, as well as policy coherence between various stakeholders and users of airspace. Current initiatives implementing GNSS, and, in particular, ADS-B, technology have furthered these goals by maximizing the safe and efficient management of airspace; however, they are merely a beginning. To ensure the safest and most consistent access to outer space, all users of airspace ought to adopt such new technological capabilities.