Geospace Traffic Management

by William O. Glascoe III, PMP

There comes a time when the factors that determine the mode of control for a particular region of flight evolve sufficiently enough to require changes in those controls. Outer space has already experienced one such transition and is approaching another. "Reaction control" replaced "no control" by the efforts of organizations such as the United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS). In the next transition, "reaction control" must give way to "positive control." The transition is quickly approaching with the realization of commercial space tourism.

The first task at hand will be to define the volume(s) to be controlled. UNCOPUOS has not come to a consensus on the matter because the apparent economic and legal implications of delimiting air space and outer space seem too great given the immense cash flows of the satellite telecommunications industry and nations' space-based security practices. Nonetheless, distinguishing outer space from geospace and lunar space may prove easier when the lines of demarcation are defined in terms of revenues. If partitioning space into distinct regions, such as geospace, lunar space, and outer space (with "outer space" becoming "interplanetary space") proves successful, then perhaps that process, and those involved in it, will break the impasse for the delimitation of air space and geospace that abuts lunar space and interplanetary space.

The geospace is a tremendous, albeit limited, resource that should be strategically managed and tactically controlled. Air, water, and electromagnetic spectrum usage are managed internationally at varying degrees of efficiency and effectiveness, but they are locally controlled because these resources are owned by nation-states. Though the physical world is partitioned to protect and support political and cultural systems, geospace is not configured into zones, regions, or sectors for control or ownership - nor should it be. To manage the physical and electromagnetic traffic in geospace is to do so indirectly by managing information about humans' space activities and their effects on each other and the environment. Moreover, to manage human activity in geospace requires a plan to mitigate operational risks as we continue to exploit and explore in the regime.

One must understand the dynamics of geospace without human activity before beginning the architectural design of a traffic management system intended to mitigate the risks of death, destruction and denial of services. Our remote and in situ space missions have generated volumes of gravitational, magnetic, ionic, gaseous and meteoric data to aid in that understanding. Our spotty, multi-sensory networks provide measurements that enable modeling, which supports mission planning. This yields more data for unifying models, validating them and creating remarkable 4-D, false color simulations and animations. The emulation of that information capability for traffic management may be needed.

Underlying traffic management is the acceptance of loss of life, property and service availability. Our laws accept these events as a matter of human fallibility in the face of nature's overwhelming power and uncertainty. Moreover, the competition, cooperation and conflict extended to space operations from behaviors in air, underwater and on the earth's surface can result in a similar gamut of calamities. The differences between accidents in geospace and everywhere else will be the range of the effects. Geospace accidents will rarely be localized events like air and underwater collisions, which result in zero velocity debris that transition to the Earth's surface or seabed. When accidents between orbiting objects occur, the debris, like the originating objects, remains in orbit to become a hazard to traffic and interfere with transmissions.

A brief examination of the traffic statistics does not set off any alarms, but there are concerns, and budgets have been raised to study and address parts of this emerging domain. First, no one has died in a space traffic accident, to date. Space vehicle failures have taken the lives of several, but those accidents occurred in airspace. Aside from space weapon testing during the 20th century, no operational spacecraft has been totally destroyed by another operational spacecraft. The Hazards of Spaceflight report (International Space University, 1998) stated that spacecraft are impacted by objects from the size of dust particles to spent rocket bodies, which degrade payload performance and damage entire subsystems. The time over which the services provided by space assets are temporarily interrupted is nearly impossible to estimate accurately because there is no organization that requires it - interference reporting is voluntary and stove piped within military, intelligence, commercial, and civil space sectors or by nation-state or political- military alliances.

Space mishap investigations will benefit from a regime that fuses space traffic surveillance and operational reconnaissance after it has coordinated flight plans and hazardous operations. Spacecraft failures and traffic incidents, including near misses and major accidents, usually result in investigations that determine cause and liability. Regular inspections of existing and newly integrated products, processes, and personnel in systems are good safety practices but not fail proof. These inspections are costly and lack uniformity across space systems and infrastructures, which begs the question of whether or not there is value in common standards and practices for space safety at the supranational level. If so, the liability of mishap might be easier to determine and the penalty code could be commonly accepted. Having a supranational regime to administer and update the Liability Convention into policies, regulations and practices amenable to nation- states should create a center of gravity from which to promote new space activities unencumbered by the concomitant safety precautions.

Incidents of radio frequency interference prompt investigative projects of elimination and consultation, sometimes within a nation-state's military and civilian sectors. Emitters or transmitters outside of geospace that deny spacecraft transmissions via uplink/crosslink/downlink - regardless of denied medium of reception or reflection - would not be counted. Operators count the dollars lost to their competitors who have higher availability and reliability. The space insurance industry counts claims, which primarily result from failures, but they will be the first to acknowledge calculated risks of collisions with revealing policy clauses. Operators will be trained to avoid maneuvers and operate through interfering radiation. Ultimately, legislators and courts write the rules to the burden of proof and process of blame in order to establish liability and damages from increasing numbers of uncoordinated and unmanaged human activities.

There is coordination and mission management; however, studies are underway to formalize coordination and management above the national or regional level. The UNCOPUOS has the International Academy of Astronautics (IAA), which is in the process of defining traffic a management rule for space operations. The results of a 90-page draft of their Cosmic Study report reveal that much work remains before the final draft. The International Telecommunications Union Radiocommunications Bureau (ITU-R) has been coordinating inter- satellite services by frequency allotment and allocation for decades. Since their purview ends at 3,000 GHz, they do not regulate lasers, and that will become an issue. Their Radio Regulations document the results of a 5-week negotiation called the World Radio Conference held every two or three years. Those regulations are like international law, which is duplicated in national laws. The Hazards to Spaceflight report also suggested that a space flight authority would be needed, soon. Regional and international congresses, conferences, and meetings have had space flight safety and traffic management on their agendas in recent years. The conclusions are similar; This is a latent issue that will get more attention with increasing death, destruction and environmental damage. The recommendations address several issues: the facilitation of space situational awareness without compromising national security; coordination of operations without compromising advantages in competition and conflict; and the transfer of spacecraft/launcher technology in such a way as to conserve the space environment without violating intellectual property rights or export control laws. It must be understood that there is a balancing loop of causation in the system thinking of space safety. More traffic causes more mishaps, which leads to more regulation, which results in lower traffic growth leading to a decline in the mishap rate. The immediate compliance in new safety regulations can prevent or delay any return to higher mishap rates. The team of players in this system is large, consisting of space and international lawyers as well as subject matter experts in orbital debris, the space environment and space technology. If more cooperation is to be achieved, they must have guidance.

A debate brewing between lawyers and non-lawyers surrounds the question of whether or not organizational development should precede or lead any technological development in order to maintain first-rate traffic statistics for space into the 21st century. At least seven international entities are directly related to this domain. For space weather services there is the Committee on the Space Research (COSPAR); for law and regulation there are the ITU-R, UNCOPUOS Legal Subcommittee and the International Institute of Space Law; and for scientific and technical operations of space flight there are the IAA, the Inter-Agency Debris Coordination Committee (IADC) and the UNCOPUOS Scientific and Technical Subcommittee. These entities have assembled many of the brightest minds in national space agencies, societies and organizations. These professionals understand the uniqueness of space flight today and probably have fueled the lofty prognostications of traffic volume based on a few key technological breakthroughs and United States legislative turns in economic policy and technology export control (i.e., non- proliferation regulations). The fact that the US does not support any organizational development that could weaken its sovereignty by yielding operational decision- making to outside entities presents a challenge, to be sure. What may be needed is a supranational corporation to manage all geospace traffic and technology developments in order to mitigate risks. The enforcement component of a geospace traffic institution would come from the US whose space superiority rhetoric has some analysts and critics think a space weapons race is before us. The international court of justice might have jurisdiction to judge cases from geospace traffic "arrests" and accidents involving two or more international parties.

If one ignores the idealistic incorporation of an operations-oriented, supranational institution without any distinct territory, people, currency and military to perform the singular function of geospace traffic management, what remains are the foci of traffic law & regulation and the technologies that enable traffic safety in space operations. Those technological areas are surveillance, navigation and telecommunications. When conflict or competition erupts involving space assets, the safety-minded traffic managers and controllers will invoke special telecommunication protocols. For example, broadcasts may become narrowcasts at certain times and/or regions. A narrowcast is messaging (e.g., email) or streaming audio/video (e.g., cable TV) sent to subscribers, but the term multicast is commonly used interchangeably. A traffic controller would switch its multi-mission constellation broadcasts off at certain times in specific volumes during conflict to eliminate its dual use services, which might reduce the likelihood of being attacked by an aggressor in the conflict.

Two challenges the supranational entrepreneur faces are the creation of a technical architecture and requirements system and balancing such a system with nations' security, defense, secrecy, privacy, and safety issues.

A cornerstone of effective traffic management is space surveillance. Perhaps the most technically challenging aspect of traffic management, space surveillance, if performed cooperatively, will provide a sense of safety through visibility into recent events. Independent surveillance gathering by traffic managers is a must for verifying traffic. There is a need for space surveillance networks to be interdependent either periodically or continuously to guarantee space situational awareness during surges of space traffic, including debris producing mishaps. A synergistic effect of awareness may be possible if the sets of closed space networks are opened for unified tasking and collection. It may be rare and take a catastrophe for this internetworking to persist, but the space surveillance community should promote standards. A convergence of surveillance and reconnaissance into a common operating picture with uncommonly smart people interpreting the plans and activities would be ideal but remains a quixotic vision. Scenarios of deception by militaries and commercial competitors will slow the processing of a common operating picture for traffic controllers under pressure to notify, warn or command vehicles away from imminent danger. The traffic management center might have to employ two teams to cull out deceptive operations and misinformation, doubling the capital investment of the surface segment computing machinery, software and personnel. The US military and a few others have mastered small-scale network architectures that are balanced by requirements engineering of the sensors calibration, surveillance coverage, and detectable objects to create a family of pictures for combatant commanders and their battle staff. The enterprise of geospace traffic management will need to leverage the engineering of these efforts to minimize its non-recurring engineering development costs.

Navigating around large structures, debris toriods or questionable conjunction ellipsoids will not be easy for many spacecraft without a refueling and/or assisted velocity control infrastructure. Spacecraft not hardened and artificially intelligent to anticipate and react to damaging EM energy, which military and industrial developments (e.g., space-based laser or solar power stations) aspire to deliver are reasons this author proposes that electromagnetic spectrum management be part of geospace traffic management. A global utility service of astronautical guidance, such as the US NAVSTAR GPS that provides orbital navigation signals, may be needed, but few groups seem to be brainstorming to provide any solutions.

The Earth Outer Space Organization is studying a highly elliptical and spherically symmetric constellation for optimal navigation up to super-synchronous altitudes (<100,000 km). The baseline constellation is derived from the 20 vertices of a dodecahedron, where 2 orthogonal orbital planes per line of apsides (i.e. vertex) are oriented to be isogonal with respect to both sets of 20 planes; the two satellites per orbit are phased with respect to the others so the range between the nearest satellite to an earth-centered inertial platform is minimized for surveillance and cellular communications with traffic and the geometric dilution of precision is maximize over all inclinations and orbital altitudes to 50 Mm. The value of this constellation design as a system solution is that national surveillance, navigation and telecommunications assets can be used to cover the "hot" regions of debris and traffic while the core constellation provides a predictable, accessible and broader coverage area to reduce the element of surprise. Lastly, a microelectronics or photonics breakthrough that delivers the equivalent of an aircraft's black box in the form of a "black chip" might enable supranational regulators to promulgate the integration of these low mass/power devices for space traffic safety. Whether the space object is a picosat or the International Space Station, communicating, reconnoitering, and navigating periodically or continuously decreases the safety risks before, during, and after mishaps. Concurrently, the steps of equipping space vehicles with safety devices, training space operators using simulators, exercises and games have to be linked with a licensing regime in order to bolster a liability framework with ever more rules and penalties.

The evolving space safety practices published as handbooks, standards, or guidebooks specifying debris prevention and mitigation requirements of space programs will remain rooted in national space agencies. But eventually it will be influenced by a supranational or a stateless corporation delivering traffic safety services. Such a relationship between national space agencies and the supranational body will function as a standardization body of mechanical, materiel and chemical interfaces.

The informational interconnect between traffic control systems of the airspace and geospace will be a technical development as much as a social and political one. The International Civil Aviation Organization (ICAO) is the single point of contact with doors to the military portions of the air domain. Protocols for handover of spacecraft and warning airspace controllers of non- cooperative space objects, which are about to become air objects, has a high priority in the enterprise. A similar protocol must be developed for space systems that are large, complex or secure enough to claim a proximity zone around themselves such as the International Space Station. Proximity controllers and geospace traffic controllers will hand over vehicles and communicate information regarding space weather phenomena. A traffic control system configuration for collective sense-making under pressure of conflict between nations in space must be thought out or this system might fail to materialize or exist as adversaries prepare the battle space (i.e. blind and make deaf all sensors that threaten combat operations). Information operations and non-cooperatives are arguably the largest threats to this concept.

To manage geospace traffic is to manage the risks inherent in the chaos and complexity between nature and human activity. Geospace traffic managers will form the basis of a highly reliable organization designed and operated to respond and react to losses in an endless race to be superior, secure, successful and safe, simultaneously. The uniqueness of spaceflight and the vastness of outer space might permit the incorporation of a true supranational regime to control traffic and mitigate incidents and accidents in this frontier.

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