EXTENDING COOPERATIVE STRATOSPHERIC OPERATIONS TO SPACE

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ABSTRACT

The Karman line marks the extent of feasible air travel and is a presumed boundary between ICAO and UNOOSA authority. Though the stratosphere is not consistently regulated around the globe, the risk of collision between aircraft, sub-orbital space flights, and vertical space launch operations occurs largely in this airspace. While notice is made of space activity, there is not follow up to ensure the stratosphere is free of aircraft at the time of space activities. In developing a surface-to-space architecture, that links on-orbit activity back to pre-launch and transition through congested airspace, MITRE and the Aerospace Industries Association realized a potential solution to address the gap in governance for high-altitude airspace. This paper presents principles for cooperative stratospheric operation and relates them to the contested nature of operations and controls for managing risks in low earth orbit operations. It defines how surface-to-space traffic management uses cooperative operations to manage acceptable risk for parties with different risk appetites.

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THE SHRINKING DIVIDE BETWEEN AIRSPACE AND OUTER SPACE

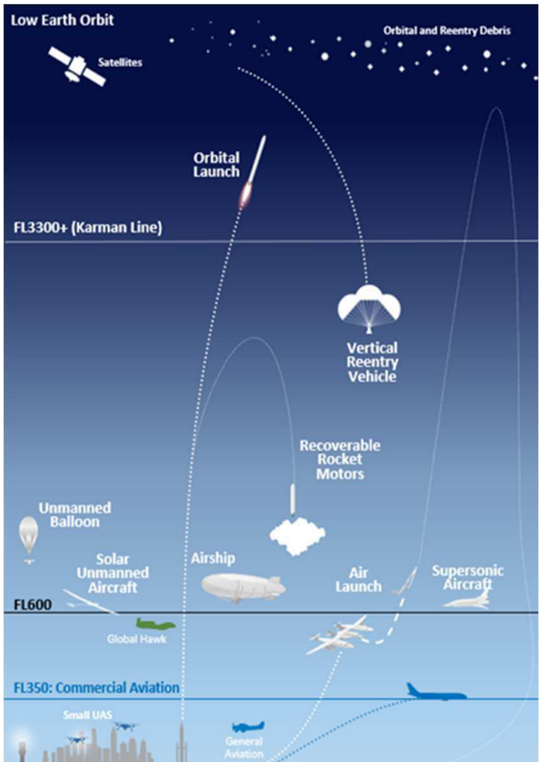

Exhibit 1 – Surface-to-Space Environment

Today, air traffic control clears airspace for orbital and sub-orbital operations, including potential hazard areas. This process protects both the aircraft and spacecraft from potential collisions. However, operations in the stratosphere are not consistently regulated and the path of (sub)orbital or launch trajectories are not routinely deconflicted. Like space, most stratospheric operations do not benefit from traffic management-type services, nor is there continuous surveillance of all moving vehicles.

Until recently, the vast region that stretches above commercial jet traffic and up to low earth orbit (LEO) has largely been uninhabited with few, if any, associated traffic management services. However, in recent years, a strong uptick in orbital and sub-orbital commercial space operations, as well as new vehicles planning to linger in the stratosphere, have increased the region's profile.

Stratospheric operations exhibit characteristics of both air and space vehicles. Companies are keen to deploy highly automated fleets that will linger for months in the stratosphere, providing services that rival space-based satellites (telecommunications, earth observation, surveillance, etc.). The purpose-built characteristics of these vehicles often results in various levels of maneuverability, including some vehicles with high susceptibility to wake or winds. Consequently, the vehicle trajectories will need to be deconflicted in advance to avoid airspace in use by transiting commercial space operations and/or hazard areas from possible termination during launch.

At the same time, satellites in LEO are evolving to take on characteristics like vehicles in the stratosphere. New business models that aim to blanket the globe in coverage require satellites to maneuver on orbit. Additionally, the number of satellites in this region has been rapidly increasing in recent years, which creates the need to manage the increased density. Fleet or constellations of vehicles with an integrated mission, and more autonomous control for that purpose, are also a characteristic of both domains.

With continued air and space operations growth, there is an increased need for traffic management systems to safely manage high altitude airspace. Any new system will require improved coordination among operators in order to strategically identify and deconflict trajectories. The similarity between space and stratospheric challenges and operations offers the basis for interoperable traffic management from surface to space.

In fact, both domains become increasingly more viable if the regulatory and traffic management environments are globally harmonized and interoperable. Unlike the low altitude traffic management concepts being developed independently around the globe [also known as unmanned aircraft systems traffic management (UTM)] for relatively localized operations, high altitude and space operations will typically traverse great distances and multiple countries' airspace over extended periods of time. Thus, the more consistently these two regions are managed, the better. In other words, there is considerably more at stake if a fragmented system were to emerge, as opposed to a collaborative approach.

This paper presents the principles for cooperative stratospheric operation as proposed by industry, NASA, and others. It describes how community traffic management, via multiple platform service suppliers (PSS), could enable operators to cooperatively manage acceptable risk and mission success for parties with different risk appetites. It

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then relates this concept to the challenges for controlling risks in LEO operations. We will show how these techniques may be extensible beyond high altitude airspace, creating a more seamless surface-to-space traffic management for the air and space communities.

CONCEPTS FOR COLLABORATIVE TRAFFIC MANAGEMENT IN THE STRATOSPHERE

In 2019, industry from around the world, led by the Aerospace Industries Association (AIA), developed a concept to address stratospheric traffic management needs.[1] This concept, known as Collaborative Traffic Management in the Stratosphere (CTMS), places accountability for mission and safety assurance on each operator. Each operator must balance their mission need for maneuvering with the risk of collision or other undesirable events that a maneuver might entail. The safety performance of new manned and unmanned operations must be understood by its operator as part of a new risk-based framework, defining the acceptable risks for their own and other's operations. Similarly aligned concepts of a of "flight centric traffic management" are part of the German Aerospace Center's near space operations.[2]

In the concept, operators are expected to provide their intended business trajectory, track their own vehicles, and forecast future location to determine any course changes to support their mission. A PSS [rooted in the unmanned aircraft system service supplier (USS) and referred to in other concepts as a traffic manager or xTM] aids with the surveillance, conflict identification, weather, and other basic services to support the forecast. PSSs may specialize in handling certain types of operations, tailoring their services to the unique performance and mission complexities of different operations. With multiple PSS providing independent sources and monitors, operators can benefit from the collective picture with the assistance of all available surveillance and weather sources to reduce uncertainties in position or forecast trajectory. By sharing intent data, PSSs function as an intermediary for operators, like the Space Data Alliance, to support strategic deconfliction. A Discovery and Synchronization Service (DSS) with blockchain-enabled means of information sharing to protect and authenticate exchanged information as operators and PSSs connect[3].

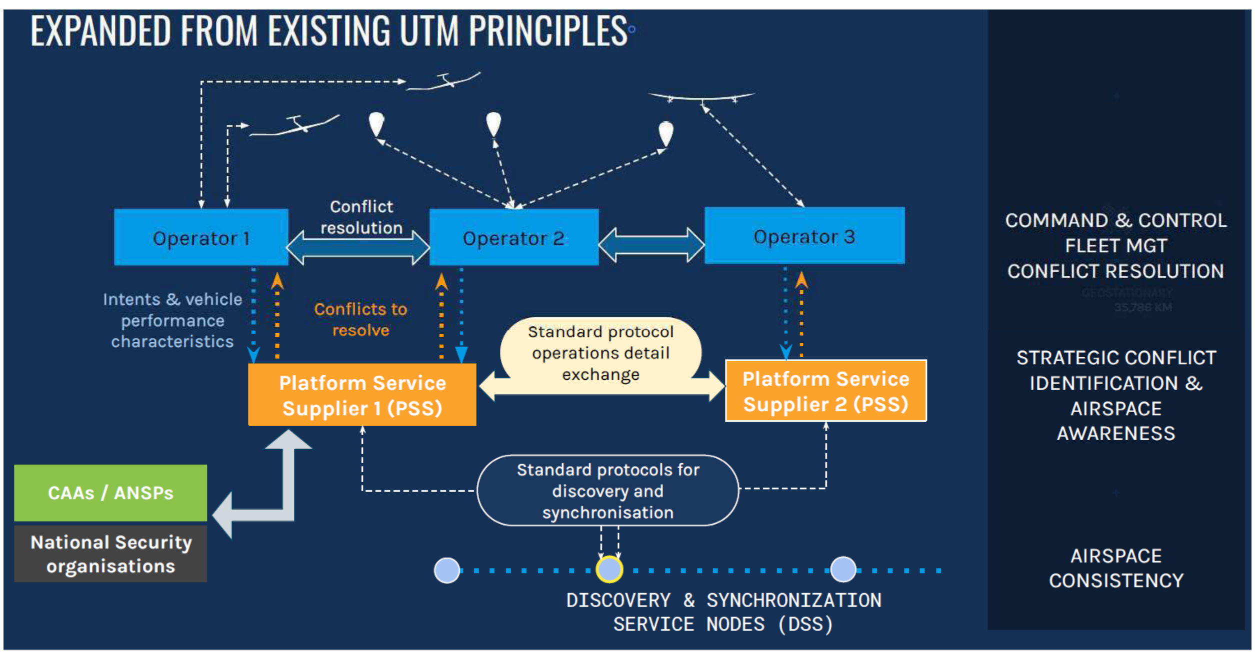

Exhibit 2 – CTMS Proposed Architecture (Source: ICAO Drone Enable CTMS Presentation)

With each adjustment in intent, including pre-departure planning, new risk is introduced for existing operations. That risk is mitigated by an operator sharing intent prior to these maneuvers. A PSS will process this updated information, then adjust the collision risk assessment and highlight potential risk areas. Once warned of a significant

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new risk, the affected operators can seek additional information through the PSS to reduce forecast uncertainty and refine their risk estimation. Through this exchange the involved parties can understand each other's urgency and timing of any maneuvers, gaining the clarity they need to cooperatively negotiate a strategic deconfliction.

Strategic deconfliction allows the possibility of negotiation up until the moment one of the parties reaches the time at which they must act to avoid unacceptable collision risk.[4] Operators know their mission and safety risk appetites and can translate these into the time for action to manage those risks. The timing of decisions is critical to the exchange. These actions can be on human or autonomous decision-making time scales. When the conflict falls within the control window where one of the affected parties must act, then a tactical resolution, without the benefit of negotiations, will be necessary.

In some cases (e.g., a failure, environmental conditions), a change in intent may not be able to be shared beforehand. In these cases, the operator will share anomaly reports or non-conformance warnings and error estimates for the forecast flight path.

The conventions for negotiation must offer an incentive to cooperatively resolve conflicts in a strategic time horizon. However, rules for tactical interactions are necessary as a secondary level of conflict management. Conventions (like rules of the air with attribution after the fact, and not a central control in real-time) will be needed to shape negotiations so that operators will cooperatively resolve conflicts. These include right-of-way and conditions that determine how tactical conflicts are resolved when the warning time is insufficient for negotiations. Historically rules of the air are based on assumptions about intent and similar performance for setting separation standards and simple patterns for tactical maneuver.[5] The rules of the air in the stratosphere must go beyond those simple factors to account for richer knowledge of the intent, differences in mission constraints, physical performance, navigation, surveillance, the presence of non-deterministic or conditional intent, and more complex response issues. The convention must account for these properties and the differences in risk appetite (i.e., people on board or not), which are similar to the LEO environment.

The industry concept and current convention allow state-owned aircraft to forego operational information sharing. Without regulation to compel cooperative traffic management system participation, it is possible there could be civil vehicles outside the system, as well. However, many of these vehicles are likely to be known to the system as they will have to transit controlled (Class A) airspace to reach the stratosphere. To address this potential information sharing deficiency, the system must be failsafe to account for the possibility that non-cooperating operators might be discovered or maneuver into the path of others on a tactical conflict resolution timetable. There is some practical limit on the number of non-cooperating operations for this concept to function effectively.

Tenets for Cooperative Operations

The CTMS concept builds on NASA unmanned vehicle traffic management concepts that have been suggested as a basis for space traffic management (STM)[6] and stratospheric operations.[7] It is consistent with ICAO agreements that call for greater reliance on private support services.[8] All these traffic management concepts address common themes, such as operations in areas where surveillance is not assured, the ability to accommodate large differences in vehicle performance, varying levels of uncertainty, and the potential for sudden changes in intent. Collectively these tenets are useful for creating compatible traffic management solutions that span from surface-to-space.

- Identification and authentication
    - Ensuring legitimacy of information and accountability by the one negotiating
    - PSS as intermediaries allow some anonymity while providing a means to authenticate information
- Intent, aeronautical performance and mission constraint sharing
    - Varying types of intent to represent different missions
    - Performance and ability to control (physical constraint)
    - Important constraints in the mission profile (non-negotiables)

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- Strategic conflict identification
    - PSS discovery services help pair those requiring further engagement and collaboration
    - Conflict management warnings must account for risk appetite of involved parties (e.g., a research satellite with as short life vs. an object that is part of a significant constellation investment) and the larger community risk appetite (i.e., interest in avoiding lasting capacity loss to collision debris)
    - Risk urgency will range from wait-and-see to act now, with the middle ground allowing increased information exchange to reduce uncertainties in forecast events
    - Conflict resolutions may consider constraints in the mission plan, if the resolution would preclude one of the parties from successfully completing their mission
- Sharing state data on request to reduce uncertainty or formulate resolutions
    - Where risk is inconclusive as to the need to act, share sources of uncertainty
    - Share decision points – look ahead time and decision point will vary
    - Seek information or state changes that will drive action by the first party
- Continuity of operations
    - Preplanned contingency intent for certain state changes
    - Dynamic emergency procedures for certain state changes
- Tracking and conformance
    - Own ship must be known in position and other state variables for projecting the intended path
    - Self-manage conformance to published intent, or amend intent
- Conflict resolution with other vehicles
    - Largely occurs in pre-tactical time frames to identify mutually agreeable outcomes
    - States have the authority to establish enforceable rules for their sovereign airspace
    - Tactical resolution according to rules serves as a fallback
- Limited non-participation
    - State operated vehicles are not required to participate in collaborative operations in the stratosphere and there is no convention on orbit to compel participation
    - These vehicles must be capable of monitoring potential traffic directly and monitor the intent and actions of others through a PSS
    - They are accountable to maneuver to avoid others, always yielding the right of way

SPACE AND STRATOSPERIC TRAFFIC MANAGEMENT NEEDS

These tenets have a strong connection to the challenges experienced in LEO and STM needs. As described above, collaborative traffic management is not a control service, but a system of advisories and warnings which allow operators to manage their risk. It is not founded in regulation, but in a convention that creates orderly flow out of distributed decision making. To understand its STM implications, we consider space industry inputs regarding the challenges and needs for Space Situational Awareness (SSA) to identify the similarities, differences, and touch points between air and space traffic management.

Space Industry Input on SSA and STM

There have long been questions as to what is necessary for STM. What kind of data repository is necessary to facilitate greater data sharing with satellite operators and enable the commercial development of enhanced space safety services? What key aspects of nongovernmental SSA and STM products, technologies, and approaches will enhance current publicly available SSA data and STM services? Is STM only a set of advisory services to identify risks or does it do more? And, under what regulatory structure should space operate? In April 2019, the U.S. Department of Commerce (DOC) Office of Space Commerce published a notice seeking input on SSA data and STM.[9]

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About half of the industry comments to the DOC proposed a commercial PSS to help create a real-time catalog with validation of intent for dynamic space operations. Combining this space picture with the stratospheric picture would help ensure launch operations, sub-orbital flights, and multi-satellite deployments are planned with a more precise and complete picture of potential encounters.

Nearly a third of the DOC inputs recognize the space environment will truly be dynamic, so real-time coordination and risk assessments will be required. Without the benefit of collaborative data sharing, individual space operators are likely to have unmanageable numbers of predicted conjunctions. Understanding the quality of those assessments and being able to ask further to reduce sources of uncertainty is key to avoiding high false alarm rates, adding extra margin, or reducing effective capacity of the stratosphere or LEO.

Several commenters suggested creating a more robust surveillance in space or from the ground. Others sought to network existing governmental surveillance and tracking capabilities to inform space operators. Alternatively, there were calls for better risk models to reduce the need to create more surveillance capability, and proposals to further involve operators in continuous negotiations and sharing of their own tracking information.

Industry noted anomaly detection and diagnostics of sudden intent changes are essential to characterizing risk and providing better situational awareness. While this paper talks to physical encounter risks, a similar risk model could exist for radio interference to inform maneuver and transmitter management decisions.

Similarities in Stratospheric and STM Needs

Similarities in the orbital and stratospheric environments create an opportunity to revisit the emerging stratospheric concepts for applicability to STM. Both concepts depend more on operator self-interest in protecting their operation from collision, than on a robust regulatory environment. Both rely on quantifying risk and the ability to identify sources of uncertainty to inform operator decisions. Industry, in both cases, has expressed a willingness to share information through third-party PSSs to protect sensitive information, while still informing others of factors that affect projected collision risk.

Operators would continuously update their intent. Since government-furnished surveillance is not complete, operators are the best source of tracking information for their own objects. The PSSs need to take in the intent, position, and uncertainties to continuously update risk assessments throughout the operation. Individual risk-based decisions must account for the immediate risk of that action. The conventions for negotiations and tactical resolutions must contain the cumulative long-term risk of all operations to the space ecosystem. All operators must be good stewards of their environment in order to maintain public support for continued commercial operation.

Missions in both domains can extend for a months or years, leading to uncertainty in future intent or trajectory. Both space and stratospheric balloon operations exhibit non-deterministic behavior with uncertainty that grows over time. Therefore, decision-making timing is key to avoid reacting to false alarms. At the same time, limited maneuverability and varied forms of mission intent makes it critical that trajectory deconfliction be predicted and resolved well in advance. Overly simple right-of-way rules could open the door to less-maneuverable vehicles occupying valuable positions or orbits for extended periods as an area denial maneuver. Conventions for negotiations must account for and limit this potential behavior.

Fleet or constellation operations may use swarm logic to assure best positioning to assure the mission. These systems are high sensitivity to initial conditions and control feedback loops that depend on the decision of other vehicles in the fleet. These systems generate behaviors that could be described with chaos theory. These are factors in the predictions of conjunctions that will add uncertainties which can only be resolved with the knowledge of the fleet swarming logic.

Conflicts between unmanned vehicles and manned vehicles pose the challenge of resolving two very different risk appetites under the same flight rules. There will need to be additional precautions or structure to balance the risk appetites, otherwise manned operations will be at a disadvantage when negotiating strategic maneuvers, which

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may not be practical in applications such as low boom supersonic transport where significant mission constraints exist in order to limit sonic boom exposure.

Both environments must contend with some remaining unknown risks due to the presence of non-cooperating operators and/or debris. If a non-collaborating operator performs an unannounced maneuver, even though they have accepted liability and are monitoring and avoiding potential risks, it could still pose a risk to others. There is also risk associated with debris encounters, including that from burnup on re-entry. The coalition-of-the-willing must include most of the operators, as non-cooperating operators pose the greatest risk to each other and to the system.

And finally, both domains are global in scale crossing multiple boundaries. This creates the possibility of perceived or actual threats from these vehicles. The Woomera Manual Project is an international research project working to objectively articulate and clarify existing international law applicable to military space operations.[10] The definition of hostile acts would be part of the conventions for negotiation. So, the conventions could include clear lines that are not to be crossed without raising potential international incidents.

Differences in Stratospheric and STM Needs

Some contrasts between the stratosphere and LEO will create boundary conditions and conceptual differences. These will need to be managed in order to create a seamless surface-to-space traffic management environment.

First, the consequence of a collision in space is significantly more lasting in the ecosystem due to the Kessler effect. The lasting loss of capacity and future opportunity put space safety assurance at an even higher level than commercial air operations. The individual operator may not be able to fully account for the loss's magnitude in their risk calculations (i.e., negative externalities). Yet there is no enforcement of that target safety performance as in space there is no equivalent of a flight information region to enforce conflict resolution rules. While each space operator could follow 'rules of the sky' set by the state that authorized and accepted liability for them, the common denominator is committing to a lowest acceptable risk appetite for all operations. The acceptable level of safety risk should be much lower in space due to the long-term negative consequences to the environment generated by collisions.

Second, many commercial space operations are in their early development and consequently have a lower reliability, leading to a disproportionate number of off-nominal events. These events introduce forecast errors that do not follow any stochastic model, but instead reflect deviations from projected intent. These are pop-up events and minor failures that may occur with minimal notice. Space operations may need margin in projected collision risk to account for a greater rate of uncoordinated changes and contingency events. This also includes significant uncertainty for re-entry event timing and location. These rapid change of plans like rocket motors returns, horizontal launches, and re-entries with an undetermined burn up altitude may also occur amid stratospheric operations.

There is a potential difference in surveillance fidelity and availability. Both communities have considered transponders as a part of the concept, but there is no firm answer. Communications links with the ground stations might also provide reliable location information in real-time. In the absence of cooperative, continuous surveillance, assets must be tasked to provide greater detail for the resolution of near conflicts.

Lastly, space has significant amounts of debris. The trajectory of these objects is an extrapolation of its momentum and represents great unknowns for operators. Debris presents recurring risks for orbital operations, and so, can be monitored. However, that means most of the risk in space is from objects with which operators cannot negotiate.

Interactions between Stratospheric and Space Domains

Under the CTMS concept, space operators would participate in stratospheric collaboration: sharing intent to inform others and manage their own collision risk on their way to orbit. In most cases, initial intent will be known well in advance of launch (or reentry), however the speed and trajectory by which these vehicles transit the stratosphere will pose some challenges. To address this, the conventions for right-of-way will need to consider the

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risk appetite, stated mission constraints, operational performance, non-deterministic behaviors, and uncertainties including those due to surveillance. In particular, shared intent would include preplanned contingency events or autonomous maneuvers with conditional changes in intent, such as where booster rockets might return under different conditions. The form of these variable intent statements is important, as there would not be time for prior coordination of intent changes initiated by autonomous decision makers.

Participation in stratospheric collaboration would be most critical to space tourism operations, as they will likely spend most of their flight in the stratosphere. Suborbital space tourism launches would be a routine short duration interaction for space and stratospheric operators. Some of these concepts involve a stratospheric launch and a recovery phase. The timing and location of horizontal launches would offer the opportunity to use structure to organize the airspace for this unique purpose. Reusable launch motors that return to barges or drop in the ocean are another dual launch and recovery operation that would fit under the intention sharing concept for other stratospheric operators.

The longest strategic deconfliction horizon is likely the launch operation itself. Launches and de-orbits would also be treated as maneuvers with an expectation for timely notification to allow negotiated strategic deconfliction. A mission broker for space operations could work the scheduling for strategic deconfliction between launch sites, space operations, and other special events accounting for both nominal and scrub dates. That would avoid cascading delays in launches due to scrubs or other maneuvers.

Other forms of manned space flight to and from LEO and the cargo operations to support humans in LEO will add separate launch and reentry encounters that are days apart. Without a seamless traffic management approach, these operations will appear to the CTMS concept as new operations that begin at the boundary of the stratosphere, just like other operations in the CTMS concept. In a seamless traffic management approach, the intent would start at pre-launch or re-entry.

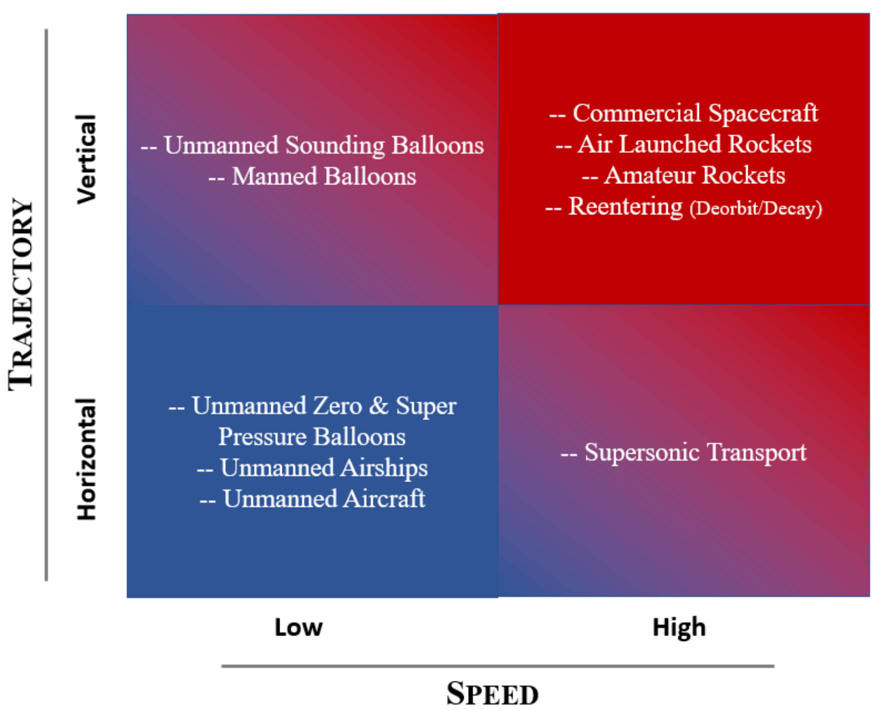

Exhibit 3: Anticipated Vehicles in the Stratosphere[11]

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The last form of interaction is the intentional re-entry to burn up, with the intent being the operation ends and the objects disappear from surveillance before reaching the ground or the lower end of the stratosphere. The challenge will be in projecting the intended path or monitoring these objects for possible stratospheric interactions.

EXTENDING THE COLLABORATIVE CONCEPT BEYOND THE STRATOSPHERE

The MITRE Corporation (MITRE) developed a surface-to-space architecture which recognizes the need for compatible traffic management across all domains. It envisions a surface-to-space traffic management function that runs from pre-launch through continued operations with maneuvers on-orbit. Traffic management in this case does not refer to a control authority, but to the collaboration by which the operator makes decisions to manage their own mission success and risk.

This architecture does not claim to have the answers, but a representation of future operations based on a variety of industry inputs described previously. It allows community members to pose and answer questions about roles and responsibilities, conventions or norms, timing of decisions, and functional gaps in the proposed systems. It is used here to highlight the questions and decisions needed to converge on a solution that works for the air and space communities.

MITRE is researching a risk assessment approach for high altitude encounters to inform those conventions or rules of the air. A continuous risk assessment from each object's perspective would inform the timeline for intent notifications, and collaboration to reduce false alarms. The risk model should provide greater clarity for strategic deconfliction on a pairwise basis and inform how high-altitude conventions could carry over into space.

Collaborative Traffic Management for Space Operations

Once reaching orbit, maneuvers on orbit could be managed through the same means as they used in transiting the stratosphere. Each operation would have the benefit of continuous steady state risk monitoring to inform contemplated maneuvers for mission success or safety risk mitigation. For space, a major portion of the risk assessment will be about the debris and other items with a non-deterministic intent. Should a forecast risk begin to rise to the level of a warning, refining those warnings will occur through collaboration and enquiries into uncertainty. As industry suggested in its DOC inputs, additional surveillance or devising ways for PSS to pool the community surveillance picture in space may aid in reducing the uncertainties and false alarms. One study MITRE is undertaking as part of the surface-to-space initiative is to understand how risk, intent uncertainty, surveillance, and information networking can reduce these alarms.

Another major question for both domains is when intent must be shared to allow a negotiation period. This will partially be influenced by closure rates, which can be very rapid at orbital and hypersonic speeds. If intent is shared after the strategic horizon, then the only response of the affected operator is a tactical avoidance maneuver. Tactical maneuvers may cause a runaway cascade of maneuvers. Thus, every effort must be made to ensure that intent is shared early enough to avoid notification inside the tactical adjustment window for the affected party. Operators will know of potentially affected operations for a contemplated maneuver via PSS services. From the assessment, the operator should understand the lead time needed for sharing intent changes. The operator should share its intents as soon as possible with the PSS, which could share the information and risk assessment with the affected party as an alert on a much shorter time horizon, depending on the relevance of the conflict and uncertainty behind a possible false alert. Whether humans are in the loop or automation is making the decisions to maneuver the sequence of events ideally should create a sequence, see exhibit 4. For the conventions to allow for negotiation, the one contemplating a maneuver will have to know and meet a look-ahead time of the affected operator to avoid cascading effects.

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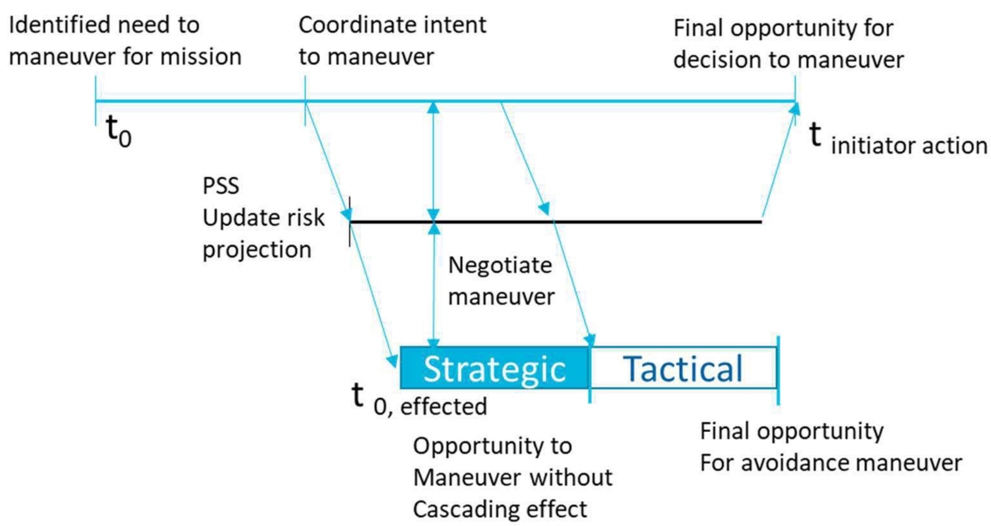

Exhibit 4 – Collaboration Timing to Avoid Cascading Effects

The conventions for conflict resolution through negotiation are the most important development for each domain. The conventions should match the specific level of collaboration throughout the detection, comprehension, communication, and resolution between the operators. The conventions must consider the decision point for each operation and its performance to determine who has a right of way, who will take the lead in collaboration and who makes the final tactical decision to resolve the conflict.

Addressing the Differences for Space

The lasting consequence of LEO collisions makes any collision, independent of risk to life, an unacceptable outcome because of the risk of debris generation. The space community will have to test their solutions with greater consideration of the Kessler effect when setting the look-ahead time for planned maneuvers. Given the heightened consequences, what should the conventions or rules of space be to reflect the magnitude of that risk? Can agreement on some cumulative risk be an answer (e.g. maximum expected collision risk for the entire system or minimum years between collisions)? And how is it allocated to individual operators?

> The acceptable level of risk in space pushes back that look ahead time, changes the risk calculations and places greater emphasis on collecting and networking information to reduce uncertainty in the forecasts.

Space involves more complex forms of intent, with many off-nominal branches and a greater role of autonomous mission management and contingency resolution. Contention between strategic intent may be viewed differently as each operator is working both risk and mission assurance decisions on a mixture of human and automation timetables. The space community is defining some of these more complex maneuvers even as deployments are already underway.[12] What can be shared in the autonomous environment to maintain SSA and accommodate autonomous planning/maneuvering decisions?

> The intent information defines the business objectives and nominal course of action to fulfill them. With increased automated response to situations, it will be necessary to explicitly describe pre-programmed contingency intent for off-nominal events. Risk assessments from a PSS will have to consider possible off-nominal or pre-planned events by passing operators in space.

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The space environment risk will be dominated by non-cooperative debris. What can be done to reduce the false alarm rate? And, how can a collaborative traffic management system counter the dominant risk from these events to prevent cascading avoidance maneuvers?

> Space situational awareness will require a real-time catalog for dynamic space operations. The main issue is knowing the magnitude of maneuvers and their relevance to the strategic coordination time horizon which must be shared. This relationship also must understand those maneuvers operating on a human decision-making timescale and which can be allowed as machine to machine collaboration. CTMS envisions to take the decision timescale as a factor. Some decisions may be automated, some may involve humans. Latency to communicate the change of plan to the vehicle will also be part of the computation. Studying performance-based rules of the stratosphere and sky will work out the relationship between risk assessments and the negotiation timeline. MITRE is studying form and timing of the shared intent, the risk appetite, and look-ahead time through the high-altitude airspace and its potential application to space risk assessment.

Seamless Surface-to-Space Traffic Management

The similarities between space, the stratosphere, and transient operations between the two, may advocate for a shared set of PSS or separate platforms in each domain that coordinate on behalf of the operators. A common theme is the idea of risk assessments for the individual operation accounting for all of its potential interactions. An agent-based model could represent each object as its interactions, intent, and risks. These models could continuously be fed with relevant data to its intended path and operations to monitor risk. This is a departure from monitoring the space or airspace as a region to look for potential collisions. These models could span multiple domains and move with the object(s) through the domains they transit. They could tie together multiple objects such as a rocket with its reusable engines or a fleet or a constellation with a shared behavior.

Whatever the solution, it requires a means for expressing complex intent, pre-conditional and autonomous actions, and the timing of notifications and conventions for negotiated actions. The intensifying deployment of operations in space and the stratosphere is already underway. The community must begin to work through these significant questions.

However, it is achieved, seamless surface-to-space traffic management would provide operators that pass between domains the insights they need to decide on and manage their own risk to both mission and safety. That should be the objective of the traffic management paradigm for each domain. Using industry inputs on SSA furnished to DOC and the industry CTMS concept, we believe it is possible for the community to move forward toward a more seamless surface-to-space traffic management.

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[1] Collaborative Traffic Management in the Stratosphere (CTMS), Presented at ICAO Drone Enable in November 2019, Montreal

[2] Towards a Near Space Operation Management, Sven Kaltenhäuser, German Aerospace Center, DLR, 70th International Astronautical Congress (IAC), Washington, USA, 2019

[3] International Space Reference Architecture, Nathaniel Dailey & Harvey Reed, The MITRE Corporation, 70th International Astronautical Congress (IAC), Washington, USA, 2019

[4] U.S. Federal Aviation Administration, Flight and Flow – Information in a Collaborative Environment (FF-ICE) Execution, Initial Concept of Operations, 2019

[5] Analysis of Separation Minima Using a Surveillance State Vector Approach, Tom G. Reynolds & R. John Hansman, 3rd USA/Europe Air Traffic Management R&D Seminar, June 2000

[6] Prototyping Operational Autonomy for Space Traffic Management, Sreeja Nag, David D. Murakami, Nimesh A. Marker, Miles T. Lifson & Parimal H. Kopardekar, NASA, 2019

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[7] https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20190033109.pdf, Upper E Traffic Management (ETM) Concept, Parimal H. Kopardekar, NASA, 2019

[8] Unmanned Aircraft Systems Traffic Management (UTM) – A Common Framework with Core Principles for Global Harmonization, International Civil Aviation Organization (ICAO), 2018

[9] Federal Register, Request for information, Department of Commerce, 2019

[10] Woomera Project Manual, The University of Adelaide, The University of Exeter, the University of Nebraska and the University of New South Wales – Canberra, 2019

[11] Framework for Evaluating Traffic Management Services in Higher Airspace. The MITRE Corporation. Presented at University of Texas, Austin, February 2019.

[12] Update on the Consortium for Execution of Rendezvous and Servicing Operations (CONFERS), Brian Weeden, Secure World Foundation, Feb 2020

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