SURFACE TO SPACE INTEGRATION: Mixed Use of the Aerospace Domain

Mr. Andy Anderegg
The MITRE Corporation, United States, aandereg@mitre.org
Mr. Christian Zur
U.S. Chamber of Commerce, United States, czur@uschamber.com
Mr. Bob Porter
The MITRE Corporation, United States, rporter@mitre.org
Dr. Joseph Johnson
U.S. Chamber of Commerce, United States, jjohnson@uschamber.com
Mr. Dean Fulmer
The MITRE Corporation, United States, dfulmer@mitre.org
Dr. Scott Kordella
The MITRE Corporation, United States, kordella@mitre.org

Commercial space launch and reentry operations have been increasing in frequency. This increase will strain the shared use of the national and international airspace. Commercial airlines, business and private aviation and the US military have worked closely with the FAA, NASA, and the national security establishment to accommodate the current launch needs. However, even the current schedule, with fewer than three launches per month on average, already exacts an economic toll on these operators, their passengers and customers as huge swaths of airspace are closed to accommodate launch and reentry. Conversely, increased diversity in air operations also pose greater risk to space operation cancellations. In this paper we establish a risk analysis framework focusing on strategic, operational, and tactical challenges associated with the shared use of airspace and present an architecture for future surface to space operations which addresses these challenges through policies, procedures, and practices. In creating this framework, we identify some of the seminal questions for the successful development of this new industry, commercial aerospace.

I. COMMERCIAL SPACE TIPPING POINT

Commercial space launch and reentry operations have increased in frequency over the past decade. The Federal Aviation Administration (FAA) has granted an increase in the number of launch sites, or spaceports, in recent years. In FY2018, FAA licensed 35 operations to include 32 launches and three re-entries. In FY2019, there were 43 scheduled launches with over 50 anticipated in future years.[1] Space tourism and other forms of horizontal launch will add new launch and re-entry points to an already busy and complex air and space operation. This increase will strain the shared use of the national and international airspace.

Commercial airlines, business and private aviation and the US military have worked closely with the FAA, NASA, and the national security establishment to accommodate the current launch needs. However, even the current schedule, with fewer than three launches per month on average, already exacts an economic toll on the airlines and passengers as huge swaths of airspace are closed to accommodate launch and reentry.

Currently, the FAA manages space launch and re-entry operations by segregating space and aircraft operations. This approach closes a volume of airspace for the exclusive use by a space operator for a window of time. The same may be done for air operators and special events using Special Use Airspace (SUA) to manage safety risk. The closure translates into a loss of access and even may jeopardize predictability for scheduled operators due to increased distance flown, extended pilot and crew duty cycles, ground-based gate slot management interruptions, and added fuel burn. Each scheduled launch even may have multiple cancelations and long windows to account for the uncertainty of the conditions and reliability of the systems. This approach is not scalable commensurate with anticipated future launch and re-entry activities.

At the same time, increasingly diverse air operations test the scalability and agility of air traffic management and challenge the use of segregation of airspace for all operators. Dedicated airspace is not fool proof. Space launches have been cancelled for flights that violate a SUA or when aircraft that are part of a mission are inadvertently denied access. At scale, launch facilities need assurances they can operate on a schedule without interruption by airspace violations. The segregation approach represents an airspace access risk for space operators.

Approximately 1,200 commercial airline flights were rerouted or delayed accommodating launch and re-entry operations resulting in an estimated 39,000 additional miles flown, in 2017.[2] By contrast, a single aircraft straying into the hazard area has scrubbed a launch resulting in cancelation and losses that exceed the air operator costs to avoid the area.[3] The challenge to safety, access and predictability are bi-directional. As unmanned aerial systems (UAS), space tourism, sub-orbital and orbital operations grow in number and diversity, mixed use of the aerospace domain will be essential to manage the safety risk without further compromising predictability or access for air and space operators.

In this paper we establish a risk analysis framework associated with the shared use airspace by air and space operations. The framework can help organize community efforts to resolve the challenges and implement solutions to the seminal questions of safety, airspace access and predictability for future space and air operations.

The paper is organized as follows: Section II describes the challenges associated with surface to space mixed use. These challenges are described as being at a high strategic level, requiring new policies, at an operational level, requiring new procedures and at a tactical level, requiring new practices. Section III introduces a Risk Analysis Framework and delineates several risks associated with the mixed architecture which must be addressed. Section IV provides several recommendations based on a systems architecture study, to enable the mixed-use architecture to safely and efficiently operate. Section V describes the fundament, seminal questions associated with implementing these architectural changes, and the approach that our team is taking to address these questions. Section VI provides conclusions.

II. SURFACE TO SPACE MIXED USE CHALLENGES

Consider three types of challenges in moving from segregated airspace to mixed-use airspace. First, strategic challenges that originate in the high-stake safety and economic consequences, which pose a threat to the viability of new operations or sustainability of existing services. These are typically addressed by policy solutions and possibly operational constraints. Second, operational challenges characterized by the causes of contention between operators seeking access. These are normally resolved by clarity in roles and procedures. Third, tactical challenges that are related to differences in operational objectives and mission profiles (e.g. loitering, transport, parabolic space flight) which make success unique to each operator. These drive differences in airspace use and tactics for interoperability and clear expectations of operating behaviors. The best practices must be understood across the community that is to operate in the mixed-use airspace.

The segregation designates an airspace for a specific use through a SUA, temporary flight restriction or warning area. Other uses of the area are prohibited for the duration of the designation even if unoccupied. Alternative concepts would allow a dynamic SUA that shifts in space and time to limit the unused airspace resource. Alternatively, a less restrictive warning area could be designated to allow certain classes of air operations to enter at their own risk and be advised of the activity in the area. The goal of this paper is to consider what it takes to move toward mixed use airspace where more than one type of operation is allowed at the same time by monitoring their status and safely separating the two operations with an appropriate distance.

Strategic Challenges for Mixed Used

The potential consequences of a space and air safety incident are so great as to pose a strategic threat to the nascent space industry or for the sustainability of air operators. Each operator needs assurances they can establish and sustain their business model. The policy constraints translate into costs of doing business. Reasonable measures to assure safety can be worked into those costs, however constantly sudden changes and operational surprises may wreck a business model. These strategic challenges are visible in the complexity, uncertainty and regulatory framework for airspace access.

Entrepreneurs are exploring a variety of uses of space and potential business models, especially for low Earth orbit (LEO). The FAA predicts that the number of airline passengers flying in the U.S. will grow by 50% over the next two decades, with global air traffic from developing countries growing even faster and cargo miles growing roughly with the economy.[4] Commercial space launches from the ever-expanding number of spaceports are more difficult to predict, but will likely increase exponentially as new market entrants begin operation and emerging technologies like space tourism and low Earth orbit small satellite constellations are deployed. The nature of launches and reentries grow more diverse. Horizontal launches from altitude and glide returns are a standard concept for space tourism. On the surface, launch and landing sites are in development at new locations and for greater capacity in anticipation of the expanded activities.

New space operators, vehicle manufacturers, spaceports, and payload owners are all planning their operation and path to achieving business success. With so many new operators and potential partners or competitors and the pace of growth complexity is the first challenge to the viability of a new operation. The operational planning requires knowledge of dependencies on partners and some understanding of other operations that overlap in time and space. The challenge is optimizing an operation with limited knowledge of the plans contending for the same resources. The planners need a way to discover critical factors affecting their plan without exposing proprietary knowledge of those plans.

A key part of the complexity of operational planning is reaching agreement of several governmental agencies to obtain approvals and complete any trade-offs in capability and business application. Even with streamlined rules for vehicle approval, multiple agencies and corporate entities are involved in planning a single space enterprise. The payload owner must secure several approvals for the use, transmitters, orbits, deployment elements. These highly technical negotiations are mixed with adjustments in business objectives and feasibility of the enterprise. The payload, tourist operation or constellation owner must also select the best partners in terms of vehicle manufacturers and launch sites. These organizations require a means to work through trade-offs on technical and business matters like the lifecycle, deployment and the other kinds of services and applications to be offered. Cross-enterprise coordination is necessary to manage the uncertainty, complexity of business, and technical decisions during operational planning that otherwise may be barriers to capital entry. A one-stop-shop, as described by the National Space Council Space Policy Directive Two (SPD-2)[5], is a start toward addressing these challenges.

The evolution from surface-to-space (S2S) is full of many uncertainties. It is easy to debate what is real and what might be unrealized aspirations, yet the system must be robust enough to support the evolution. Many of the potential uses like communications and sensing applications are being explored by competing high altitude long-endurance substitutes that will need airspace access. The growth in high-altitude air operations increases the risk of a space launch or reentry encounter in the transition airspace. Just as space operations are viewed as a disruption for traditional air transport, the high-altitude air operations will also need access for their transitions. The increase in volume and variety of flight characteristics suggest the issue is no longer simply about launch windows and conjunction analysis, rather about the uncertainty of interactions that occur between surface to space. The airspace during this period needs an agile environment to develop a more robust traffic management capability.

The possibilities from unmanned air operations and space operations lead to a period of constant discovery through the first generation of deployment. It will not be before the end of that 'discovery period' that the behaviors of a contested environment begin to take shape and normalize. Until then, the uncertainty of the evolution and the timing by which new needs emerge and other needs evaporate will remain the second major challenge to operational planning.

Lastly, the regulatory structure and its differences between commercial space and civil aviation industries pose a challenge to operational planning for new operators. While the Commercial Space Act of 1984 first established a regulatory framework for promotion of economic growth and entrepreneurial activity in the space environment, uniform implementation of civil aviation rules began with the Air Mail Act of 1925 and the industry has been strictly regulated ever since. Aside from the authority of the Federal Communications Commission (FCC) under 47 U.S. Code to regulate the use of radio frequency spectrum for operational communications, commercial launch and reentry responsibility resides within the Department of Transportation under 51 U.S. Code. Specifically, the Federal Aviation Administration (FAA) establishes and enforces standards for commercial launch vehicle design, space ground facilities, operators and acceptable payloads.

The regulation of air operators also includes vehicle design, airports, operators and payloads. Similarly, the FAA has limited authority over the location of new ground facilities for air or space operations, only over how it will affect the airspace that is required for those operations. Environmental regulation is likely the greatest barrier to new air or space port development. That is where the similarities end.

The acceptable level of safety differs between air and space operations. The extremely improbable standard for transport category aircraft[6] and improbable for space operations[7] represent a wide range of safety risk appetite. The expectations also differ in terms of who's safety is considered. Space operations must show acceptable risk to people on the ground including during anomalous events such as mechanical failure or a self-destruct event as a mitigation. By contrast, commercial air operations must show they can safely continue and land with high reliability despite mechanical failures. However, they do not explicitly calculate their risk to persons on the ground. Fuel laden aircraft may be less of a risk than rockets, but still have the potential to do significant harm to communities on the ground[8]. The risk of general aviation accidents to persons on the ground is about the same as the acceptable level for space operations, with the goal being to make them improbable[9].

Human spaceflight differs in nearly every way with its aviation counterpart under a loosely configured "informed consent regime" providing for minimal safety oversight of spacecraft crew and passengers. Moreover, a statutory moratorium is in place prohibiting the FAA from promulgating any regulations governing the design or operation of a launch vehicle involving human spaceflight requirements through 2023 with the rationale that regulations would be disruptive and costly to implement. These differences in regulatory expectation are codified in different regulatory structures and expectations of safety. Mixed use airspace needs to reconcile joint use with different safety objectives.

Importantly, SPD-2 directs the Department of Transportation (DOT) to implement improvements to streamline licensing process with an objective of shifting to a performance-based set of design and operational requirements, recognition that a one size fits all approach is inadequate to conform to the variety of innovative spacecraft design and manufacturing specifications.

Operational Challenges for Mixed Use

The strategic planning environment leave contention over access to the airspace and an unfulfilled desire to preserve one's own flexibility while expecting predictability from the system. The policy constraints are not yet in place to link the air and space operating environments in ways that can serve these objectives. The MITRE S2S architecture considered several future scenarios to stress the current baseline and postulate a possible future to identify key operational challenges. The architecture identified the need for links in transition airspace rules and structures, situational awareness, and integrating operational controls.

The transition airspace above 60,000 feet (FL 600) has historically been viewed as so sparsely populated with air traffic that it does not pose a risk to space operations. Proposals exist to add to this airspace aerostat balloons which remain stationed in one area for hundred-day missions. At the other extreme super or hypersonic vehicles transporting people are also envisioned. With the increased use of air operations at greater altitudes space operators will be more likely to encounter traffic in the airspace above FL600. It is important to note that this airspace above Canada and the US is controlled airspace (Class E). Even though it is designated as controlled, this airspace requires no specific equipment nor notifications of entry or maneuver[10].

The emerging air and space operations that plan to operate above FL600 will have a diverse array of performance in terms of speed and flight profiles making this an extremely dynamic traffic area. These operators also have different safety risk appetites depending on whether they are manned or not, and the level of investment they represent.

The procedures and control systems that provide situational awareness and clear the lower altitudes of air traffic for launch or re-entry do not apply in transition airspace. In the rest of the world including the Atlantic and Pacific Oceans, this airspace is considered uncontrolled, including over major warning areas for the coastal ranges and launch sites. This airspace is not surveilled or automatically cleared as controlled airspace, nor reliably cleared for a launch or re-entry by a notice to airman. This means the contested entry into space begins as soon as an object leaves controlled airspace. The transition region continues into space as deployments will have to maneuver through LEO traffic already on station. This will increase conjunctions and shorten available launch windows over time. The challenge is the space object transition through increasingly congested airspace and LEO requiring greater reliability and flexibility to understand and manage the associated transition risks.

The absence of situational awareness is the second major operational challenge. The National Airspace System (NAS) with positive control, requiring deconfliction between civil aviation and space launch operations occurs below FL600. FAA tracks and controls civil aviation in this region moment by moment to assure safety, maximize throughput and efficiencies. At low altitude and above FL600 there is not radar separation. New air vehicles operating in these transition regions may not be known to the space operator or to other air operators. Currently, controllers are unable to accurately and reliably determine with precision the position and state of launch, re-entry vehicles, and aircraft in all environments. Specifically, there is lack of real-time coordination procedures and tactical data dissemination to support control of off-nominal launch or re-entry vehicle operations. As a result, segregation is the approach to managing space launch and re-entry operations.

Each of the spaceports has a unique operation and notification tempo and coordination process with surrounding organizations and communities, including the air operators. Reliance on manual systems to receive and distribute launch and re-entry data across all NAS users sub-optimizes the domain for all users. Availability of state data and surveillance from operators may aide the creation of mixed-use procedures and best practices for informing others of activities in these regions.

The last operational challenge is the overlap, gaps and coordination of control systems. Every air or space operation is commanded by its owners to ensure its mission success. For an individual operation a chain of command is established with partners and regulator. It is comprised of overlapping control loops for the space operators, air operators, spaceport, airport, air traffic control, and national security each with a different scope of responsibility and definition of success. These control loops lack shared understanding of the consequence of each decision makers actions on others or the implications of other's decisions on their options. Space launches have been scrubbed by individual sailboat or aircraft actions intruding in the debris hazard area. Space vehicle re-entry also reserves large volumes of segregated airspace without understanding implications of options on other airspace and maritime users.

To the extent that operational interaction does occur, it is largely by human communication with inherent limitations of verbally sharing of situational understanding of the plans and objectives between control rooms. The challenge with the increased tempo and diversity in operations is that the dynamic response by one decision-maker must be understood well enough by others to avoid misunderstandings of intent. Decision makers across a range of commercial enterprises and agencies must be well informed about the impact their actions will have on others, and how others' decisions might impact their operations. This is further complicated by the evolution of decisions making automation such as automated flight safety systems or detect and avoid aircraft systems, with the real potential for a cascading series of corrective actions that compound the solution set complexity. The challenge is unifying traffic management and operational controls with shared understanding of actions across the surface to space operations.

Tactical Challenges for Mixed Use

Variations in the commercial space operations and new air vehicles are a challenge to establishing best practices. The emerging operators and sites are in the discovery phase where innovation is leading to new practices and tactics. We examined the ad hoc processes that vary across multiple public and private launch sites and operations to understand interoperability needs. The challenges are pronounced in areas of environmental dynamics, situational awareness, and aeronautical performance.

The first challenge is the increasing diversity of operating dynamics and anomalous behaviors. Civil aviation operations have achieved highly predictable vehicle performance and are relatively static as compared to commercial space operations which are developing new vertical, captive carry and horizontal launch modes of ascent which involve several likely anomalies. Air operation innovation is focused on increased efficiency with use of lighter composite materials to increase fuel efficiency and onboard automated systems designed to reduce overall operating costs and increase throughput. Airlines seek the most efficient routes and follow market demands to establish new routes. Recreational flight is still likely to experience anomalies, but the patterns are predictable enough to establish best practices. For commercial air operations best practices for likely anomalies such as a microburst or high wind "go around" approach or emergency landings are standardized.

By contrast, space operations are more unique, vary with the size of the vehicle and the operational objectives for orbit, sub-orbital flight, or glide return. The operational reliability is not as high as that of commercial transport or even recreational flight. These create less predictable flight operations and require more dynamic procedures with a wider variety in the anomaly resolution procedures. Thus, the need for segregating airspace for many likely anomalies. New capabilities like automated flight safety systems are in development which may change the predictability and timing of these dynamics and will enable best practices to be established.

Unmanned aerial systems (UAS) propose a wide range of flight performance which civil aviation will also have to contend with. The advent of commercial space vertical launch and re-entry operations introduced new complexities in deconfliction of air and space vehicles within existing management systems and procedures. Horizontal launch and glide returns, returning capsules, aerostats and other unmanned vehicles have significantly different performance. As the commercial air and space industries continues to expand, application of integrated airspace traffic controls and consensus driven operational practices will be necessary for safe and efficient future use of the airspace. Even with significant differences in performance, tactics and best practices for separating air and space vehicles is possible. Best practices for a mixed performance, joint use airspace rely on intent information, performance and state data including anomaly detection. To move away from segregation of airspace into homogeneous operating areas, practices are needed for accounting for all forms of performance including anomaly management as part of the intended trajectories.

III. RISK ANALYSIS FRAMEWORK

Segregation of airspace is a strategic or blanket mitigation of the safety risks. It is safety at the expense of secondary objectives of access, and predictability. It denies access to space operators if aircraft intrude into the SUA. It denies efficiency and ultimately predictability to air operators when space launch reliability results in events that are repeated rescheduled.

A risk analysis framework considers the challenges and their effect on safety, access and predictability outcomes to determine when and how mixed-use airspace can improve upon segregation approaches. The framework is a matrix of cause and effects, with risk statements at the intersections to characterize the risk contribution of each challenge to one of the outcomes. The framework is introduced by outcome in the following sections and summarized in Figure 1 for Safety Risk Contributions, Figure 2 for Access Risk Contributions, and Figure 3 for Predictability Risk Contributions.

Statements of Risk for Mixed Use of Airspace

Safety is essential to continued operations by any air or space operator. It is the public perception and confidence in the industry that allows continued operations. This can be jeopardized by even a small number or single incident depending on the harm to society. The safety outcome is paramount and will always be addressed first in the system design, usually at the expense of access or predictability.

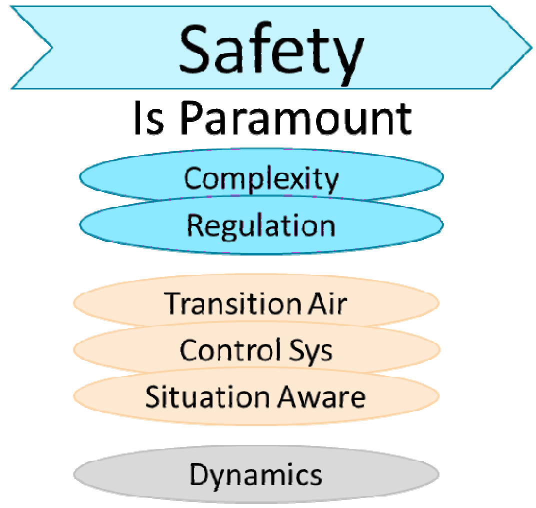

Fig. 1: Safety Risk Contributions

There are several challenges in the future operation which expand the risk of safety incidents.

- Complexity from proximity of new spaceports vertiports, and airports and flight interactions
- Regulatory differences for what are acceptable encounters to one party and not to another
- Transition airspace population growth above FL600 or in uncontrolled airspace below 400 feet near launch facilities
- Separate control regimes for UAS and other new entrants
- Flight dynamics with lower reliability and more frequent anomalies
- Situational awareness is critical to the speed of automation and decision-making

Once the need for acceptable level of safety is achieved, the next most important objective is access to the airspace. The success of each operation depends on its unique access constraints. Equity of access is the balance of airspace access by air and space operations for a variety of purposes so that each may successfully run its operation.

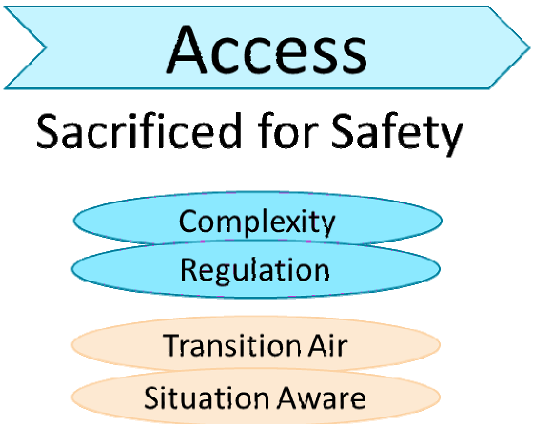

Fig. 2: Access Risk Contributions

The challenges pose the following risk to air or space operator access:

- Complexity may strand ground infrastructure investments (airports, vertiports, or spaceports) with inadequate access
- Regulations to coordinate access beyond simple exemptions to first come, first served do not exist
- Transition airspace is not monitored, and access management is limited to entry events
- Situational awareness of each other's decision-space and actions is masked by current practices

The last outcome we examine is predictability which drives the sustainability of existing operations. The cascading risk is that the safety consequences are mitigated through segregating large volumes of airspace, which impairs access and jeopardizes predictability for air operators. More directly, too great of chaos or uncertainty disrupts business or operating plans, curtailing capital expansion and service delivery for space or new air entrants.

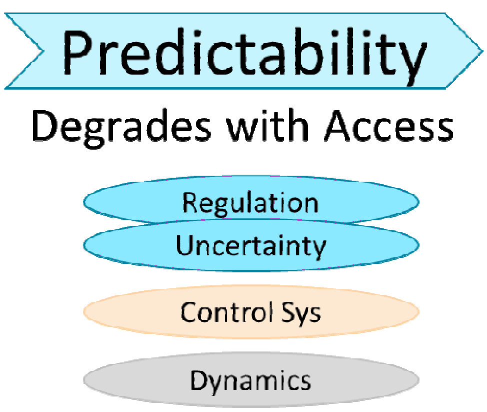

Fig. 3: Predictability Risk Contributions

The sources of predictability loss include the following challenges:

- Regulatory regime for space operations is an open-ended process for closure on business or technical decisions
- Uncertainty in the resource demands from other new entrants leaves unknowns in operating planning
- Separate control actions through operator, site and regulator decisions may create cascading effects
- A more dynamic environment with greater rate of anomalies

IV. SURFACE TO SPACE ARCHITECTURAL RECOMMENDATIONS

The resolution of those risks depends on a mixture of policy to address strategic risks, process clarifications for operational and strategic risks and best practices for operational and tactical risks. Finding mitigations for those risks will be necessary to migrate from segregation toward mixed use airspace for greater safety, access and predictability.

Our goals in addressing the risk framework are to assure safety in ways that facilitate access for all operations to meet their success criteria and provide the predictability needed to establish new and sustain existing operations.

Recommendation: Establish a Mission Broker – Policies and Procedures to Advise and Coordinate on Strategic Risks

A mission broker is a new role, supported by policy and procedures for completing the operational planning with proper coordination. The role is necessary to address risks to access and predictability arising from complexity, uncertainty in the evolution and the regulatory structure.

A broker provides insights on complexity and unknowns where the organization might contend for scarce resources that would limit access. The broker cuts through the complexity by working in parallel with multiple organizations to advise each on mitigations so that plans are compatible with the access needs. It partitions sensitive information to identify and share the risks in operational planning without divulging other operator's information or the source of the contention.

This new role works through uncertainties in the evolution by connecting operators with regulators during the planning phases to understand dependencies in the business and technical trade-offs. It complements the Department of Commerce concept of a one stop shop by allowing individual organizations to navigate the approval processes, connect with each other and allow discovery of unknowns that might be detrimental to the expectations for access or predictability of operating tempo.

As a single point of contact for all the certifications, licenses, and trade-offs in planning the space operator's mission, the broker facilitates a path to closure on operational limitations that will meet the mission parameters. Regulations for resolving resource contention and general access rules are essential to effective planning. These trade-offs may involve the vehicle manufacturer, spaceport or local aerodromes and airports coordinating with involved agencies on spectrum allocation, orbits, launch vehicles, sites, transition issues, etc. The broker offers a space operation a predictable path to the multi-agency regulatory approvals.

Recommendation: Structure Airspace using new Policies and Procedures to Operationally Address Strategic Risks

Airspace structure is implemented in policy and procedures as readymade paths for routing traffic. This operational practice is the failsafe to assure safety by isolating operations on defined paths when they are not interoperable. Segregation of space operations is a blanket approach which ideally will give way to mixed use airspace. When done on a granular level airspace structure can provide predictable access with greater throughput. Mixed use airspace can consist of a set of structures that are activated briefly to accommodate access temporarily for otherwise incompatible operations.

Structure is useful to sort out the complexity from new types of interactions and new geometries for these new operations. Designing airspace for overall efficiency for a variety of legacy and new uses requires a way to characterize these new demands and to shape structures that will serve different levels of safety assurance in the same airspace volume. New microstructures would assure separation while allowing greater joint use airspace by acknowledging the conditions for incompatible operations to be segregated.

Lastly, structures are needed to grant new spaceports and airports assurances that access will be available to justify the ground infrastructure investment. Policy for granting access to the airspace immediately departing a spaceport or airport is essential to addressing the uncertainty in the evolution. Sites near one another may plan operations that would interfere or may assume a certain tempo to be viable. The value of ground infrastructure investments and the contribution to the system capabilities for new sites depends on assurances for access to ground infrastructure (airports, spaceports, vertiports).

Recommendation: Establish New Surface to Space Traffic Management and Contingency Management Policy and Procedures

Traffic management is policy and procedures to facilitate safe and equitable access for all kinds of operations. Extending traffic management beyond its existing confines creates a seamless flow for space operations and a predictable environment for controlled operations given a higher tempo of transitioning launches and reentries, including new unmanned entrants. The function may be shared between the current air navigation service provider (ANSP) and other commercial entities coordinating flight paths for unmanned vehicles and high-altitude operators. NASA has proposed unmanned traffic management (UTM) procedures which may be extensible to other parts of the surface to space architecture.

The policy and procedures require intent information and state data from all operators to safely separate traffic procedurally. This is done by identifying control points where further action may be required including contingency management. These control points defer action when possible to preserve flexibility for operators to manage flight decisions within their whole operation, while assuring a safe outcome. Practices for unifying control actions rely on situational understanding across the regulatory and commercial decision makers to tactically resolve contention in advance of the control points. Key to distributed control will be advanced knowledge of possible contingency responses and real-time awareness of situation and decisions made by others. When necessary pre-planned intent will enable contingency coordination in real-time to ensure actions across the community safely account for decisions by others. These procedures address the safety risk posed by the need for coordinated plans.

In the interest of access, traffic management procedures extend Collaborative Decision Making (CDM) to cover the access objectives for operations other than air transport operations. The overall surface to space traffic management benefits by understanding operational success factors and constraints for each operation and connecting organizations where resource contention must be resolved. The policy will give preference for access to satisfy the tightest constraints for success (e.g., limited launch window, life flights, or time over target) with the goal of maximizing the opportunity for success by each operation. CDM procedures will negotiate access accounting for the opportunity cost of delaying or denying another operation in a way that would jeopardize its operational success.

Recommendation: Develop Performance-based, dynamic separation standards

Dynamic, performance-based separation is the policy and procedures to supports varying levels of acceptable risk and aeronautical performance in mixed-use airspace. The goal of the policy is to allow autonomous and manned aircraft co-exist at scale in controlled or uncontrolled airspace by aligning the regulatory structure more closely to the desired safety outcomes for air and space operations based on public expectation and accounting for performance differences.

With dynamic separation, access is granted based on mission objectives and constraints. The nominal performance determines the airspace needs and access constraints. The concept of performance-based trajectory separation is a form of this use, where the structure exists as a moving designation of airspace only for the duration of the flight.

Performance enabling dynamic separation standards require knowledge of capability, intent, performance and uncertainty to be properly applied to expectations for detecting, reacting and resolving potential conflicts. The procedures may vary depending on the role of automation, flight crews and controllers in the decision chain. The concept can be applied across these different types of operations from controlled traffic, to self-separation, detect and avoid, or "due regard" for the safety of navigation of civil aircraft. Separation may be required from paths for likely anomalies as well as the nominal flight path. Airspace segregation is reserved for incompatible operations is and likely anomalies for which tactical resolutions will not be possible. Performance-based separation can reduce the need to block airspace as anomalies become less likely and mitigation is demonstrably more reliable.

Recommendation: Create new High-altitude flight rules and Cross-agency Coordination mechanisms

High altitude flight rules are policies and procedures to address the increased risk from new operations in uncontrolled airspace. The policy addresses the transition airspace safety risk by formalizing the operator role in self-separation for safety when and where appropriate without increasing air traffic controller involvement. The transition between Air Navigation Service Provider (ANSP) controlled airspace and self-control paradigms requires coordination, so activities are tracked in high-altitude for the benefit of space operator safety. There is a need to sort out the expectations and roles of operators so that operations can scale and prioritize access based on the tightest constraints for all operator's success. The new procedures will include sharing of situational awareness in the transition region where surveillance is not currently provided and "due regard" is expected.

Procedures will assure distributed decision-making with forethought and knowledge of the implications for other operators and agency missions. Communications support shared situational understanding (awareness and analysis) to coordinate decisions and manage activities from new sites, vehicles and operations. Surveillance and state information of air and space operations will be shared between agencies across the difference control regimes.

FAA is seeking to migrate away from the manual processes in place today through the Space Data Integrator (SDI) pilot initiative to limit the affected geographical area and duration of NAS closure for launch and re-entry events with the ultimate objective of integrating airspace across all users including vertical and horizontal space launch, hypersonic transit, aerostats, and civil aviation. Tools such as SDI are a start, but multi-agency coordination will require more automated capabilities to increase the comprehensive understanding and forecasting of implications from intent and state data.

V. UNCOVERING THE SEMINAL QUESTIONS

MITRE developed an S2S functional architecture to evaluate and experiment with concepts and resolve impediments to strategic implementation, integration and interoperability challenges. In creating the risk analysis framework, we identify some of the seminal questions for the successful development of this industry. These will be the major areas of collaboration between MITRE and US CoC, regulatory agencies and the air and space industry members.

What are the Measures for Efficient Use of Airspace?

The community could employ the economic concept of efficiency, meaning that airspace gets allocated to its highest valued use. In commercial markets, prices are the allocation mechanism, with the quantity sold in the market at any price going to those willing to pay the prevailing price. Thus, efficient allocation of airspace requires a mechanism to reflect the economic value that competing users place on access to particular parcels of airspace.

An alternative to economic value of the resource, is to consider the vitality and growth of industries that require airspace access, including both the air and space industries. Is the system achieving the kind of access and predictability required to meet growing demand, predicted future developments, and accommodate the operational tempo for air and space operations with limited disruption? For instance:

- Growth in the launch and landing capacity of commercial space operators, including accommodations for space tourism
- Growth in industry scale across nascent, developing sectors (space, UAS package delivery, surveillance, people transport)
- Incumbent industry growth

These economic measures can be validated through operational statistics to show the airspace is delivering what the participants seek - the predictability to accomplish their plans and the flexibility to adjust for routine events and discoveries.

- Schedule completion and block time growth for air operations (delay/schedule stability)
- Space ops interruptions (cancelations for stray flight in hazard area)
- Consumed resources (ATC services, 3rd party services, airspace as a resource)

The seminal policy questions to move the metrics are about those access rights that afford growth opportunities, provide appropriate return on investment in infrastructure, and sustain the conditions for continued incumbent operator success.

- What is the appropriate regulatory regime to provide the needed insights to encourage business investment and innovation in emerging industry sectors?
- What policy will manage use of the most valuable airspace? Recognizing that all airspace is not of equal value to all users, how do we create an incentive system that is closely matched to the best use of airspace? Or to create air and space industry growth across all industry sectors without *ex ante* bias in favor of particular sectors?
- With the potential for significant growth in private sector investment in new infrastructure, what is the policy for airspace access rights above infrastructure designed for airspace access?
- What policy best incentivizes opportunity cost considerations (e.g., commercial space launch from the "lowest impact" spaceport possible that can handle their payload and logistics)?

What are suitable Risk Expectations?

The shift from segregation of airspace to mixed-use will only be successful if all operations are achieving their acceptable level of safety. The focus becomes less on assuring flights remain outside the presumed areas of risk and more about understanding the risk in real-time for operators and those on the ground. For example, maritime operators can operate in a launch hazard area with only 30 minutes advanced notice of the high-risk hazard area.[11]

The public acceptance of new air and space operations depends on the appetite for risk. Safety incidents involving vehicles, anomalous events and ground strikes are all of concern. The seminal policy questions for the safety expectations are about the public context, perception of harm and accountability:

- What is the overall safety case by airspace volume or by operation? Who is accountable for the real-time safety? And what does it mean to accept the safety risk?
- How should policy and operational procedure assure an extremely improbable risk result for commercial air transport?
- What should be the policy for risk to people on the ground? Uniform risk based on or likelihood of loss or differentiating users based on the scale of harm (small UAS, aircraft, rocket)?
- How should access be managed and tracked above 60,000 feet? Who should control and for what target level of safety?

We propose the policy solutions to the questions above need to be addressed without bias to air or space operators that might incentivize investments solely due to the regulatory structure.

VI. Conclusions

Commercialization of space and UAS are in a 'discovery phase' that will shape the opportunities domestically and globally. The safety, access and predictability risks will ultimately determinate whether these opportunities are seized or loss. Our collective answers to these seminal questions will determine how robust these operations are in the U.S.

Much of the risk from the existing approach to safety will impair access and degrade predictability to the point which it jeopardizes the opportunities for this growth. The risk framework allows for linking answers to the seminal questions to the introduction of mixed-use airspace for space operations at scale in parallel with the new air operations.

The early innovation phase of new space operations is necessary to discover and develop capability. This 'discovery phase' is well suited to a joint exercise approach. We have a risk analysis framework, a set of policy and procedure concepts for consideration, and an evaluation test bed construct for the community to move forward together. The U.S. Chamber of Commerce and MITRE are committed to facilitating the discussions and development through dialogue, modelling, simulation, observation, measurement, and visualization of integrated solutions and implementation issues.

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[4] https://www.faa.gov/data_research/aviation/aerospace_forecasts/media/FAA_Aerospace_Forecasts_FY_2019-2039.pdf

[5] https://www.whitehouse.gov/presidential-actions/space-policy-directive-2-streamlining-regulations-commercial-use-space/

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[10] https://www.faa.gov/regulations_policies/handbooks_manuals/aviation/phak/media/17_phak_ch15.pdf

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