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Space Launch and Reentry Operations Collaborative Decision Making (CDM) Concept

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Collaborative Decision Making for Space Launch and Reentry Operations: Concept Description

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Abstract

The National Airspace System (NAS) is a shared resource that is managed for all users by the Federal Aviation Administration's (FAA's) Air Traffic Organization (ATO). Increasingly, multiple users need concurrent access to this limited resource. Demand for this airspace is growing as space launch and reentry (L/R) operations increase in number, vehicle and mission types, and locations. Collaborative Decision Making (CDM) is a well-established practice for resolving airspace demand issues among multiple NAS users as it considers multiple stakeholders' perspectives to make informed decisions. The MITRE Corporation has developed an initial concept for applying CDM principles to L/R operations. In the concept, collaboration and data exchange inform decision-making during preliminary mission planning, airspace scheduling, airspace management, and real-time operations. Post-operations analysis is performed, and feedback is provided to improve decision making. This gives L/R operators information on airspace congestion as they consider options for launch and reentry locations and times. Airspace management planning to address airspace congestion considers mission flexibilities and constraints provided by operators. Real-time air traffic management is more dynamic due to increased certainty provided by L/R operational status updates. Through CDM participation, L/R operators have a voice in how airspace demand is managed and in prioritizing processes, information sharing, and capabilities to improve operations. All NAS users experience less uncertainty and more predictability of access and schedules through new information exchanges and collaborative processes. This research began in fiscal year (FY) 2018 and continues in FY19 with concept socialization, feedback, expansion, and refinement.

Introduction

The growing number of space launch and reentry (L/R) operations challenges the Federal Aviation Administration (FAA) to accommodate the needs of these operators and those of all other National Airspace System (NAS) users. To maintain safety, L/R operations currently require exclusive use of airspace. Non-participating aircraft must avoid this airspace, known as Aircraft Hazard Areas or AHAs, leading to reroutes and flight delays [1]. These impacts will become difficult to absorb when aircraft operators and L/R operators routinely have concurrent needs for finite airspace resources as the commercial space industry develops and evolves [2]. To address this challenge, this research describes a concept for Collaborative Decision Making (CDM) for space L/R operations. The concept is referred to in this paper as "Space CDM."

This paper includes background and research motivation, followed by an overview of current CDM practices and considerations for L/R operations. It then provides an overview of an operational concept for Space CDM and how it addresses airspace management challenges and outcomes of Space CDM. Details about the concept including operational scenarios follow. The paper concludes with next steps in the research.

This paper reflects research MITRE conducted from October 2017 to November 2018 with limited exposure to L/R operators and other stakeholders. The next step is to socialize this work and obtain feedback from the NAS stakeholder community to shape the concept and advance its maturity.

Background and Research Motivation

Currently, L/R operations are planned months or even years in advance, in coordination with the FAA's Office of Commercial Space Transportation (AST). Based on mission needs and parameters, the L/R operator determines the location, date, and time of the mission, without information about NAS usage and congestion. Fifteen days prior to the L/R, the safety analysis is finalized, which results in the locations and duration of AHAs that are submitted to the FAA's Air Traffic Organization (ATO) as the airspace request. The ATO has little opportunity to consider the airspace request for a specific L/R mission and its potential NAS impact until 10 to 14 days prior to the operation.

The FAA's Air Traffic Control System Command Center (ATCSCC) Space Operations office has primary responsibility for L/R operations in the ATO[1]. Upon receipt of mission information and an airspace request, it evaluates the expected effect of the L/R operation on the NAS, renders a decision on mission approval, and plans the airspace management initiatives necessary to accommodate the L/R operation. An L/R operation generally requires exclusive use of airspace. Other NAS users are required to reroute or delay to avoid the AHAs set aside for space operations [1].

The short lead time usually doesn't allow for significant L/R operation modifications that would lessen the anticipated impact on other NAS users without jeopardizing the mission. Additionally, the ATO has limited understanding of what modifications would be viable or acceptable while still meeting the operational requirements of the L/R operator.

CDM practices involving aircraft operators have long been applied[2] to inform FAA decision-making about airspace management. Recently the CDM Stakeholder Guidelines have been updated to include new entrants[3] [3]. Our research investigates how CDM principles and practices can be extended and tailored to include L/R operations and to support cross-industry collaboration.

Collaborative Decision Making

CDM Principles

CDM is a way of doing business that involves data exchange and stakeholder participation to improve operational decision-making and to strategically develop supporting processes and capabilities. Figure 1 shows three key CDM principles. There is a shared understanding of perspectives, leading to awareness of consequences that decisions may have on all NAS stakeholders, as well as a better understanding of which decisions and actions will be most valuable to the system. The FAA and industry discuss and decide the interactions for strategic CDM collaboration (processes, capabilities, priorities) and operational collaboration (planning, operations, and post-analysis.) The strategic partnership involves committees with both industry and FAA representatives to consider topics chosen by the CDM members. Strategically, industry and the FAA jointly decide on the development and enhancement of processes, tools, and metrics. Operationally, data is shared, and stakeholders are involved in discussions about

[1] Per FAA JO 7210.3AA, Change 2, ATCSCC Space Ops must "ensure space launch and reentry operations are safely and efficiently integrated into the NAS by approving, modifying, or denying airspace decisions directly related to launch and reentry activities, consistent with FAA policies and regulations". [11]
[2] CDM initially started in 1993 with the FAA/Airline Data Exchange (FADE) experiment and was formally established in 1995.
[3] For CDM, "new entrants" refer to NAS stakeholders and user groups that previously were not involved in CDM data exchange. Examples include airport operators, Unmanned Aerial Vehicle (UAV) operators, and L/R operators.

actions needed to address NAS issues. More information about CDM can be found at the FAA's CDM website, https://cdm.fly.faa.gov/.

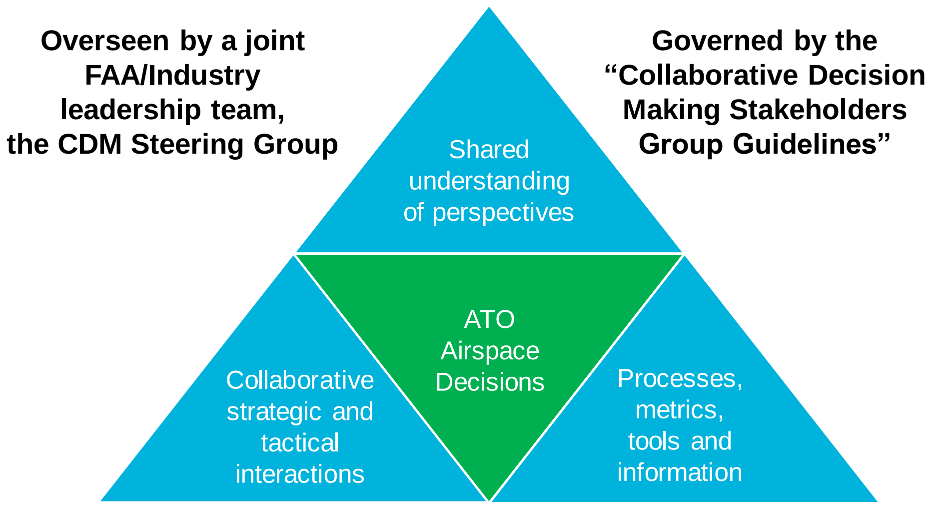

Figure 1.CDM: A Way of Doing Business

In CDM, stakeholder communities learn together and gain an appreciation for each other's perspectives. Working together, industry stakeholders can develop creative solutions that otherwise may be one-sided or unilaterally imposed by the FAA.

Collaboration Considerations for Launch and Reentry Operations

The state of the commercial space industry in 2018 is very different than the state of the air transportation industry at the time CDM was initially proposed in 1993. These differences can be characterized in several ways including those in Table 1.

Table 1. Comparison of Commercial Space and Air Transportation

	Commercial Space 2018	Air Transportation 1993
Numbers of operations	31 licensed commercial launches August 2017 – July 2018	Over 10 million air carrier and air taxi flights per year[4]
FAA's knowledge of operations and business models	Limited experience in emerging operations or business models	Well-understood operations, but limited knowledge of business models
Industry maturity and diversity	Evolving, diverse vehicle and mission types	Relatively stable, similar missions and performance across aircraft

[4] Based on an OPSNET 1993 data query, which indicates approximately 20 million air carrier and air taxi operations. A flight departure or an arrival each count as a single operation. The operations count was divided by two to obtain the approximation for the number of flights.

CDM motivation	Effects of airspace demand and congestion an emerging problem	Delays and airspace congestion an acknowledged problem

Despite significant operational differences, both industries need predictable access to airspace to provide reliable services to their customers.

While the space industry has experienced almost unhindered access to airspace, this will likely change in the future given the forecasted demand of all NAS users, including L/R operators, that may want to use the same airspace. Establishing a "seat at the table" now allows the industry's voice to be heard in proactive discussions about the future. L/R operations have data to share with the FAA that can inform and improve its decision making about airspace management. The FAA has data to share with L/R operators that can inform their decisions about their use of the airspace. Collaboration among all stakeholders will enable understanding and accommodation of L/R operator constraints, while seeking out opportunities to address other airspace user needs at the same time.

Operational Concept Overview

Space CDM seeks to leverage information exchange and collaboration between government and industry to create common situation awareness of the planned and actual usage of the NAS and any operational constraints resulting from L/R operations. Decisions affecting the safety and efficiency of the NAS can be made considering the needs of all NAS users. We are presenting our description of the initial concept for the future in the present tense as though it exists today. Our description primarily refers to the top-level organizations: FAA, AST, and ATO; however, within ATO the ATCSCC Space Operations is the office of primary responsibility for L/R operations.

The Space CDM concept is positioned in a complex environment: L/R operators' planning and executing the mission and meeting their business objectives, and the FAA's management of the safe and efficient airspace and NAS operations. Space CDM involves operational collaboration and timely information exchange between L/R operators and the FAA during L/R planning, operations and post-analysis, as shown in Figure 2, Space CDM Scope. The scope also includes strategic collaboration to develop processes and capabilities that will be used during operational collaboration.

Collaboration and information exchanges inform decisions and lead to improved airspace efficiency and predictability for the NAS user community. The initial operational concept focuses on integrating space L/R into the NAS, with the expectation that more NAS users will be involved for situation awareness and informed decision making. The environment continues to evolve, with L/R operations increasing in number, location, and diversity [2], and the FAA pursuing enhancements to air traffic operations and automation [4], [5], [6], [7].

Figure 2. Space CDM Scope

Space CDM exists within a broader context of space mission and airspace management operations and processes. CDM participants and other stakeholders operate to satisfy their missions and business objectives. Space CDM should leverage and be integrated into technical capabilities, infrastructure and functionality of both space operations and NAS operations. Technical integration needs to allow for extensibility and flexibility as the industry and process gain experience, evolve, and mature. Approaches that leverage public and private sector contributions will facilitate development at a pace better aligned with industry progress.

Figure 3 depicts our initial operational concept for Space CDM, showing the operational collaboration and data sharing across the three major phases to plan and schedule the L/R, to manage the airspace and operate the mission, and to analyze the L/R for operations improvements. Strategic collaboration, involving all CDM members in setting the "rules of the road" and foundation practices, is depicted by the blue triangle. Although the initial focus is L/R operators, aircraft operators are also shown because of the need for L/R situation awareness. The activities in the phases are supported by technology capabilities that enable seamless transfer of data, rapid data updates, and a consistent, accurate operational picture.

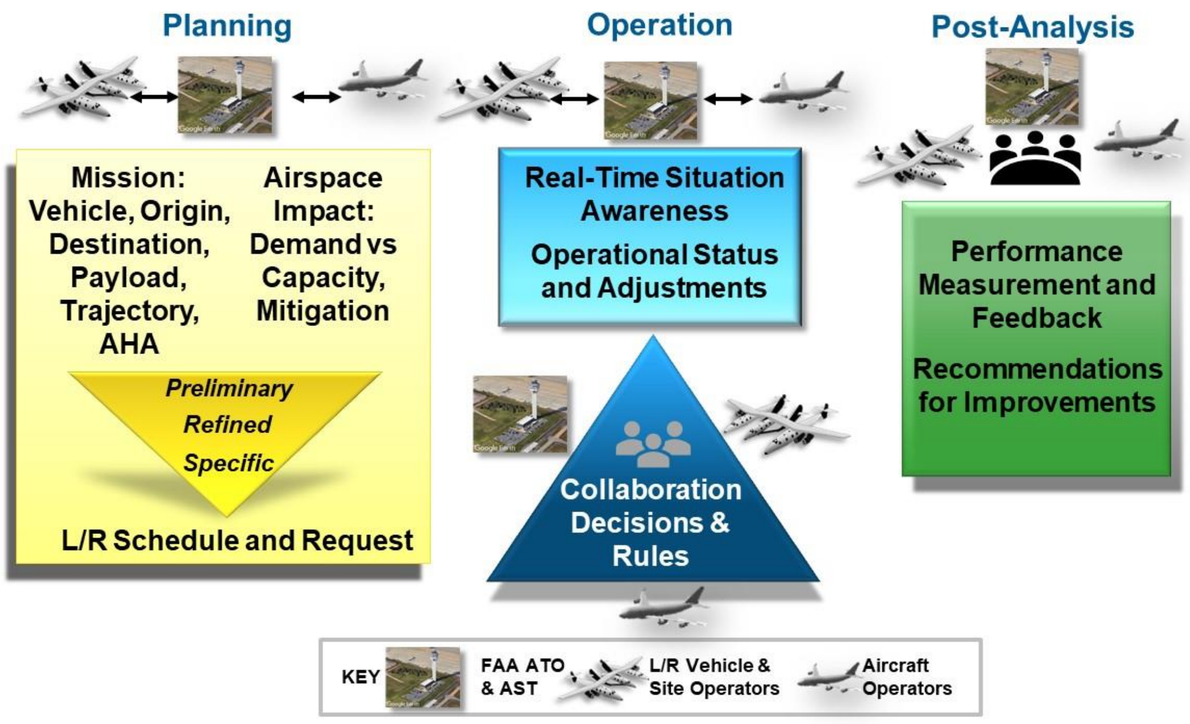

Figure 3. Initial Depiction of the Space CDM Operational Concept

Planning Phase

Early in the Planning Phase, L/R operators explore mission options that meet operational and schedule requirements necessary to ensure mission success. Viable options are then compared against airspace congestion data generated from FAA and aircraft operator data exchange. Airspace congestion may be the result of the cumulative schedules of legacy NAS users, as well as airspace requests from L/R operators. The L/R operator will then submit schedule options that consider NAS impact to the FAA for approval. Information exchange can trigger early collaboration between the FAA ATO and L/R operators when needed (e.g., when use of busy airspace cannot be avoided due to limited flexibility given the mission's payload). The FAA ATO decides L/R approval based on submitted schedule information (proposed or final) and coordinates an Airspace Management Plan (AMP) for the approved mission. Final L/R approval is contingent on the safety analysis results. Any changes or updates to mission and L/R schedule information and the AMP are shared with NAS stakeholders.

Operations Phase

The Operations phase generally extends from T-24 hours through the release of the airspace needed for the L/R. The L/R operator conducts the operation to completion. The ATO executes the airspace management plan for the scheduled operation. Real-time data exchange (e.g., occurrence of L/R events, L/R vehicle information, NAS situation) and close coordination among the parties support the activities leading up to the launch/reentry and through the FAA's release of all airspace associated with the operation. Aircraft operators also receive data and updates about the operation, its status, and the AMP. Because there is uncertainty during the planning phase, real-time conditions or events may require collaboration on decisions and actions. Future concepts that enable tactical airspace management through use of dynamic AHA activation will likely require more collaboration between the L/R operator and the FAA, and more tactical collaboration with aircraft operators [1], [7].

Post-analysis Phase

Post-event analysis review and discussion activities include evaluation and feedback on FAA service provision and evaluation of L/R operator compliance with the established collaboration agreements and data exchange. Development of metrics, such as predictability of L/R operations, and perspectives of operational performance support continuous learning and feedback. CDM stakeholders review operational trends, industry trends, and L/R operators' performance in the context of operational trends, and the FAA's provision of services across L/R operations. Stakeholder evaluations identify needed improvements, such as new concepts and capabilities, new or revised procedures, and their priorities. When needed, a review of significant L/R mission and operational events may also be conducted to provide additional input to post-event analysis reviews and discussions.

Space CDM Outcomes

Through Space CDM, L/R operators will be able to make mission planning and scheduling decisions informed by airspace usage. The ATO will have an early awareness of the mission with enough time to collaborate with the L/R operators if the L/R has a significant effect on the NAS. The ATO will also have real-time situation awareness that supports dynamic airspace management. Aircraft operators have an early awareness of space missions and can better plan their operations. The Space CDM concept will be a key component to a flexible, agile commercial U.S. space industry, while continuing to provide services needed to maintain a robust air transportation industry.

Key changes for L/R operations with Space CDM are shown in Table 2.

Table 2. Space CDM Changes for L/R Operations

Planning Phase	• L/R operator develops options that meet success criteria while considering airspace demand • L/R operator submits options prior to safety analysis • Collaborative decision reached leading to safety analysis with approved mission parameters
Operations Phase	• Real-time status and information is exchanged between L/R operator and ATO • Because the FAA has improved situation awareness and mission certainty, airspace can be managed more dynamically
Post-Analysis Phase	• Performance metrics capture all NAS user perspectives on business success • Formalized performance reviews and trend analysis identify problems to be addressed • L/R operator has voice in shaping, prioritizing, and developing enhancements to improve future performance

Space CDM expands data exchange and collaboration to include L/R operators, resulting in:

- Enhanced common situation awareness and informed decision making considering all NAS operations
- Improved predictability and stability for all NAS users

    - Airspace usage decisions are made with consideration of all NAS users
    - Overlapping L/R airspace needs are deconflicted
- Improved use of available airspace for all NAS users
    - Improved data sharing adds certainty, enabling tactical air traffic management of airspace resulting in efficiency gains for all NAS users
- Inclusion of L/R operators along with other stakeholders in making NAS operational decisions that may affect them
- Inclusion of L/R operators in defining rules of engagement, processes, metrics, criteria, and automation needs for airspace use optimization
- Increased chance of L/R approval enabled through more efficient airspace management.

Concept Detail

The Operational Concept Overview above summarizes our initial concept for collaboration and data exchange during L/R planning, L/R operations, and post analysis. This section offers details about the concept, including assumptions and constraints, the participants, the decomposition of the concept into operational concept elements, and the automation capabilities that support the operational concept elements.

Assumptions and Constraints

Key assumptions:

1. The FAA and L/R operators and site operators will invest in processes and technology to support Space CDM.
2. L/R operators have models for business and technical analysis that ingest and use airspace usage data to inform their decision-making.
3. The CDM structure and governance will accommodate aerospace entities [8].
4. FAA processes and systems will enforce non-disclosure requirements of CDM members' proprietary information.
5. As the industry and process evolve, the FAA will develop and use additional methods to separate aircraft and L/R operations beyond today's practice to segregate airspace users.
6. FAA ATCSCC Space Operations as the Office of Primary Responsibility will develop criteria and procedures for L/R review and approval.

Constraints that limit Space CDM include anti-trust laws, regulations, policies, and standards that may apply. Space L/R missions must satisfy the requirements of the payload and mission owner. Payload and mission needs are constrained by L/R window times, duration and frequency, locations, and trajectories. L/R operations are further limited by orbital mechanics and rocket operations. These operational constraints are important to understand limits for L/R collaboration. For example, while a flight may be delayed by 30 minutes but recover without major consequences, such a delay for a L/R vehicle may not be viable for meeting the mission requirements.

Participants and Responsibilities

Space launch and reentry involves many organizations and entities. The main participants in data sharing and collaboration from the L/R operations perspective are the L/R operators and site operators (may include federal ranges when the L/R operator is using the federal range). Key FAA organizations are AST and ATO, which includes the ATCSCC Space Operations, and ATO Air Traffic facilities[5]. Site operators may offer third party services on behalf of the L/R operators for data exchange. Key stakeholders are other NAS users.

Concept Elements

Concept elements are a decomposition of the concept from an operational perspective and describe the building blocks of the concept of operations. Our concept development work has seven defined concept elements, numbered from zero through six (0-6) as shown in Figure 4. A description of each of the concept elements follow the figure.

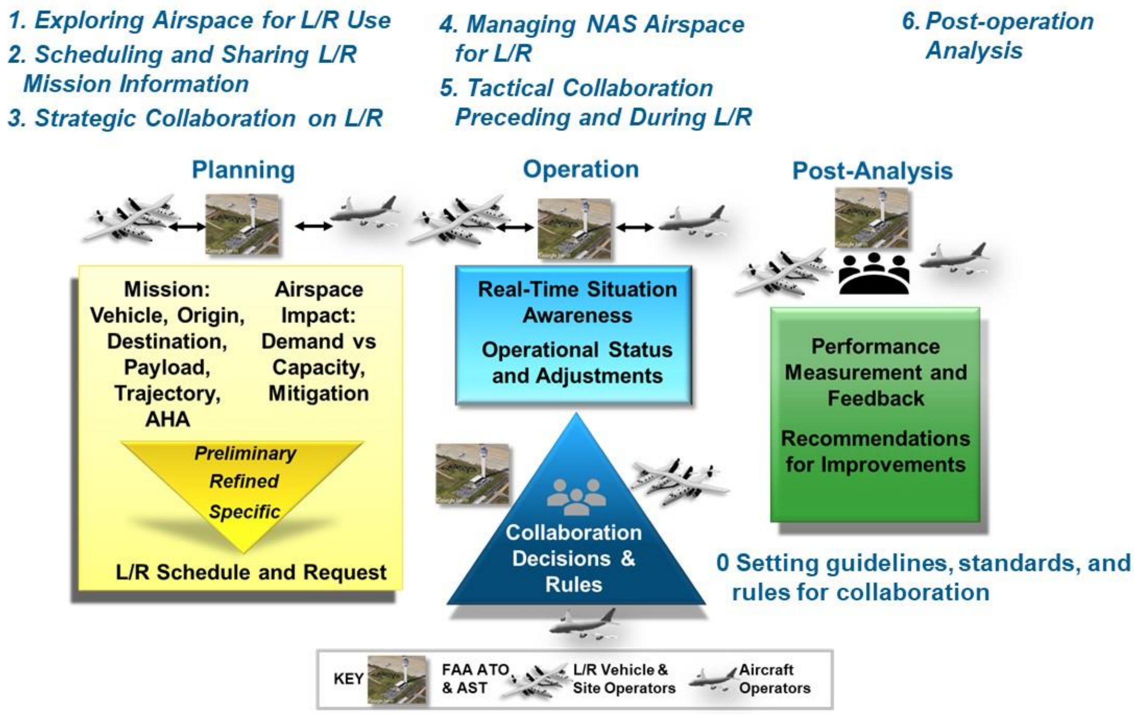

Figure 4. Space CDM Concept Elements

0 - <u>Setting Guidelines, Standards, and Rules for Collaboration</u>: This is an overarching concept element that forms the foundation for CDM. CDM members discuss and reach consensus on guidelines, standards, and capabilities for Space CDM data exchange, collaboration, and negotiation processes. The standards and guidelines also apply to performance metrics and reporting, and to the criteria to identify and prioritize improvements to the L/R operational and CDM process.

1 - <u>Exploring Airspace for L/R Use</u>: L/R operators explore airspace opportunities for an L/R mission informed by FAA-provided information on airspace usage (historical and any predicted uses, including significant events) as input to producing a narrow set of viable options that meet mission and payload needs, and have least effect on other NAS users.

[5] FAA Air Traffic facilities include the ATCSCC, Air Route Traffic Control Centers (ARTCCs), Terminal Radar Approach Control (TRACON) facilities, and Air Traffic Control Towers (ATCTs).

2 - Scheduling and Sharing L/R Mission Information:

L/R operators submit primary and backup L/R information to receive FAA feedback on predicted airspace usage as they prepare to schedule the L/R. Submitted L/R information includes primary and backup date and time windows, origin and destination, trajectory, and AHAs. L/R operators specify that the information is preliminary or final, and they can submit updates as needed. The ATO reviews airspace use and proposed schedules for each individual mission and across missions and locations. The ATO collaborates with L/R operators to deconflict airspace use, if needed. An L/R site operator or third-party service provider can submit information on behalf of the L/R operator.

3 - Strategic Collaboration on L/R: L/R operators, L/R site operators, FAA ATO, and FAA AST collaborate in timeframes needed to inform decision-making including schedules and safety analysis results leading to airspace decisions. Results captured in CDM information are available to authorized users and stakeholders, as appropriate. FAA ATO makes decisions to optimize airspace use.

4 - Managing NAS Airspace for L/R: The ATO plans for and implements NAS airspace management of L/R operations, including coordination with affected Air Traffic facilities. Options to safely separate other NAS users from L/R operations include use of AHAs dynamic airspace management and air traffic management solutions.

5 - Tactical Collaboration Preceding and During L/R: L/R operator, FAA AST, FAA ATO ATCSCC and Air Traffic facilities, and other parties identified by agreement (e.g., the range when it is the L/R site) participate in a hotline preceding L/R until airspace release. L/R operators share mission and vehicle information. The FAA shares information to support situation awareness, such as significant weather or NAS events and disruptions. L/R operators, the FAA ATO and FAA AST collaborate on an updated airspace schedule per agreed-upon operational conditions.

6 - Post-Operations Analysis: L/R operators and L/R site operators, FAA ATO and AST, and other NAS users where applicable, review mission data, logs, and processes from planning and executing the mission and airspace management to identify needed improvements. Metrics and trends are also reported and reviewed. Issues may be forwarded to a CDM working group for broader consideration in identifying, defining, and prioritizing new concepts and/or capabilities and enhancements to existing capabilities.

Capabilities

Automation and other capabilities support operational concept elements. Nine capabilities support Space CDM's concept elements, as shown by the numbered labels in Figure 5. The figure also illustrates high level information that is exchanged in the Space CDM concept. Descriptions of the nine needed capabilities follow the figure.

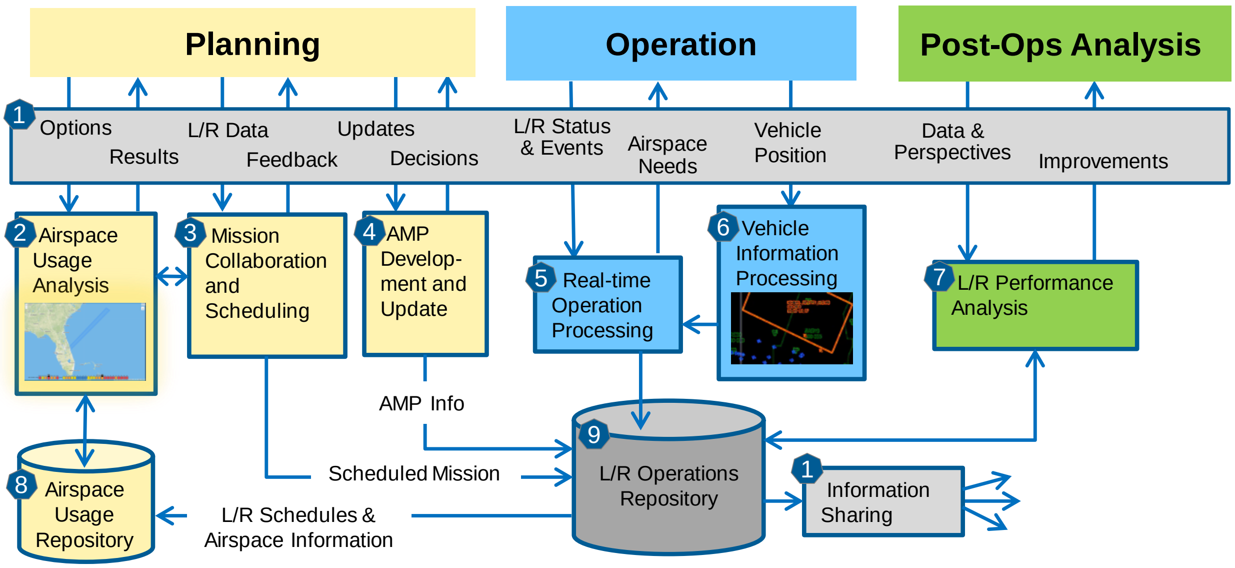

Figure 5. Space CDM Capabilities

Capability 1 - Information Sharing: This capability enables data exchange and information sharing among Space CDM stakeholders. Users and stakeholders can subscribe to notifications (e.g., notification of data updates) and information. Information sharing also provides access to FAA automation systems that process airspace management information and trajectories in the NAS [9].

Capability 2 - Airspace Usage Analysis: This capability allows L/R operators to receive feedback on airspace usage for mission options based on a projected *Airspace Usage Repository* (Capability 8). Site operators can review airspace usage information based on location and time. FAA users can also use this capability to evaluate NAS impact based on information used as input to the safety analysis, prior to generation of the AHA [10].

Capability 3 - Mission Collaboration and Scheduling: This capability allows L/R operators to submit and receive feedback for a preliminary, updated, or final mission schedule (including primary and backups) and associated airspace [10]. The capability returns feedback on airspace usage, the potential for deconfliction among sites, the need for collaboration, and the ATO mission approval decision. Mission schedules and status are updated in the *L/R Operations Repository* (Capability 9).

Capability 4 - AMP Development and Update: This capability supports coordination among the ATO ATCSCC and other Air Traffic facilities to develop, update and provide information to dynamically generate the AMP [9]. The AMP is shared with NAS users and other stakeholders and provides both background on the mission and an analysis of its airspace usage. Mission information is provided from the *L/R Operations Repository* when an L/R is scheduled and the AHA(s) received. The plan and any updates are stored in the *L/R Operations Repository*.

Capability 5 - Real-time Operation Processing: This capability enables the L/R operator to provide real-time mission information, such as planned and actual trajectories and key event times (e.g., rocket fueling, beginning of de-orbit burn), and mission status (e.g., countdown hold, use of backup L/R window, or mission cancellation and reason). The data is stored in the *L/R Operations Repository*.

Capability 6 - Vehicle Information Processing: This capability processes telemetry and surveillance data to identify and track the position and health of the L/R vehicle. Vehicle health information can provide early indication of a potential problem. The data is stored in the *L/R Operations Repository*.

Capability 7 - L/R Performance Analysis: This capability supports analysis of data and processes conducted during L/R operation with respect to performance thresholds. The capability supports aggregated analysis focused on trends for L/R and airspace management planning and compares one L/R with other L/R operations. The performance analysis also captures perspectives on the mission from L/R operators, site operators, other NAS users, the FAA, and other NAS stakeholders. The lessons learned from the discussion and collaboration process are also recorded. The L/R performance analysis supports periodic reporting (e.g., daily, monthly, quarterly, annually), as well as informing future performance related work, such as refining benchmarks or reporting metrics. The data is stored in the *L/R Operations Repository*.

Capability 8 - Airspace Usage Data Repository: The L/R operator submits mission parameters for awareness, to perform what-if analyses, or to schedule an L/R. The submitted information is analyzed against airspace usage data in this repository. The repository information includes historical traffic demand, flight and airspace usage schedules, predicted information from demand information provided by aircraft operators, and known future events (e.g., holiday traffic usage patterns, or special events such as the Super Bowl). This repository is updated when an L/R mission is scheduled (preliminary, final, and any updates).

Capability 9 - L/R Operations Data Repository: This capability captures and stores all L/R planning, operations, and post-analysis data including relevant air traffic and airspace management data and events. The repository is the single trusted source of L/R operations data for use by other Space CDM capabilities. Data is collected and disseminated in real-time and transferred to the repository for other uses.

Operational Scenarios

Scenarios are a starting point to engage stakeholders in developing, maturing, and gaining consensus on the concept so that it is operationally sound and achievable. In this paper we present two generic scenarios: one is L/R operations planning and execution, and the other is post-L/R operations analysis. Each scenario describes operational L/R CDM, as well as the enabling strategic CDM collaboration.

These initial "simple" scenarios can help to validate or to identify needed changes in the initial concept, prior to introducing more complexity. Different vehicles, missions, sites, operational profiles, and operational tempos could have (1) different timeframes and durations for steps, (2) different events, and (3) different data exchanges.

Scenario Assumptions:

- The FAA has established criteria and processes for mission approval decision-making.
- The capabilities described in the concept exist, enabling significant automated data exchange and rapid data updating, with minimal manual input required.
- There are CDM rules for interactions at decision points.
- There are data exchange standards.
- There are standard definitions of airspace demand and rules governing expected coordination.
- L/R operators have in-house models to support decision-making.

Scenario 1: Planning and Execution of a Launch or Reentry

In this scenario, an L/R operator plans and executes a launch or reentry to support a space transportation mission. For the launch, the vehicle may be a vertical rocket with a fly-back to land or ocean vessel; or the launch could be air-based. For the reentry, the vehicle may be a capsule or a winged vehicle. The vehicle may have a schedule to dock on orbit with a laboratory spacecraft or be on its own independent mission.

Precondition: The L/R operator has identified feasible options that meet payload customer, schedule, and physical constraints.

1. Exploring (nominally T-90 days or greater; may vary depending on mission type and cadence)
The L/R operator determines potential schedule options that meet the payload requirements and site availability. The L/R operator then accesses the *Airspace Usage Analysis* capability to see what the airspace demand is for each of the feasible options. The L/R operator down selects its options to avoid high demand periods for the airspace. NAS demand data results can be downloaded into and continually updated in the L/R operator models through subscription.

Depending on the mission, options may consider:

- Launch or reentry time window, including a series of shorter windows within a defined period
- Launch site availability
- Reentry/landing site availability
- Fly-back location – land or barge
- Fly-back barge location
- Jettison items location
- Schedule to leave orbit

Strategic CDM Collaboration: There are CDM criteria for airspace congestion/demand levels and the likelihood that the option would require coordination based on those levels. The L/R operator therefore knows which options would likely need little coordination, which options to avoid if possible, and which options would likely need more coordination with the ATO.

2. Scheduling (nominally T-90 to T-30 days; may vary depending on mission type and cadence)
The L/R operator coordinates with the site operator on prospective primary and backup dates and times. The L/R operator considers site schedule and NAS impact when finalizing its options. The L/R operator presents to the FAA ATO the final ranked set of options that it is prepared to commit to, using the *Mission Collaboration and Scheduling* capability. The FAA ATO reviews mission and airspace information and assesses airspace demand using the *Airspace Usage Analysis* capability. It provides feedback on the ranked options, including whether an option would require further collaboration. The L/R operator submits its final selected option for preliminary approval. Once the safety analysis is completed, the request is submitted to the FAA ATO for final approval. If the safety analysis resulted in significant changes in NAS impact from preliminary approval, further mitigation may be necessary.

Strategic CDM Collaboration: There are rules for how many options may be submitted and for the FAA ATO to consider the ranking in its response. In some cases, only one option is feasible and may require early coordination.

3. Update and Airspace Planning (nominally T-30 days to T-24 hours):
Airspace demand information continues to be updated in the *Airspace Use Repository*. Depending on the mission and associated operational conditions, the L/R operator or the ATO may request adjustments (*Mission Collaboration and Scheduling*) within agreed-upon parameters. ATO coordinates among the

ATCSCC and affected Air Traffic facilities to plan for the operation using the *AMP Development and Update* capability. The FAA ATO and AST also prepare for contingencies. The AMP is recorded in the *L/R Operations Repository*. The *Information Sharing* capability notifies authorized users.

Strategic Collaboration: There are agreements on conditions and timing for requesting mission adjustments, and parameters within which the adjustments need to fall.

4. Operations (T-24 hours to release of all airspace associated with the operation):
Throughout, *Real-time Operation Processing* and *Vehicle Information Processing* capabilities receive and process L/R inputs, FAA inputs, and events, and update the *L/R Operations Repository*. The L/R operator provides planned and actual event information, readiness and status information, and real-time information about the vehicle, which may include health and position information. The FAA ATO provides information about NAS operational conditions, such as weather, unanticipated traffic or NAS infrastructure outages, etc., that are pertinent to the operation. As events and status are reported, common situation awareness shared amongst all stakeholders provides certainty as to L/R and airspace status. This allows the FAA to make more efficient use of airspace while maintaining safety.

The *Information Sharing* capability notifies authorized users, FAA automation, and other subscribing systems. The FAA maintains awareness of the L/R status, weather, and other NAS conditions; shares conditions with L/R operators, FAA AST, FAA ATO at the ATCSCC and Air Traffic facilities; and monitors conditions for any needed changes to the AMP or mission approval. The FAA ATO tactically manages NAS airspace through dynamic coordination with the L/R operator. Airspace is released to other NAS traffic as mission status (go or cancel) and/or vehicle information is received.

Strategic Collaboration: There are agreements on what information needs to be exchanged between the L/R operator and FAA at specific points in time or as specific events occur, and what actions are expected to be taken based on the information.

Scenario 2: Post-analysis of a Specific Operation

Pre-condition: The launch or reentry operation has been completed. If there was an off-nominal occurrence, the scenario would also include an investigation activity.

This scenario describes the FAA and NAS users conducting post-analysis activities for either a launch or reentry.

1. **Event Analysis:** *L/R Performance Analysis* provides timelines and comparisons of planned and actual events of each L/R operation in the reporting period, and any unexpected variances from previous L/R operations. Data is pulled from the *L/R Operations Repository*.
2. **L/R Metrics Analysis:** Metrics related to efficient service to L/R operator, impacts to L/R operations, quality of planning capabilities and information provided, option approvals and operations changes to accommodate airspace demand, etc. are generated by *L/R Performance Analysis* or collected from the L/R operator via the *Information Sharing* capability.
3. **Airspace Management Metrics Analysis:** Data is collected from aircraft operators and from L/R Performance Analysis and ATM analysis capabilities, such as replays, projected and actual aircraft counts, NAS impact reports, FAA-required reporting, and Traffic Management Initiative (TMI) efficiency.

4. **Data Reporting**: Data and reports are provided to stakeholders in standard formats via *L/R Performance Analysis*.
5. **L/R Operations Review and Improvement:** The FAA conducts the L/R operations review with stakeholders. Unexpected or unplanned events (e.g., problems with procedures, processes, coordination) are documented and captured using *L/R Performance Analysis* and the *L/R Operations Data Repository*). Significant issues are identified and tracked for resolution by the appropriate working group, including needs for new or improved data exchanges and capability enhancements.
6. **Acceptance of Updates:** Processes and procedures are updated by CDM teams or working groups and reviewed by all responsible parties prior to implementation.

Strategic Collaboration: There is agreement on what information will be provided by all stakeholders, and when, as well as what information will be shared with specific stakeholder groups. Performance measures are defined. There is also strategic operations analysis that looks at trends and aggregate data using *L/R Performance Analysis* and *L/R Operations Data Repository* to identify issues and to develop benchmarks. Working groups are established to address specific topics.

Summary and Future Research

As demand for finite NAS resources increases, a collaborative forum is needed to involve L/R operators in developing decision-making processes, information exchanges, performance metrics, and tools and procedures to address challenges in accommodating all airspace users. This paper proposes an initial Space CDM concept that spans strategic collaboration and implementation of collaborative practices for planning, operations, and post-analysis. It also identifies several technology capabilities that are needed to support the operational concept.

This work is intended as a starting point for engaging L/R operators, the FAA, and other NAS users in how CDM would work for L/R operations. Based on that engagement, we expect that the concept will be modified, shaped, and expanded to fit L/R operational needs while integrating as appropriate with existing CDM practices.

Future research includes consideration of other L/R types, off-nominal L/R events, and post-analysis data, metrics, and processes. In addition, analysis is needed to identify how existing and planned capabilities can provide the technology capabilities described in the concept. Engagement with stakeholders is needed to specify collaboration, negotiation, and decision-making norms that consider multiple NAS user perspectives. Products of associated activities (e.g., FAA's update of the Space Vehicle Operations concept, findings and recommendations of rulemaking committees) also inform the Space CDM concept development.

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