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Research and Innovative Technology Administration
Volpe National Transportation Systems Center

Point-to-Point Commercial Space Transportation in National Aviation System

Final Report

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Table of Contents

1.0 INTRODUCTION

1.1 BACKGROUND

The advent of suborbital transport brings promise of point-to-point (PTP) long distance transportation as a revolutionary mode of air transportation. In 2008, the International Space University (ISU) of Strasbourg, France, published a report[1] documenting its appraisal of PTP transportation technology. This report describes the conditions that should be put in place to foster and sustain the growth of this industry from the technical, market, financial, infrastructure, safety, and legal perspectives. The ISU study calculates that transatlantic flight times for suborbital vehicles from London to New York would take less than 1 ¼ hours, less than one-third the travel time required by the supersonic aircraft Concorde and a fraction of that required by conventional commercial aircraft. This potential for the rapid global transport of passengers and the fast distribution of goods and services make PTP transportation an attractive space technology concept worth exploiting.

Based on ISU findings, the Federal Aviation Administration (FAA) Office of the Associate Administrator for Commercial Space Transportation (AST) recognized a need to identify issues and approaches for integrating PTP systems into the National Airspace (NAS) and International Air Space (IAS).

1.2 Objectives

The goal of this study is to provide FAA AST with technical support in formulating effective policies and regulations that address issues associated with the air traffic management (ATM) of commercially-operated, suborbital PTP transportation focused on the long distance delivery of both humans and cargo. The Volpe Center examined the issues associated with integrating PTP Systems into the NAS and international airspace by:

- Identifying institutional, operational, and technical issues that must be addressed for launching and operating either supersonic or hypersonic point-to-point (PTP) systems in or through the U.S. National Airspace System (NAS) and between international/transcontinental city pairs. This report does not address PTP economic issues.
- Prioritizing the issues, ranking them from "most challenging" to "least challenging," and explaining the rationale for the issue ranking.
- Providing and prioritizing insights into path forward to resolve the issues.

1.3 Assumptions

In this report, space vehicle launch and landing sites, which may be co-located with or using the facilities of airports or may be dedicated spaceports, will be referred to as "terminals."

Controlled airspace extends up to 60,000 feet with uncontrolled suborbital space above that altitude.

PTP flights will need to be interfaced with a congested U.S. airspace system that managed almost 44 million aircraft operations in calendar year 2008, 96% of them instrument operations.[2]

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[1] Adebola, Simon, and 22 other authors, Great Expectations: An Assessment of the Potential for Suborbital Transportation, Final Report, Masters Program of the International Space University, Strasbourg, France, 2008.
[2] Obtained from FAA Administrators Fact Book, August 2009,

PTP control strategies will depend upon individual launch and landing site flight traffic and physical characteristics.

1.4 NextGen Overview

The Next Generation Air Transportation System (NextGen) information presented in this section was extracted from information on the NextGen Fact Sheet on the FAA website,[3] the 2007 U.S. submission to the International Civil Aviation Organization (ICAO),[4] and the latest version of the Next Generation Implementation Plan, revised on February 10, 2009.[5]

The NextGen is comprehensive system upgrade to the National Airspace System (NAS) that will be implemented across the U.S. in stages between 2012 and 2025, to reduce both airborne and airport congestion by fundamentally changing air traffic management. The system concept was developed by the Joint Planning and Development Office (JPDO), the organization that is responsible for managing the transition to NextGen by 2025. The JPDO is the central organization that coordinates the efforts of the Federal Aviation Administration (FAA), National Aeronautics and Space Administration (NASA), the White House Office of Science and Technology Policy, and the Departments of Transportation (DOT), Defense (DOD), Homeland Security (DHS), and Commerce (DOC). The NextGen Integrated Work Plan (IWP), version 12, Executive Summary, and related appendices are available on the JPDO web site.[6]

The NextGen Implementation Plan presents these governing principles as a "foundation for an integrated avionics equipage strategy":

- "Target equipage and associated capabilities to maximize operational benefits …to satisfy demand…
- Consistent with safe and efficient operations provide 'best-equipped, best-served' priority in the NAS to early adopters…
- Harmonize operations, performance requirements and avionics solutions globally to ensure maximum benefits to operators who fly internationally".

To implement NextGen, the FAA is undertaking a wide-ranging transformation of the entire U.S. air transportation system - not just segments of it - to avoid congestion and to meet future demands. It is being constructed from key components of existing programs combined with evolving new advanced systems. NextGen will need to accommodate new complexities introduced by the increased use of unmanned aerial vehicles and the implementation of reusable launch vehicle (RLV) operations for both tourism and PTP transportation.

The most significant NextGen transition, which makes other innovations possible, is the migration to connected and compatible information systems that provide all system users with easy access to timely consistent information (*Network-Enabled Information Access*). NextGen moves away from legacy ground-based systems to dynamic Global Positioning Satellite (GPS)-based navigation and surveillance

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http://www.faa.gov/about/office_org/headquarters_offices/aba/admin_factbook/media/200908.pdf

[3] NextGen Fact Sheet, February 17, 2007**http://www.faa.gov/news/fact_sheets/news_story.cfm?newsid=8145**

[4] "Next Generation Air Transportation System Information System," presented by the United States of America to International Civil Aviation Organization, Tenth Meeting of Civil Aviation Authorities, RAAC/10-IP/03, Caracas, Venezuela, 13-15 June 2007.

[5] NextGen Implementation Plan 2009, **http://www.faa.gov/about/initiatives/nextgen/media/ngip.pdf**

[6] NextGen Integrated Work Plan, Executive Summary, version 12, and appendices. **http://www.jpdo.gov/library/IWP_FY12_Executive_Summary.pdf** ; **http://www.jpdo.gov/iwp/IWP_V1.0.zip**

technologies and provides the technological innovations to "enable critical transitions

- From voice communications to digital data exchange
- From a disparate and fragmented weather forecast delivery system to a system that uses a single, authoritative source
- From operations limited by visibility to sustaining the pace of operations even when impacted by adverse weather or difficult terrain."[7]

Under NextGen "operators will access all related information on the current status of the airspace system through a single source. This information will include airspace blocked for military, security, or space operations… other airspace limitations, such as those due to current or forecast weather or congestion. It also will show the status of properties and facilities, such as closed runways, blocked taxiways, and out-of service navigational aids. This will allow users to begin the planning process with a full picture of potential limitations on their flights from ground operations to the intended flight path trajectory."[8] In addition, some airports are expected to enjoy new airport infrastructure, as well as new procedures that may include the shifting of certain decision-making responsibilities.

1.4.1 NextGen Benefits

The more efficient design of airspace and improved procedures facilitated by the implementation of NextGen technologies are expected to result in improved safety, access, capacity, predictability, operational efficiency, and environment. Improved access and flexibility for point-to-point operations will benefit all phases of flight (departure, en route, transitioning, approach, arrival) by defining more precise terminal area arrival procedures that smoothly transition aircraft from the enroute system to the terminal area operations to:

- Increase the predictability of operations
- Reduce controller/aircraft communications
- Reduce an aircraft's fuel burn with more continuous vertical descents
- Reduce the miles flown in terminal airspace
- Reduce the interaction between dependent flows in complex airspace

These NextGen benefits are realized by implementing the NextGen capabilities in Section 1.4.2 using the state-of-the-art technologies' improvements described in Section 1.4.3.

1.4.2 NextGen Capabilities

NextGen's increased scope, volume, and widespread distribution of information will enable FAA air traffic managers and flight operators to work collaboratively to mitigate major demand and capacity imbalances. It will rely on the ability of aircraft to fly precise routes into and out of many airports, not just at the largest, to increase throughput during busy traffic periods. The JPDO has identified the following eight key capabilities that are not available in the current NAS system.[9]

Network Enabled Information Access

NextGen will make information available, securable, and usable in real time to users in all "communities

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[7] Ibid.
[8] Ibid.
[9] See footnotes 4 and 5.

of interest". NextGen data encompasses all relevant information including flight plan information; pilot, passenger and cargo data; aircraft telemetry and status; surveillance information; and weather data. Information that may be "pushed" to known users or "pulled" by other users may be in the form of records, databases (such as pilot licenses and aircraft maintenance records), voice communications, images, etc. with appropriate national defense, security, and privacy protection.

Performance-Based Operation (PBO)

Today's system provides one level of service and a regulatory system structured around aircraft types. PBO will enable the tailoring of services to better meet individual needs. For example, the most active airspace will require the most developmentally advanced avionics.

Weather Incorporated into Decision Making

Airspace limitations and traffic restrictions will be mitigated by improved new technology to sense and mitigate the impacts of the weather. Improved weather forecasting, information sharing, and automation integrating weather information into the NextGen network will improve decision-making. The technology includes analyses of differences between forecasts and actual conditions and applications for using the knowledge to increase available airspace.

Layered Adaptive Security

Layered, adaptive security will incorporate functions into NextGen to increase security while moving more people/goods with proportionally fewer resources. Pre-flight risk assessments will ensure that people and goods are appropriately screened as they move from the terminal curb to the aircraft or as terminal/carrier employees work to support airport and aircraft operations.

Broad Area Precision Navigation

Broad-Area Precision Navigation will provide navigation services to enable reliable aircraft operations in nearly all conditions to support both en-route navigation and precision approaches to airports. It will enable "instrument" landings to be possible at any "air portal" or location within the coverage area without the current ground-based navigation aids. NextGen Broad-Area Precision Navigation (at different required levels of performance) will likely include a next generation of Global Positioning System (GPS) satellites with non-terrestrial navigation augmentation for CAT-I[10] approaches and hybrid Global Navigation Satellite System (GNSS)/inertial avionics for CAT II/III[11] approaches. NextGen may also take advantage of other GNSS systems and broad-area navigation services such as enhanced Long-Range Navigation (LORAN).

Aircraft Trajectory-Based Operations

The critical information provided by NextGen avionics, information systems technology, and data communications will enable many pilots and dispatchers to select their own flight paths because each aircraft will transmit and receive precise data about when it and others will cross key points along their

[10] CAT-I: A precision instrument approach and landing with a decision height not lower than 60m (200 ft) and with either a visibility not less than 800m (2400 ft), or a runway visual range not less than 550m (1800 ft)

[11] CAT II: A precision instrument approach and landing with a decision height lower than 60m (200 ft) but not lower than 30m (100 ft) and a runway visual range not less than 350m (1200 ft). CAT IIIa/b: A precision instrument approach and landing with a decision height lower than 30m (100 ft)/15m (50 ft), or no decision height and a runway visual range not less than 200m (700 ft)/50 m (150 FT). CAT IIIc: A precision instrument approach and landing with no decision height and no runway visual range limitations. A Category III C system is capable of using an aircraft's autopilot to land the aircraft and can also provide guidance along the runway surface.

paths. As a result, the FAA has authorized the development of optimized profile descent (OPD) arrival procedures with optimized vertical profiles to facilitate a continuous descent to touchdown.

Equivalent Visual Operations

NextGen capabilities available from Network-Enabled Information Access, Performance-Based Services, and Broad-Area Precision Navigation will provide aircraft with the data needed to navigate without visual references and to maintain safe distances from other aircraft during non-visual conditions at all air portals.

Super-Density Operations

NextGen's new procedures will improve airport surface movements, reduce spacing requirements, and increase capacity by better matching of airside traffic flows into and out of busy metropolitan airspace to provide maximum airport use. The airport "landside" management, including security systems, will be sized to match the passenger and cargo flow to the airside throughput.

1.4.3 NextGen Technologies

NextGen will employ the key enabling technology suites summarized in the following paragraphs. Collaborative air traffic management will be enabled by the increased scope, volume, and widespread distribution of SWIM information allowing FAA air traffic managers and flight operators jointly to mitigate major demand and capacity imbalances. Under NextGen, the ability of aircraft to fly precise routes into and out of many airports, not just at the largest, will increase terminal flexibility and throughput during busy traffic periods. Figure 1 demonstrates NextGen's expected 2018 capabilities.

System-Wide Information Management (SWIM)

SWIM will provide a single infrastructure and information management system to deliver high quality, timely data to many users and applications. By reducing the number and types of interfaces and systems, SWIM will reduce data redundancy and better facilitate multi-user information sharing. SWIM will also enable new modes of decision making as information is more easily accessed.

Automatic Dependent Surveillance-Broadcast (ADS-B)

ADS-B uses Global Positioning System (GPS) satellite signals to provide air traffic controllers and pilots with much more accurate information that will help to keep aircraft safely separated in the sky and on runways. Transponders receive GPS signals and use them to determine the aircraft's precise position. This and other data is then broadcast to other aircraft and to air traffic control. Once fully established, both pilots and air traffic controllers will see the same real-time air traffic display. The avionics necessary for implementing ADS-B will be mandated.

NextGen Network Enabled Weather (NNEW)

NNEW is focused on halving annual weather-related delays. Thousands of global weather observations and sensor reports from ground-based, space-based, and airborne sources will be integrated into a single real-time, national weather information system. NNEW's goal is to provide a common, four-dimensional weather image across the NAS to improve air transportation decisions.

NAS Voice Switch (NVS)

NVS will replace the seventeen different voice switching systems currently use in the NAS, some of which are more than 20 years old, with a single air/ground and ground/ground voice communications system. The current linkage does not support sharing of airspace within and across facility boundaries; reconfiguration capability of controller position to radio frequency and volume of airspace is inflexible; and reconfigurations cannot be done quickly. NVS will allow the realization of modernization, such as network-based infrastructure and evolution toward flexible communications routing that support dynamic re-sectorization, resource reallocation, and airspace redesign.

Data Communications

Current communications between aircrew and air traffic control, as well as between air traffic controllers, are principally conducted by voice. Initially, data communications will provide an additional means of two-way communication for air traffic control clearances, instructions, advisories, flight crew requests, and reports as the new equipment is phased in. Once most aircraft are equipped, routine controller-pilot messages and clearances will be exchanged via data link to improve air traffic controller productivity and increase system capacity.

Area Navigation (RNAV)/Required Navigation Performance (RNP)

RNAV enables aircraft to fly on any desired flight path, for point-to-point operations, within the coverage of ground- or spaced-based navigation aids, within the limits of the capability of the self-contained systems, or a combination of both capabilities. RNP is RNAV with the addition of onboard aircraft performance monitoring and alerting capability that provides the system with the ability to monitor the navigation performance achieved and to inform the crew if the requirement is not met, thus enhancing the pilot's situational awareness and enabling reduced obstacle clearance or closer route spacing without intervention by air traffic control.

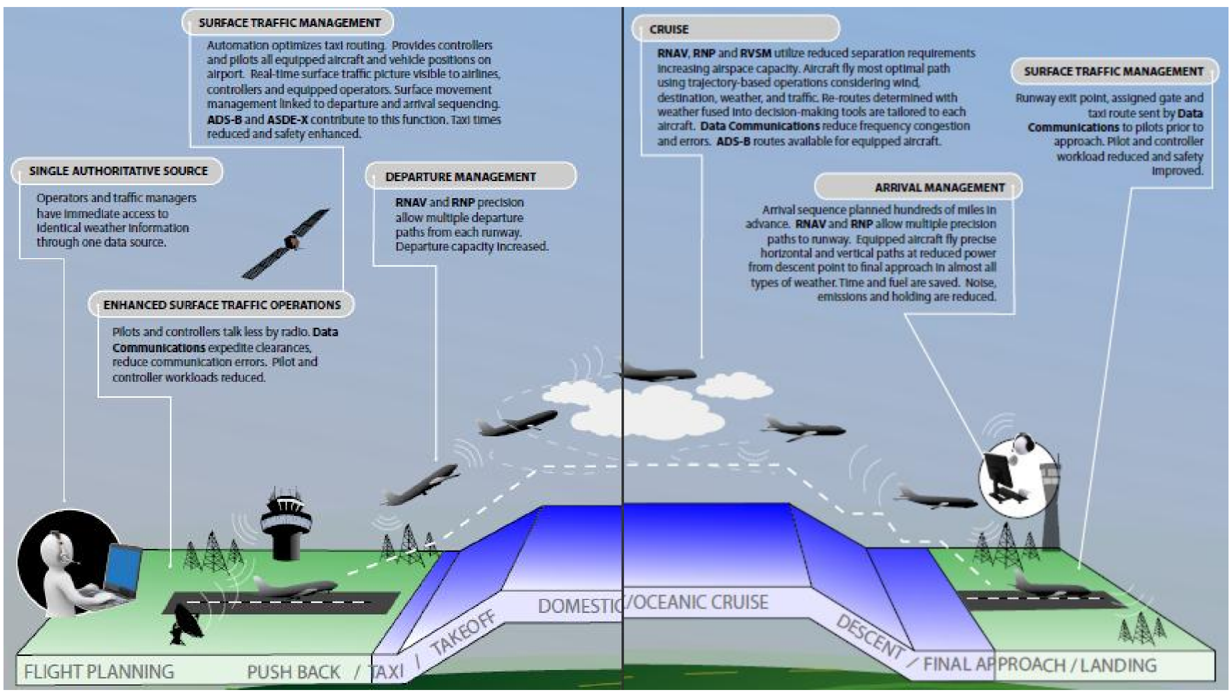

Figure 1 - NextGen Mid-Term Features[12] [13]

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[12] See footnote 5.

[13] Reduced Vertical Separation Minima or Minimum (RVSM) is an aviation term used to describe the reduction of the standard vertical separation required between aircraft flying at levels between 29,000 ft and 41,000 ft from 2,000 feet to 1,000 feet, thus increasing the number of aircraft that can safely fly in a particular volume of airspace.

Airport Surface Detection Equipment, Model X (ASDE-X)

ASDE-X is a terminal system that provides surface traffic situational awareness to air traffic controllers. It combines surface movement radar and aircraft transponder data to display aircraft positions and flight call-signs. ASDE-X uses ADS-B broadcast position, velocity, altitude, heading, and identification data.

Cockpit Display of Traffic Information (CDTI)

ADS-B and ASDE-X may feed a cockpit display of traffic information(CDTI), also called "moving map" displays, to provide pilots with improved visibility of the all instrumented ground traffic.

2.0 KEY ISSUES

2.1 Airspace Traffic Management

The anticipated commercial space traffic generated by the number of fully-operational PTP flights will eventually preclude these flights from being handled as "exceptions" by the air traffic management (ATM) system in high density terminal areas. Air carrier flights can be adversely affected by exceptions. Competition for ATM services not only has logistical consequences associated with aircraft delays in already high density terminal areas, such as crew duty cycle and gate slot management issues, but also can cause economic disruption in terms of increased fuel use, longer crew duty time, additional emissions, and passenger dissatisfaction with delays and missed connections.[14]

Commercial space PTP development could be enhanced by a framework with clear responsibility assignments and an unambiguous and stable legal platform that businesses can rely on when making decisions. Knowing in advance not only the technical and operational NextGen "rules of the game," but also the applicable/prospective government safety regulations, qualifications/credentials, and guidelines for commercial suborbital PTP would provide entrepreneurs with that surety.

2.1.1 National Strategy

Because of the "lack of a comprehensive national space launch strategy," no single federal agency currently has total responsibility for the operations of U.S. commercial flights in space.[15] Since U.S. commercial space transportation activity is expected to expand significantly in the next few years, the U.S. government needs to act soon to clearly determine responsibilities, define NAS boundaries with space, and to resolve the question "Which agency is responsible for commercial space vehicles operating in, leaving, operating above, and re-entering the NAS?" In addition, AST and NextGen will need to work closely together to define the accommodations necessary for NextGen system aircraft and commercial space transportation vehicles to inhabit the NAS safely.

2.1.2 International Coordination

Numerous international activities are underway to harmonize worldwide aviation standards with NextGen

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[14] FAA Office of Commercial Space Transportation, Concept of Operations for Commercial Space Transportation in the NAS Addendum 1: Operational Description, revision 0, June 15, 2005, **http://www.faa.gov/air_traffic/satms/media/conops_addendum_1.pdf**

[15] Dillingham, "Commercial Space Transportation: Development of the Commercial Space Launch Industry Presents Safety Oversight Challenges for FAA and Raises Issues Affecting Federal Roles", GAO Testimony before the Subcommittee on Aviation, Committee on Transportation and Infrastructure, US House of Representatives, GAO-10-286T, December 2, 2009. **http://www.gao.gov/new.items/d10286t.pdf**

requirements under the auspices of ICAO.

The European Union and European Organization for the Safety of Air Navigation (EuroControl) have defined the Single European Sky ATM Research (SESAR) program [16] for Europe "to eliminate the fragmented approach to European ATM, transform the ATM system, synchronise all stakeholders and federate resources."[17] The JPDO and EuroControl are working together to coordinate the two developmental programs.[18] The U.S. reported to ICAO that "International harmonization accommodates both the demands of U.S. users to operate globally without unnecessary constraint, and similarly, to embrace the needs of non-U.S. users to operate in the United States.[19]"

The aviation community is continuing to pursue the benefits of Performance-Based Navigation (PBN) through the implementation of RNAV and RNP-based air traffic routes and instrument procedures. In March 2007, ICAO completed the PBN Manual[20] which involved collaboration with technical and operational experts from several countries. The manual provides global harmonization of the RNAV and RNP requirements of ATM Planners, Air Navigation Service Providers (ANSPs), Air Operators, Airport Operators, Regulators, Air Traffic Controllers, and Procedure Designers. To promote global awareness and understanding of the new Manual, FAA, and EuroControl, with the ICAO PBN Program Office, presented 10 seminars throughout the ICAO Regions that were completed by December 2008.

"The ICAO Caribbean/South America Regions (CAR/SAM) have been at the forefront of ICAO PBN strategic planning, as well as its activities to advance readiness for PBN implementation in its Member States."[21] In April 2007, the CAR/SAM PBN Roadmap, developed in 2006, was approved by Member States several months before ICAO Resolution A36-23 on PBN. An Asia/Pacific PBN Task Force first met in January 2008 to begin developing a PBN implementation plan for the Asia/Pacific Region, and continues to address regional PBN planning and implementation issues.[22] In February 2010, the International Air Transport Association (IATA) proposed "expanding the scope of the PBN Progress Reporting Template to enable States to better measure and report progress in alignment with ICAO performance framework requirements." [23]

This same kind of cooperation will be needed between countries affected by operational commercial RLV suborbital PTP human and cargo transportation. Since current space-related laws, as well as aviation

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[16] Patrick Ky and Miaillier, Bernard. SESAR: Towards the New Generation of the Air Traffic Management Systems in Europe, ACTA Journal of Air Traffic Control, January to March 2006.
http://www.jpdo.gov/library/SESAR.pdf

[17] SESAR Brochure, **http://www.sesarju.eu/sites/default/files/documents/reports/SESAR_Bochure.pdf**

[18] JPDO Paper No. 08-001. A Comparative Assessment of the NextGen and SESAR Operational Concept, May 22, 2008. **http://www.jpdo.gov/library/InformationPapers/NextGen_SESAR_JPDO Information Paper_FINALv2.pdf**

[19] See footnote 5.

[20] Performance-Based Navigation (PBN) Manual, Document # 9613, **http://store1.icao.int/search.ch2**

[21] U.S. presentation, "Review of Performance Based Navigation (PBN) Initiatives and Need for Advancement of Operational Approval and Flight Validation Expertise," ICAO South American Regional Office, Eleventh Meeting of the Civil Aviation Authorities of the SAM Region, RAAC/11-WP/18, (Santiago, Chile, 6 – 8 May 2009).
http://www.lima.icao.int/MeetProg/2009/RAAC11/RAAC11WP18.pdf

[22] ICAO Asia Pacific Office, "Summary – PBN Development," 2009.
http://www.bangkok.icao.int/meetings/2009/pbn_tf5/1sum_pbn.pdf

[23] IATA, "Expanding the Scope of PBN Implementation Progress Reporting," Sixth Meeting Of The Performance Based Navigation Task Force, PBN/TF/6 – WP11, Hong Kong, China, 3 – 5 February 2010.
http://www.bangkok.icao.int/Meetings/2010/pbn_tf6/wp11.pdf

regulations, do not include consideration of suborbital PTP transportation, there is not a consistent, comprehensive body of law addressing the related issues. In initial stages of PTP operation, issues and regulations might be resolved with bi-lateral agreements between countries that are origin/destination and/or overflight stakeholders. Since international agreements can take protracted periods of time to execute, the FAA will need to address these issues with stakeholders, including ICAO, well in advance of RLV PTP operations.

Under the Chicago Convention ICAO has authority to regulate the international flights of civil aircraft to facilitate the safe and orderly development of civil aviation and to establish international air transport services, but not those aircraft in state service, e.g., military, customs, and police operations.[24] Since the Chicago Convention, the ICAO General Assemble has adopted a number of resolutions related to international civil aviation and outer space and has stated that occurrences "relating to the exploration and use of outer space are of great interest to ICAO, since many of these activities affect matters falling within the Organization's competence under the term of the Chicago Convention."[25] Some authors have stated that ICAO already has the legal authority to regulate aerospace vehicles, since the Chicago Convention places no restrictions on ICAO's authority to regulate the international flights of civil "aircraft" based on their altitude and its fundamental mission to ensure safety and order, as well as provide international air transport service.[26] The authors differentiate between ICAO's legal authority and the question of policy regarding whether the Chicago Convention *should* apply which requires an interpretation of the Convention and its relevant Articles. Its Articles demonstrate ICAO's purpose "to create a unified and harmonious regime of safety and navigation of airspace…It would thwart the Convention's essential purpose to conclude the treaty was meant to be frozen in time".[27]

To enable commercial suborbital PTP operations, the FAA will need to work with international partners to harmonize standards and procedures for both air and space transportation policies worldwide.

2.1.3 Safety

Since many features of NextGen are scheduled for implementation between 2018 and 2025,[28] its schedule provides sufficient time and advanced information for AST and PTP stakeholders to plan for technology, communications, trajectory, and operational NextGen adaptations required for safe operation.

The FAA's current safety steps for commercial space transportation were reported in the December 2009 General Accountability Office (GAO) testimony presented before the U.S. House Subcommittee on Aviation, Committee on Transportation and Infrastructure.[29] GAO concluded that, as commercial launches increase,

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[24] Preamble to the Chicago Convention

[25] ICAO General Assembly Resolution A29-11: Use of Space Technology in the field of Air Navigation (1992), Doc. 9600, A29-RES.

[26] Dempsey, Paul Stephen, and Mineiro, Michael C, McGill University Institute of Air & Space Law, "ICAO's Legal Authority to Regulate Aerospace Vehicles," Proceedings of 3rd IAASS Conference, Rome, October 22, 2008, **http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1289547**

[27] Ibid.

[28] NextGen Implementation Plan 2009, **http://www.faa.gov/about/initiatives/nextgen/media/ngip.pdf**

[29] Dillingham, "Commercial Space Transportation: Development of the Commercial Space Launch Industry Presents Safety Oversight Challenges for FAA and Raises Issues Affecting Federal Roles", GAO Testimony before the Subcommittee on Aviation, Committee on Transportation and Infrastructure, US House of Representatives, GAO-10-286T, December 2, 2009. **http://www.gao.gov/new.items/d10286t.pdf**

- FAA will face increases in its licensing and regulatory workload
- FAA will need to determine whether its "current safety regulations are appropriate for all types of commercial space vehicles, operations, and launch sites"
- FAA will also need to develop safety indicators and collect data to help it determine when to begin to regulate crew and passenger safety after 2012
- FAA will face policy and procedural issues when it integrates the operations of spacecraft into its next generation air transportation system
- Coordinating the federal response to the commercial space industry's expansion is an issue for the federal government in the absence of a national space launch strategy for setting priorities and establishing federal agency roles.

GAO reported that spaceport operators and experts raised concerns about the suitability of FAA safety regulations for spaceports and thought that safety regulations should be customized for each spaceport to address the different safety issues raised by various types of operations, such as different trajectories and ways that vehicles launch and return to earth - whether vertically or horizontally. This resulted in the conclusion to measure and track safety information and to use the information in determining whether regulations should be promulgated or revised.

GAO testified that FAA is taking steps that will enable it to be prepared to regulate and that space tourism companies informally collect lessons learned and share best practices with each other and with FAA, which eventually could lead to industry standards. In addition, senior FAA officials also told GAO that FAA is reviewing NASA's human rating of space launch vehicles, as well as FAA's Office of Aviation Safety aircraft certification process, as it considers possible future regulation of human spaceflight standards.

The key hazards associated with PTP launch and reentry operations are collision between the space vehicle and an aircraft and falling debris from an in-flight RLV failure hitting an aircraft.

The probability of collision between a similarly instrumented PTP RLV and an aircraft will need to be similar to that between two aircraft. Adequate separation will need to be maintained during the relatively short time that the high speed RLV is transiting the NAS.

2.2 Vehicles

Although several horizontal and vertical commercial space vehicles designs are evolving, those with an aircraft-like appearance and those that launch horizontally will most probably to be used for PTP flights, since the cargo and passenger loading and unloading processes can be executed with a minimum of auxiliary equipment. In the FAA's 2001 "Concept of Operations for Commercial Space Transportation in the National Airspace System, Version 2.0," [30] the launch and return flight characteristics of commercial space vehicles types were described by the description replicated in Figure 1.

The communications, avionics, and maneuverability capabilities of PTP RLVs will determine how smoothly they can be integrated into a full-implemented NextGen airspace.

[30] "Concept of Operations for Commercial Space Transportation in the National Airspace System, Version 2.0", Federal Aviation Administration, May 11, 2001, **http://www.faa.gov/about/office_org/headquarters_offices/ast/media/CST_CONOPS_v2.pdf**

2.2.1 Operating Environment

In the future, since PTP markets will be near large cities, the FAA will not be able to confine NAS portions of PTP flight to existing, active restricted airspace, as it did during a 2004 SpaceShipOne flight from a sparsely-populated (<5000) Mojave, CA location. The airspace corridor employed was about 50 miles by 25 miles in area and went from the surface to an unlimited altitude.

Traffic controllers, aircraft, and RLVs must have communications and comprehensive situational awareness capability, and RLV's a degree of vehicle trajectory control, to prevent airspace conflict as RLVs appear in rapid descents from extreme altitudes into the controlled airspace altitudes.

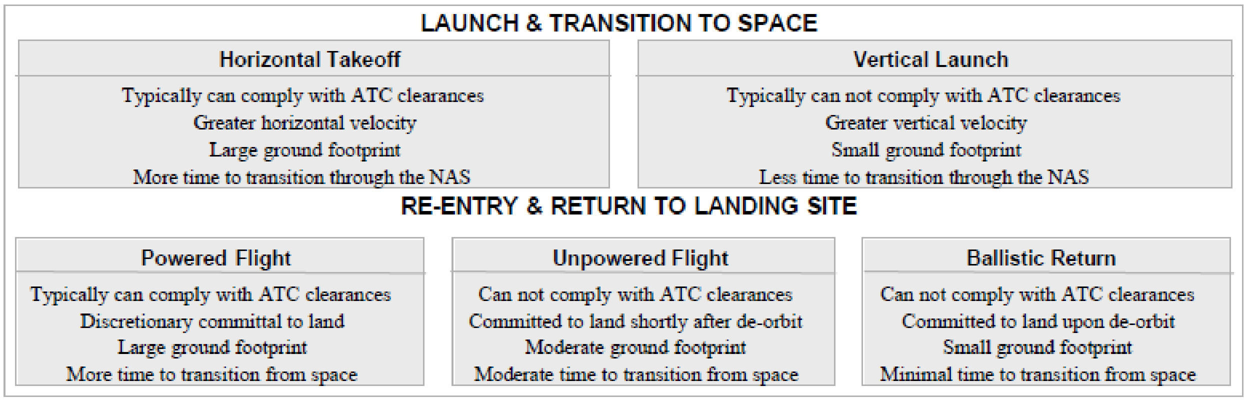

Figure 2- Launch and Re-Entry Concepts

With NextGen, the U.S. is seeking to establish seamless operations beyond its borders. NextGen improvements will extend to oceanic operations as the system assures that each aircraft will enter oceanic airspace on its most optimal trajectory. Airspace entry will be specified by entry time, flight path and assigned altitude. As weather and wind conditions change above the ocean, both individual reroutes and changes to the entire route structure will be managed via a data communications link. Trajectory control, communications, and situational awareness will be critical for PTP operation throughout the NAS.

2.2.2 Physical Environment

While developers and manufacturers are certainly designing vehicles to consider acceleration, vibration, and temperature impacts, a vehicle's instrumentation and avionics must operate reliably under the same conditions to provide shared situational awareness and operate effectively in the NextGen environment. PTP RLVs will have to be approved for operational passenger and cargo in harmony with FAA rules for vehicles functioning in controlled airspace and departing from an aviation terminal facility. The design, adaptation, and deployment of instruments are components of overall spacecraft design to be undertaken by the various developers and manufacturers. However issues that directly affect the spacecraft's ability to operate in concert with aircraft operating in controlled airspace that need to be considered are:

- Qualifying standard aircraft instruments for the space vehicle and operating environment or qualifying spacecraft instruments for interface with NextGen
- Maintaining advanced instrumentation
- Operational contingencies for a failed instruments

In addition, the RF Blackout of re-entering space vehicles is an issue that has been and will continue to be addressed by AST. In 2007, the Aerospace Corporation published its AST-funded assessment of the radio frequency blackout phenomena caused by plasma generated during reentry and of known methods to mitigate this communication-inhibiting effect for RLVs[31]. The report stated that "The ability to predict the ionized flow field for classes of vehicles most likely to emerge as hypersonic space transportation systems, with sufficient accuracy to identify the altitudes of blackout onset and recovery within reasonable bounds, has been demonstrated for altitudes greater than approximately 100K feet. This altitude regime is most the likely for future space transportation due to low g forces and low heat loads. For the lower, suborbital altitudes, many commercial RLVs will not be subjected to RF blackout because their relatively low velocities will not create conditions that generate plasma."

2.2.3 Equipment

"The safety controls necessary to provide for operational launch and reentry in an integrated traffic environment will depend largely on the outcome of the hazard analysis of the vehicles and their intended operations." [32] A NextGen-compatible RLV instrumentation suite that will provide at least advanced communications, navigation, and surveillance (CNS) technologies will be necessary even if the PTP RLVs do not employ airports as their origins and destinations. Knowledge of the space vehicle's flight plan and a downlink of voice and tracking information for incorporation into SWIM would provide air traffic controllers with the situational awareness to maintain adequate separation between the RLV and aircraft under their control.

Future automatic dependent surveillance-broadcast (ADS-B) technology can provide both RLV and aircraft pilots with increased situational awareness on cockpit displays of vehicle information and enable each to take appropriate action. ADS-B Consists of two elements - ADSB-Out and ADS-B In. ADS-B Out provides high accuracy and frequent aircraft position reports that can be used by air traffic control (ATC) to provide radar-like separation in non-radar areas. ADS-B In provides information to the cockpits of properly equipped vehicles that can be used for multiple applications, including:

- Cockpit Display of Traffic Information (CDTI) will provide a graphical depiction of air traffic to improve situational awareness for a variety of operations using Traffic Information Service - Broadcast (TIS-B), a service which provides ADS-B equipped aircraft with position reports from secondary surveillance radar on non-ADS-B equipped aircraft, and
- Guidance Display that uses ADS-B In to provide relative guidance, predominantly based on speed control, to maintain a given spacing from a selected target and supports a number of benefits, including merging and spacing and limited delegated separation.

The following figure provides the NextGen Implementation Plan's mid-term (year 2018) avionics standards publication schedule.

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[31] Hartunian, R.A., G.E. Stewart, S.D. Fergason, T.J. Curtiss, R.W. Seibold, Causes and Mitigation of Radio Frequency (RF) Blackout During Reentry of Reusable Launch Vehicles, The Aerospace Corporation, El Segundo, CA, Volpe Center Report # DOT-VNTSC-FAA-06-23, Contract # DTRT57-05-D-30103, 26 January, 2007. **http://www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/media/ATR-2007%285309%29-1.pdf**

[32] Murray, Daniel P., FAA AST, Space and Air Traffic Management of Operational Space Vehicles, AIAA 2008-6890, AIAA Atmospheric Flight Mechanics Conference, 18 - 21 August 2008, Honolulu, Hawaii. **http://www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/media/AIAA-2008-6890-470%5B1%5D.pdf**

Plan for New Aircraft Capability Guidance

Avionics Enablers	Aircraft and Operator Guidance		Aircraft Implications	Flight Crew Implications
	Guidance	Schedule		
Data Communications: ATN Baseline 2	AC20-140B, AC120-70C	2014	Based on RTCA SC-214	AC 120-70C
CDTI (ADS-B IN)	AC, TSO	2010	Receive capability in 1090ES or UAT, display of traffic, and ability to select traffic to follow	
CDTI with alerting (ADS-B IN)	AC, TSO	2011	CDTI, plus display of target speed to maintain desired spacing (distance or time) and alerting if minimum requirement is exceeded	
ADS-B Guidance Display (ADS-B IN)	AC, TSO	2012	Along-track guidance (achieve spacing in time/distance).	
Paired approach guidance	TBD	2015	Builds on ADS-B guidance display to address wake vortex and collision risk	
GLS (CAT II/III)	Project specific policy	2012	GBAS Landing System (CAT II/III) (detailed requirements being developed)	Common expect procedures with ILS

This table shows when the standards for various avionics equipage will be published.

Figure 3 - NextGen Avionics Standards Publication Schedule[33]

For an RLV to be fully equipped for NextGen operations, it would need to have equipment providing the capabilities shown in Table 1 below.

RLV Avionics Equipment Capabilities for full NextGen Integraton	Flight Planning	Pushback, Taxi, and Departure	Climb and Cruise	Descent and Approach	Landing, Taxi, and Arrival
Data Communications (DC) for real-time routing	X	X	X	X	X
RNAV/RNP	X	X	X	X	X
Future Air Navigation System (FANS) in Oceanic Airspace			X	X	
ADS-B In and Out		X	X	X	X
CDTI		X	X	X	X
Ground Based Augmentation System (GBAS) using VHF or UHF tranmission bands				X	
Traffic Information Service - Broadcast (TIS-B)		X			X
Flight Information Service - Broadcast (FIS-B)		X			X
Vertical Navigation (VNAV)				X	

Table 1 - RLV Avionics Needed for Full NextGen Integration[34]

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[33] See footnote 5

Without addressing additional communications desirable for space flight portions of the RLV operation, at least the following communications and antennas are needed for nominal ATC operation:

- GPS
- Communications
- Satellite Communications
- ADS-B Broadcast (aka Squitter) or the equivalent.

The suborbital vehicle's avionics and communication equipment must be light weight, robust, and highly reliable, as well as satisfying redundancy needs. Typical commercial transport aircraft have redundant systems for communications because they are critical for operation in controlled airspace, and because loss of communications is a potentially catastrophic failure. Typically, the aircraft has redundant radio systems each capable of communicating over many channels. In addition, the aircraft has redundant antennas and interconnection points to eliminate the possibility of a single point failure.

For the suborbital vehicle, equipment requirements will be more stringent since equipment will have to withstand more mechanical stress, and items near/outside the vehicles surface must survive re-entry heat and possibly extreme cold. The following paragraphs describe the PTP RLV equipage needs associated with NextGen capabilities.

Network-Enabled Information Access

To properly operate the advanced NAS, information about system information (from geometry and geography to equipment status to weather to traffic and traffic flows) is accessible to all stakeholders through SWIM technology, a backbone of communications coupled with massively distributed computing resources. Each user can receive and provide information vital to efficient, safe operations. RLVs will need basic avionics and communications equipment, at a minimum to maintain contact with terminals and airspace controllers as well as visibility to aircraft, which could include:

- Digital data communications
- Digital voice
- Interface to on-board systems
- Pilots CDTI displays
- Flight control automation
- RLV status telemetry
- Navigation and tracking automation
- Weather.

Performance-Based Operations and Services

Area Navigation (RNAV)[35] equipment enables aircraft to fly on any path within coverage of navigation

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[34] Table Note: Future Air Navigation System (FANS) is an international standard compliant avionics system for digital communications and position reporting over oceanic airspace. Traffic Information Service - Broadcast (TIS-B) provides ADS-B equipped aircraft with position reports from secondary surveillance radar on non-ADS-B equipped aircraft Flight Information Service - Broadcast (FIS-B) transmits graphical National Weather Service products, temporary flight restrictions (TFRs), and special use airspace.

[35] Area Navigation acronym is RNAV with the R from "aRea" and the NAV from "NAVigation."

aids, permitting more access and flexibility for point-to-point operations. Required Navigational Performance (RNP), like RNAV, enables aircraft to fly on any path covered, includes onboard performance monitoring and alerting capability, and enables closer enroute spacing without intervention by air traffic control for more precise arrivals and departures.[36] To participate fully in these NextGen PBO services, PTP RLVs would need the appropriate on-board avionics coupled with:

- Advanced Pilot Interface
- Advanced Navigational Equipment
- New, adapted ATC Procedures

PBO is conceived as a concept to meet standards of operation not a mandated set of specific technologies. As advanced spacecraft are developed during the NextGen deployment, RLVs may need to meet NextGen performance standards, but they should be able to use equipment designed for operation in space that is compatible with NextGen standards.[37]

Weather Assimilated Into Decision-Making

In the past, weather information was often guess work, even when reporting existing conditions (called a now-cast). NextGen will apply the most advanced technology to provide operators with full knowledge of weather conditions, predictions, and expert guidance in avoiding and/or coping with the weather.[38]

For Commercial Space operations, NextGen Weather will be a critical infrastructure element, since PTP RLVs must maneuver part of the time in the atmosphere, and terrestrial weather information and operational guidance will be components of this NextGen system. Key space-specific weather-related information (triggered lightning, high altitude winds, radiation) is not currently included in the NextGen. The FAA will need to establish needed terrestrial and space weather information that might be added to the NextGen baseline, such as space weather components described in Section 2.5, including predictive tools, and terrestrial weather especially that related to re-entry dynamics throughout the atmosphere.

Broad Area Precision Navigation[39]

Space operations must be compatible with positioning services when in controlled airspace. This functionality is critical to the operation of NAS and NextGen technologies. Passive tracking via RADAR (Radio Azimuth Detection and Ranging) combined with dependent tracking via ADS-B will probably be used together, where available, to better assure operators of spacecraft position. Special problems may develop around positioning while in space and positioning during re-entry, which are technical areas requiring further study.

While positioning locates an object (aircraft, spacecraft) with respect to a grid or another object (spacecraft or aircraft), navigation locates the object with respect to the Earth. The Global Positioning System (GPS) produces very accurate ranging, timing, and self-position signals. PTP RLVs should be able to use GPS and ADS-B (a GPS-based system) when in controlled airspace, because NextGen relies this technology. Space operations may require additional capability beyond these systems, namely:

- GPS in Space (visible satellites, accuracy, geometry, re-entry).

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[36] Dillingham, Gerald L. FAA Faces Challenges in Responding to Task Force Recommendations, GAO-10-188T, October 28, 2009. **http://www.gao.gov/new.items/d10188t.pdf**
[37] NextGen IWP V1.0, ibid, p. 33.
[38] JPDO. NextGen Weather Plan, v1.1, 2009. **http://www.jpdo.gov/library/NextGen_Weather_plan_1.1.pdf**
[39] NextGen Avionics Roadmap, October 2008. **http://www.jpdo.gov/library/Avionics_Roadmap_V1.0.pdf**

- Navigation during re-entry and relay of position to ground.
- Ability to operate in controlled airspace with ADS-B or equivalent technology.

Trajectory-Based Operations

These operations are crew-managed flight progress operations that permit an aircraft to operate without specific contact with Air Traffic Control. In this mode, the vehicle operates according to a pre-agreed trajectory through time and space that is available to the other participants in NextGen. The Traffic Management System (TMS) then relies on the aircraft to occupy specific points in time and space in order to manage traffic flows, merges, and departure/arrival patterns. This agreed-upon trajectory is often referred to as a "4-D Contract" between the aircraft and the TMS. In order to operate in this fashion, a vehicle must be capable of meeting the trajectory plan with limited error and high reliability. In particular, if a sub-orbital vehicle re-entering controlled airspace in unpowered flight were unable to participate in NextGen operations because of maneuverability limitations, it would have to be handled as an exception, similar to emergency conditions. Issues that need to be examined further are:

- PTP RLV capabilities to fulfill a 4-D Contract with ATC
- Effects of hypervelocity ballistic trajectory performance on 4-D Contract and perturbations
- Unpowered flight segments within controlled airspace
- Space pilot effects on the RLV trajectory.

Equivalent Visual Operations

Equivalent Visual Operations provide the aircraft and pilot with sufficient information to allow operation as if there were perfect visibility and is usually associated with weather-related visibility loss. Equipment exists in the current NAS (e.g., Instrument Landing System or ILS) to partially alleviate the problem by providing the pilot with a landing path guide. However, the controller must still maintain aircraft separation and monitor the descent to assure that the aircraft does not deviate. This process can reduce throughput by half, or even more. NextGen will have advanced instruments, including visual aids and adjacent aircraft position information, that will allow a pilot in extremely occluded conditions to operate as if there were a perfectly clear view.

For a suborbital RLV, visual problems might become critical during re-entry with heating effects impairing visual operations and blinding the instrumentation as well (e.g., communications blackout). It is unclear, whether these effects will allow the craft to participate in NextGen Equivalent Visual Operations as the spacecraft slows. After re-entry, the spacecraft will still have very high velocity that might create visual acuity issues for the pilot and accuracy issues for the instrumentation. This area requires ongoing investigation.

Super-Density Operations

Super density operations use NextGen capabilities of advanced modeling, navigation, and intercommunications to operate aircraft in densely occupied airspace while on approach to and departure from large, busy airports. The technique will allow automation and pilots to maintain much closer spacing and higher throughput than pilots could accomplish on their own, while maintaining safety.

If a PTP RLV has substantially different performance than a commercial jet transport, it may not be easily accommodated in the congested airspace (or possibly accommodated at the expense of disrupting the carefully-crafted aircraft flows). Steep glide slopes, unpowered flight, and limited maneuverability are all issues that need to be considered in conjunction with RLV dense airspace operations. This presents a conundrum, since a reentering RLV craft may be unable to participate in this type of operation and be precluded from the facilities of major commercial airports, since the postulated PTP RLV market includes only very large cities.

2.2.4 Passenger Accommodations

FAA has requirements for keeping passengers safe while flying on commercial aircraft, which range from passenger restraints to emergency procedures announcements at the start of every flight, emergency operational procedures, and trained cabin crew emergency assignments. In the future, similar requirements and procedures may be required for commercial PTP operations to be licensed for the carriage of passengers and cargo. While an RLV may appear similar to an airliner, the sub-orbital RLV physical and flight characteristics, such as

- Passenger restraints and allowed cabin movement
- Passenger preparation for confined space, launch g-forces, weightlessness, and re-entry g-forces
- Emergency announcements and passenger procedures
- Provisions dealing with a panicky or sick passenger

need to be taken into account to ensure safe passenger accommodation and controlled vehicle operation.

2.2.5 Cargo

In general, cargo employing suborbital PTP transport most probably will be high value, extremely time-sensitive, and/or possibly fragile. Cargo characteristics (proximity limitations), storage, and securement issues will need to be resolved for safe vehicle operation:

- Cargo mingling, restraints, and operational contingencies for loose cargo
- Protection of high value and/or fragile cargo
- Loading/unloading procedures including weight and balance
- Cargo only or combined passenger/cargo flights
- In-cabin luggage storage allowance.

2.2.6 Security

PTP vehicle security will be similar to that for an international flight of conventional aircraft, but will require careful review of the procedures and incorporation of changes necessary to assure effectiveness for its unique operating environment. NextGen incorporates pre-flight security capability that would most probably be adopted by or adapted for PTP transportation. However, careful analysis is necessary to ascertain whether new procedures will be required to assure the vehicle's secure operation.

Thorough pre-flight passenger and crew screening to ensure suborbital PTP vehicle security would minimize the need for onboard steps to thwart threatening or disruptive occupants. However, the security implications of an unanticipated adverse passenger reaction to the suborbital environment during the flight will need to be addressed as an emergency procedure to prevent access to vehicle controls and crew.

2.2.7 Emergency Response

During a survivable emergency such as a water landing, the RLV may need to have emergency equipment similar to that carried by aircraft. The devices may include emergency radios, water- and/or force-activated emergency beacons, hand-held units for crew members to signal to each other or to assist search and rescue teams, and possibly secondary battery-powered radios that can signal over the vehicle's system in case its radios are inoperative.

2.3 Terminals

Unlike currently-envisioned, near-term recreational or "space tourism" suborbital flights that are planned to be launched from and return to the same terminal facility, fully operational commercially-viable PTP suborbital flights are expected to operate frequent trips to provide cargo and passenger service between densely-populated international hubs.

The ISU report corroborates this view in its statement "A key point to consider in the early phases of PTP suborbital transportation, however, is where the initial spaceport facilities will be located. A primary goal of PTP transportation is to significantly reduce the amount of time that it takes cargo and passengers to reach long distance destinations. If a spaceport is located in a remote location, as some of those currently under development are, then the transportation time from the spaceport to the final destination must also be considered. Once this is factored in, for some spaceports, the total transit time of cargo or passengers may not be significantly less than that of an aircraft that flies directly to a destination for a lower cost."[40]

2.3.1 Logistics

The PTP launch and landing facilities must be rapidly and readily accessible to market sources for passengers and cargo to exploit the time-saving benefits of suborbital PTP transportation. As well as interfacing with the NextGen aviation system, fast and convenient landside transportation needs be considered an integral part of an operational PTP system.

In determining time savings, it is not sufficient to merely look at the origin-destination time of the RLV flight. The journey time for the full supply chain or door-to-door passenger service, including time zone effects, must be considered. Although a carrier like Federal Express or United Parcel Service might establish a hub for its operations at any location that suited its business model, passengers demand convenient access to terminals.

A PTP terminal location must be able to provide RLV flexible facilities (possibly for multiple RLV types) and speedy turnaround services, but also have passenger amenities; streamlined processes for the requisite pre-flight security crew, passenger, and baggage/cargo screening; baggage/cargo handling and marshalling facilities; and customs and immigration clearance capability. While tourist facilities locations might be less constrained, these factors seem to indicate that PTP terminals will need to be proximate to major airport facilities.

To provide expeditious service, origin and destination sites will most probably service population-dense locations similar to those identified in the ISU report and FastForward [41] reports. The comprehensive ISU analysis recommended the PTP passenger routes shown in Table 2, with New York to Los Angeles identified as the most promising route for passenger traffic.

The potential PTP -serviced cities defined by the FastForward Study Group are grouped into three tiers by potential demand as follows: Tier 1: Los Angeles, New York, London, Cologne, Shanghai, Hong Kong, and Tokyo; Tier 2: Mumbai, Dubai, and Sydney; and Tier 3: Buenos Aires, Sao Paulo, and Johannesburg. Table 3 lists the city pair route counts associated with each feasible origin city.

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[40] See footnote 5

[41] Charania, A.C., Kelly, Michael, and Olds, John R., FastForward Study Group, Space Works Engineering, Inc., "Aiming Towards Viable Business Models of Global Hypersonic Point-to-Point Cargo Transportation," 12 October 2009, Copyright ©2009, **http://www.sei.aero/eng/papers/uploads/archive/IAC-09.E6.1.9.pdf**

Rank	Route	Rank	Route
1	Los Angeles → New York	11	Beijing → New York
2	New York → London	12	Hong Kong → New York
3	Tokyo → New York	13	Chicago → Paris
4	Tokyo → London	14	Beijing → London
5	Chicago → Tokyo	15	Hong Kong → London
6	Chicago → London	16	Frankfurt → New York
7	Los Angeles → Tokyo	17	Singapore → New York
8	Paris → New York	18	Frankfurt → Tokyo
9	Paris → Tokyo	19	Los Angeles → Paris
10	Los Angeles → London	20	Singapore → London

Table 2 ISU PTP Routes

Feasible City Pair Route Counts by Origin			
City	**Tier 1 Routes**	**Tier 2 Routes**	**Tier 3 Routes**
Los Angeles	2	2	2
New York	2	2	4
London	2	2	4
Cologne	2	4	5
Shanghai	1	4	4
Hong Kong	0	3	3
Tokyo	1	4	4
Mumbai	0	5	6
Dubai	0	5	6
Sydney	0	3	3
Buenos Aires	0	0	2
Sao Paulo	0	0	2
Johannesburg	0	0	5
Total	**10**	**36**	**50**

Table 2 FastForward PTP Routes

The heavy concentration of aviation traffic at these locations provides impetus for PTP operations to integrate as seamlessly as possible with traffic flow that should be operating under the fully-implemented NextGen. For example, one-third of all aircraft in the NAS transit the New York area during a typical day[42].

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[42] Fleming, Susan, Director Physical Infrastructure Issues, "National Airspace System: DOT and FAA Actions Will Likely Have a Limited Effect on Reducing Delays during Summer 2008 Travel Season," GAO-08-934T, Statement

2.3.2 Equipment

Terminals will benefit from an infrastructure incorporating SWIM capabilities that will enable them to communicate with NextGen controllers as needed, maintain situational awareness of the airspace (and hopefully the suborbital environment), access timely weather conditions and predictions, and sustain continuous communication with appropriately-equipped with PTP RLVs within international controlled or oceanic airspace.

2.3.3 Security

Like current airports, PTP terminal security will require

- physical protection and access controls for facility borders and internal area boundaries with surveillance and alarms
- controlled human access with required government-issued identification
- controlled vehicle access
- pre-flight security clearances of crew, passengers, vehicle, baggage, cargo, and ground crew members
- compliant procedures for managing hazardous materials and for some aspects of environmental protection.

2.3.4 Emergency Procedures

RLV terminals will need to have emergency plans, conduct exercises, and maintain tested response procedures to deal with accidents and incidents of all types, including violent weather, fires internal or external to the facility, explosions, flooding, hazardous materials spills, and physical intrusion.

2.4 Human Factors

Since NextGen NAS functions are targeted at increasing airspace throughput while maintaining safety, implementing NextGen will require pilots to learn about more instruments. A complete change in roles will evolve as more automated/automatic functions cause vehicle automation to become a more active partner with the pilot in controlling the vehicle. In particular, the pilot will have to deal with activities ranging from direct control of the vehicle to oversight and situational awareness to planning. The much larger array of instruments and situations may require the pilot to quickly shift to a different activity using different instruments. A significant change will be the use of instruments to replace vision in a more direct fashion, so "flying on instruments" will be a different, more intense experience than pilots experience today. In addition, cockpit moving map displays indicating the location of all other nearby surface or airborne traffic will require pilot attention.

In this environment, the pilot may be subject to confusion and cognitive overload. With a suborbital vehicle, which also must operate in normal airspace, this array of shifting requirements could be more difficult than that previously encountered. This issue will require careful study to determine human limits that can be expected and to ensure those limits will not be exceeded.

Space operations to be addressed include weightlessness, acceleration management, course correction, diversion, potential space traffic control communications, and re-entry are known issues for a point-to-point spacecraft. Integrating these functions with normal ATC and newer NextGen procedures will

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of in Testimony Before the Subcommittee on Aviation Operations, Safety, and Security, Committee on Commerce, Science, and Transportation, U.S. Senate. July 15, 2008. **http://www.gao.gov/new.items/d08934t.pdf** require a review of pilot human factors in dealing simultaneously with these issues.

Training and qualification will be a key issue because crew will have to demonstrate competence to operate in both the NAS and suborbital environments. Since commercial PTP operations will involve many flights, the industry will require a large number of trained crew members. Initially training individuals efficiently and undergoing qualifying procedures may require significant industry effort.

2.5 Weather

Suborbital PTP transportation could benefit from the NextGen weather forecasting and communication advances, if NNEW incorporated those weather issues that significantly affect space operations, such as high altitude winds, triggered lightning, and space weather, with its terrestrial weather features.

2.5.1 High Altitude Winds

Compliance with planned PTP trajectories will require knowledge of suborbital altitude wind conditions. Currently the precise system performance (accuracy, precision, reliability) required to support RLV flights is unknown. [43] An investigation of high altitude wind detection and measurement technology compared the advantages and disadvantages of various wind technologies that support launch activities, as well as their vertical coverage. The study concluded that "The most effective approach to meeting upper air wind requirements may involve a mixed set of instruments, each with different strengths. Balloon-based systems tend to have finer spatial (vertical) resolution than radar-based ones, whereas the radar-based systems have finer temporal resolution. The two kinds of systems appear to have approximately equal accuracy and reliability. As implemented at the Eastern Range, the QC [quality control] latencies for balloon- and radar-based systems are each about 5 minutes. The radar profilers scan a fixed vertical volume whereas balloons drift with the wind. The volume of the latter sample is neither constant from profile to profile, nor is the volume overhead. The best mix for generating high-quality wind profiles may consist of a DRWP [Doppler Radar Wind Profiler] in combination with balloons. The former gives more timely observations in a fixed volume, while the latter provide higher resolution."[44]

2.5.2 Triggered Lightning

A new Aerospace Corporation report[45] examined the triggered lightning phenomena for four potential launch vehicle configurations and determined that "Triggered Lightning field thresholds are quite uncertain in absolute terms, but they should be reasonably comparable between vehicles at the same altitude. Thus, they provide a quantitative basis for the following conclusions:

1. For vehicles that are designed for unpowered horizontal landings, there is a significant increase in triggering threshold (qualitatively, a reduction in triggering likelihood) during the glide phase of the flight.
2. During the glide phase, these concept RLVs have higher triggering thresholds than medium-sized aircraft (which have been measured to be on the order of 45 kV/m at 4–5 km altitudes).

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[43] Walterscheid, R.L.,"High-Altitude Wind Prediction and Measurement Technology Assessment," Report No. DOT-VNTSC-FAA-09-13, The Aerospace Corporation under contract to the Volpe Center, 30 June 2009.
[44] Ibid.
[45] Walterscheid, R. L., G. S. Peng, P. F. Zittel, G. W. Law, F. S. Simmons, R. W. Seibold, J. C. Willett, E. P. Krider, Triggered Lightning Risk Assessment for Reusable Launch Vehicles at Four Regional Spaceports, The Aerospace Corporation, El Segundo, Ca, Volpe Center Report # DOT-VNTSC-FAA-10-01, Contract # DTRT57-05-D-30103, December 2009. In publication.

3. Not surprisingly, all of these concept RLVs have much higher triggering fields than the Titan IV (which is typical of large orbital boosters for which the current Lightning Flight C[ommit] C[riteria] were designed).

Although the largest vehicle has an appreciably lower triggering threshold than the others, during boost phase all of them appear to be roughly comparable to medium-sized aircraft. This conclusion is less certain that the others because conventional aircraft do not have electrically significant exhaust plumes and, consequently, are not strictly comparable to space vehicles during boost phase."

2.5.3 Space Weather

The 2008 Aerospace Corporation report on space weather[46] provided the following definition "From a safety perspective, space weather is a blanket term used to refer to the potentially hazardous effects of natural phenomena encountered in the space environment. In particular, it refers to ionizing radiation coming from deep space (galactic cosmic radiation), the Sun (solar cosmic radiation), and trapped radiation." The issues addressed in this section were raised in and extracted from that report.

The report stated that "Except in the highly unlikely event of a sudden change in solar activity after launch, a single sub-orbital flight will not expose space flight participants to unsafe doses of ionizing radiation. Part of the overall hazard communication process should be to inform space flight participants of the exact exposure they received during their flight at mission's end. A formal requirement to this effect would be fully consistent with the intent of Congress. It also would support not only informed acceptance of risk but an understanding of actual exposure upon which post-flight decisions regarding subsequent medically required or employment-related exposures could be based."

In addition, launch operators will need to properly protect spacecraft crew members, who will be repeatedly exposed to the hazards associated with space weather. Crew safety and health issues could attract Occupational Safety and Health Administration (OSHA) interest in space operations and operators.[47] "The "grandfathering" that limits OSHA's ability to regulate exposures of aircrew members (specifically, pilots and flight attendants), may not be applicable in the space domain, since it may be argued that pre-existing regulatory standards are not in place." The OSHA "typically requires four tests to be applied to each hazardous condition:

- There must be a hazard.
- The hazard must be recognized.
- The hazard causes or is likely to cause serious harm or death.
- The hazard must be correctable."

In the context of space weather-related hazards to space crewmembers, these criteria may be relevant to safety and occupational health risks arising from radiation exposures - either prolonged, relatively low-dose cumulative radiation exposure or, alternately, unpredictable but dangerous single exposures.

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[46] Turner, R. E. , T. A. Farrier, J. E. Mazur, R. L. Walterscheid, R.W. Seibold, Space Weather Biological and System Effects for Suborbital Flights, The Aerospace Corporation, El Segundo, CA, Report # DOT-VNTSC-RITA-08-03, Contract # DTRT57-05-D-30103, 31 October 2008.
http://www.faa.gov/about/office_org/headquarters_offices/ast/reports_studies/media/ATR-2009%285390%29-1.pdf

[47] Section 5(a)(1) of the Occupational Safety and Health Act (29 U.S.C. §654): "Each employer shall furnish to each of his employees employment and a place of employment which are free from recognized hazards that are causing or are likely to cause death or serious physical harm to his employees."

“This report has identified uncertainties in the biological and electronic system susceptibility to radiation, as well as uncertainties in what the radiation environment might be during flight...The radiation field at suborbital altitudes has not been extensively studied,” so this is an area where additional study is needed.

Vehicle systems may be protected from damaging exposure, such as single event upsets, by applying shielding techniques that are used in the satellite and aircraft avionics industries and applying them to suborbital missions. These details will depend on the actual equipment, and the quality of the prediction will depend on testing in the relevant environment.

2.6 Environmental Impact

RLV terminals should be prepared to deal with environmental issues which may spillover from the intensifying focus on aviation fuel use, green house gas (GHG) emissions, and carbon footprint issues, as well as air pollution, noise, vibration, water and land use, groundwater contamination, hazmat materials spills and disposal, and flora and fauna protection. In particular, the issues during RLV launch of

- noise
- vibration
- emissions
- sonic shock waves

as well as similar environmental effects associated with re-entry, maneuvering, and landing.

The characteristics of Stage 4 (very quiet) aircraft engines, similar to those used on all new jet transports, will establish the standards that suborbital vehicles may be expected to meet. This will need to be addressed since departure from a conventional airport or near the densely populated areas, which will provide PTP with its markets, using very high performance devices (e.g., afterburners or rockets) could produce unacceptable levels of noise.[48]

All aircraft produce emissions, and their environmental regulation focuses on minimizing their effect by very efficient engine use, following energy reduction trajectories, and using fuels that produce less dangerous emissions. The infrequent Space Shuttle operation and other current activities have allowed operation with no strident regulation of emissions. The licensing the regular operations of suborbital PTP transportation will require careful consideration of emissions impacts and will have a dual focus on the quantity and the chemical components of the emissions so that minimum emissions are produced for the required operations.

Hazardous materials associated with the suborbital spacecraft, which must be managed properly, are its

- Operational space craft fuels and chemicals (e.g. Hydrazine, hydraulic fluids, flammables)
- Contaminants (e.g., foreign materials from other satellites and/or flights or unknown materials created elsewhere and deposited in/on the vehicle)
- Hazardous Cargos

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[48] DOT/FAA 14CFR Parts 36 and 91, Stage 4 Aircraft Noise Standards, RIN 2120-AH99 [Docket No. FAA-2003-16526, Amendment No. 36-26, 91-288], Effective: August, 2005. **http://rgl.faa.gov/Regulatory_and_Guidance_Library/rgFinalRule.nsf/0/767f48f6311bfa348625703700522b0b!OpenDocument**

2.7 Military Operations

The U.S. military's Small Unit Space Transport And INsertion (SUSTAIN) program, initiated in 2002, may provide an impetus for resolving some PTP RLV transportation issues before commercial flights take place. SUSTAIN is a program to provide space vehicles for transporting Special Operations forces since "Only space-enabled solutions combine the necessary speed, global reach, and unconstrained overflight."[49]

Project Hot Eagle was launched by the Defense Advanced Research Projects Agency and the Air Force Research Laboratory to investigate suborbital spacecraft to fulfill this vision. Hot Eagle posits using a SpaceShipOne-type vehicle to launch a squad on a suborbital trajectory in two stages and deliver it anywhere on two hours' notice. The spacecraft is designed to hold a 13-man squad and land in almost any terrain at any time, avoiding diplomatic concern for airspace rights. Extraction would come by other means. Future proposed capabilities for the Marine Corps include launching into low earth orbit to choose the time of an attack.[50]

The rocket soldier delivery has been recommended before, including in the1950s by General John B. Medaris, head of the Army Ballistic Missile Agency.

As a military operation, a SUSTAIN mission may be handled as a NextGen exception, however many relevant PTP operational issues may be resolved by SUSTAIN first.

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[49] SUSTAIN CONOPS, Draft, 18 November 2008, **http://www.acq.osd.mil/nsso/conference/SUSTAIN%20CONOPS%20-%20Version%203%200%20_4%20Mar%2008_%20with%20watermark%20_2_.pdf**

[50] Wikipedia, **http://en.wikipedia.org/wiki/SUSTAIN_%28military%29**

3.0 CONCLUSIONS

In general, the priorities for addressing issues associated with the operation of RLVs for suborbital PTP flight should mirror the sequence of the various technologies' implementation. For example, one current space tourism concept is focused on the use of an aircraft as a launch platform for a manned suborbital vehicle. For the next few years, as NextGen is evolving to its mid-term capabilities, these flights will operate fairly infrequently and from a few relatively remote sites. As a result, special operational procedures specifically directed at these operations and by-passing ATM Standard Operational Procedures and qualifications may be allowable.

The most likely next advancement will probably use similar equipment to launch more frequently flights from more sites that may not all be remote from densely-populated cities. This evolution will require the reconsideration of procedures. While the vehicles themselves may qualify for commercial transport, they will have to be licensed for flight using regulations like those for jet aircraft or ones specifically crafted for suborbital PTP RLVs. Flight rules for operation near densely-populated places will have to be established where operations are more likely to impinge on existing air traffic and to require more coordination with ATC. Thus, the likely next phase will be to integrate suborbital flight operations with some nominal ATM Standard Operational Procedures (ATM/SOP).

Once the technology advances to point to point operations, the vehicles and operations will have to be more integrated into nominal ATM operations and be fully qualified for passenger transportation. Whereas the "space tourist" mode may use experimental vehicles, suborbital PTP transportation operations will need to gain public confidence by employing vehicles that are perceived to be safe and reliable as a result of receiving some form of government approval. Table 4 summarizes the interface of NextGen Capabilities with space operational issues, where a "?" indicates that the need is unclear.

Space Issues / **NextGen Capabilities**	Infrastructure (Dual Use for NextGen and Space)	Communication Data, Radios, Antennas Frequency	Vehicle Environment G-Force, Heat, & Vibration	External Environment Very High Speed & Shock Wave	Human Factors Pilot and Passengers	Earth Weather	Space Weather
Network-Enabled InformationAccess	X	X	X		X	X	X
Performance-Based Operation	?	?		X	X	X	X
Weather Incorporated into Decision-making	X	X			X	X	X
Layered, Adaptive Security	X	?	X		X		
Broad Area Precision Navigation	?	X	X	X	X		
Trajectory-Based Operations	?	?	X	X	X		
Equivalent Visual Operations	?	X	X		X	X	
Super-Density Operations	X	X	X	X	X	X	

Table 4: NextGen-Space Vehicle Potential Interfaces

Since the timing of these developments may coincide on the introduction of NextGen, many of the

NextGen capabilities will need to be incorporated into the spacecraft and operational procedures for suborbital transportation. Table 5 summarizes the issues that need to be addressed in priority order and provides best estimates of start dates based upon the author's consideration of the potential difficulty of resolution, the associated NextGen capabilities' implementation schedule, and the likely time before suborbital PTP transportation is implementable.

Priority	ATM Issue	Issue to be Addressed	Start Date
1	National Coordination	Institutional and policy decisions take extended periods of time to resolve. Need to address incorporation of space-related issues into NextGen.	2011
2	International Coordination and Control Ground Rules	Institutional and policy decisions take extended periods of time to resolve. Need to initiate coordination for PTP implementation similar to that for NextGen aircraft in international transportation which is being coordinated through ICAO.	2012
3	ATM Communications	Vehicle-to-vehicle, vehicle-to-ground, and automated communications (e.g., ADS-B).	2015
4	Advanced Weather	Ensure that high altitude winds, national lightning detection, and space weather input are incorporated into the weather component of NextGen decision making.	2012
5	ATM in Space	Determine surveillance, situational awareness and control procedure needs	2015
6	Human Factors	Begin addressing training and crew qualification needs, crew/instrumentation interfaces, effect on trajectory maintenance, and emergency response.	2012-2015
7	Occupant Safety Guidance	Address flight safety and emergencies procedures, which may evolve from space tourism flights.	2012
8	Navigation and Timing	Access to advanced technology from space.	2015
9	Security	Security of the terminals and vehicles.	2015
10	Advanced ATM Procedures	RNAV, RNP, and NextGen trajectory-based operations.	2015-2020
11	PTP Operational Flight Rules	Functioning within, leaving, and returning to the NAS ATC and guidance for international operation.	2015
12	Super-Dense Operations	Determine applicability based upon likely terminal locations and	2018
13	Environment - Noise	Stage 4(very quiet) noise standards.	2015
14	Environment - Emissions	Special fuels impacts.	2020
15	Environment - Hazmat	Standards for handling and storage that expand upon existing industrial guidance, where needed.	2020
16	Detailed ATM Operational Procedures	Detailed ATM procedures for eventual scheduled, revenue-generating commercial operations.	2020

Table 5: ATM Issues for Further Study and Resolution in Priority Order

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