FEDERAL AVIATION ADMINISTRATION
CENTER OF EXCELLENCE FOR
COMMERCIAL SPACE TRANSPORTATION

COMMERCIAL SPACE TRANSPORTATION RESEARCH ROADMAP

DECEMBER 2015

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Center of Excellence for Commercial Space Transportation
Research Roadmap Report - May 2015

Funded under FAA Cooperative Agreement 10-C-CST-SU-41
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EXECUTIVE SUMMARY

In 2010, the Federal Aviation Administration's Office of Commercial Space Transportation (FAA AST) established a Center of Excellence for Commercial Space Transportation (COE CST) in order to identify solutions for existing and anticipated commercial space transportation problems. This COE CST is a cost sharing partnership of academia, industry, and government that focuses on research areas of primary interest to the FAA and the U.S. commercial space transportation industry as a whole.

Developing a roadmap for future research was identified among the COE CST's first round of research tasks. To complete this, workshops were held where representatives from industry, academia, and government gathered to discuss what they saw as priority research objectives and the underlying organizational structure. The results from these workshops were compiled into a roadmap in 2011 that was then used to help direct research spending within the COE.

In 2014, it was recognized that the recent rapid evolution of the commercial space transportation industry in the United States warranted an update to the roadmap. A new research task was identified and a second set of workshops were held both to capture updated input from stakeholders and secondly to address topics and areas that were not included or fully examined in the first research roadmap.

The resulting updated research roadmap is detailed in this document and shown in Figure 1. It represents a near consensus opinion from representatives of disparate fields. It is our conviction that these COE CST research goals and objectives will find broad application and relevance to the entire commercial space community.

For each of the four research themes[1], a description is provided below along with a sample near-term, high-priority research item that was identified in the workshops:

Theme 1A. Space Traffic Management (STM)

Part of the first research theme focuses on the management of space vehicle traffic from the ground to orbit. More specifically, this includes suborbital STM, orbital STM, and the integration of air and space traffic, including issues such as orbital debris. In the area of Air/Space Traffic Management:

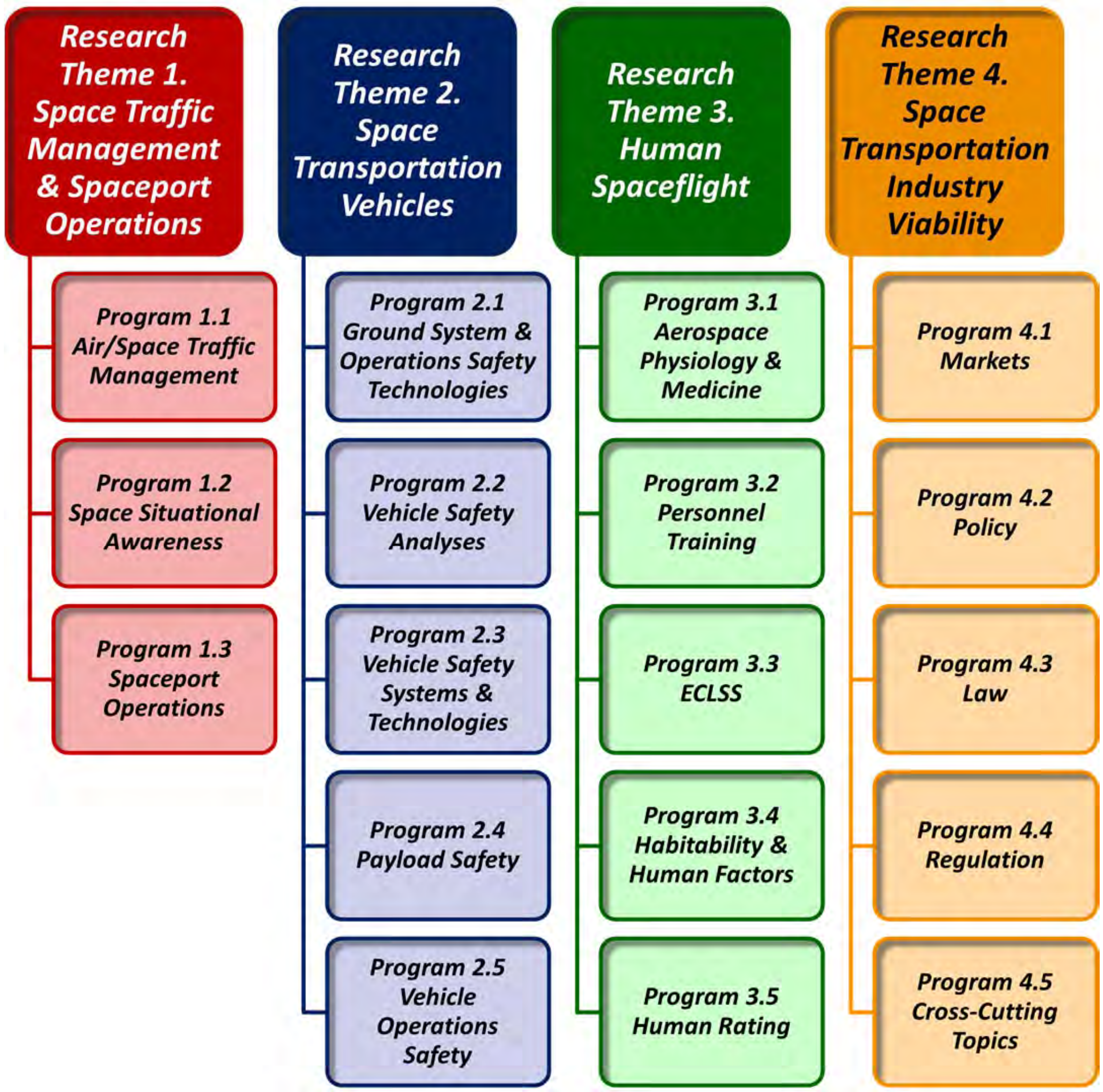
- High-priority, near-term research in dynamic de-confliction for nominal and off-nominal operations includes work to inform first-generation implementation of air/space traffic management architectures including: automation tool requirements, equipage, conveying information to ATC, safety requirements in a high-hazard

[1] Research theme 1 was broken into two parts for the purpose of the research roadmapping workshops and will, therefore, be described separately throughout this report.

environment, and utilization of NextGen technologies (4DT and SWIM) to aid with further automation.

- High-priority, near-term research in integrated procedures above/below FL600 includes the establishment of procedures and ConOps for re-entry trajectories that unify orbital mechanics and re-entry demands and leverage existing and near-term ATC infrastructure.
- High-priority, near-term research in debris debris monitoring and forecasting methods involves recognizing the ownership of this problem by other government agencies beyond FAA, short-term research focuses on FAA-appropriate work including orbital debris detection and prediction to forecast intersection between known debris fields and potential flight paths (sub-orbital and orbital); modeling of satellite and debris orbit and attitude dynamics to predict long-term evolution for planning.

Figure 1. Updated Commercial Space Transportation Research Themes



- High-priority, near-term research in debris impact modeling and risk assessments includes research directed towards improving understanding of impact of orbital debris on man-made vehicles and satellites; characterization of electromagnetic impacts; risk assessments and risk mitigation strategies.

Theme 1B. Spaceport Operations

The other part of the first research theme is focused on the operations and management of spaceports. In the area of spaceport operations, the high-priority research would be to provide guidance to spaceport operators and launch operators on emergency response and communications in the event of an incident.

Theme 2. Space Transportation Vehicles

The second theme is made up of a wide range of research areas pertaining to the space vehicles. Ground system and operations safety technologies, vehicle safety analyses, vehicle safety systems and technologies, payload safety, and vehicle operations safety are all part of this theme. The high-priority research identified for this theme include the development, test, and refining of promising flow control methods to reduce flow unsteadiness in rocket plume interactions with launch pad structures.

Theme 3. Human Spaceflight

The third research theme is concerned with the medicine, technology and training that is needed for both crew and spaceflight participants. This includes aerospace physiology and medicine, personnel training, Environmental Control Life Support System (ECLSS), habitability and human factors, and the human rating of vehicles.

High-priority research identified includes research to determine the highest risk medical conditions that would require more data and need monitoring.

Theme 4. Space Transportation Industry Viability

The last research theme is focused on the business and government related aspects of CST. This includes markets, policies, laws, and regulations and is the research element of the FAA's "Encourage, Facilitate and Promote" mandate. High-priority research for industry viability includes the determination of the government regulatory structure that will minimize cost to the industry while maximizing safety.

While the structure and prioritization presented in this report were developed with COE CST in mind, the results need not be limited only to the COE. The representatives that attended the workshops and whose input is codified here captured the ideas and demands of the entire industry.

PREFACE AND OVERVIEW OF THE STUDIES

The results presented in this report were generated through a total of seven workshops where numerous companies, agencies, research centers, universities, NASA, and the Department of Defense (DoD) were contacted and invited to send representatives. Two workshops were held in 2011 as part of the initial research roadmap development process, and five additional workshops in 2014 and 2015 were used to update the roadmap.

The initial pair of workshops in 2011 each included discussions on all 4 research themes. The first workshop was held at Stanford University in Palo Alto, CA, April 6-7 and the second was at the Lockheed Martin Global Vision Center in Arlington, VA, August 16-17. The two locations and times allowed us to capture the views of a broad range of researchers with difficult schedules and travel availabilities. For each, approximately 60 people were in attendance.

At these workshops, the attendees were presented with several overviews on the different research themes. In addition, presentations from General Jay Santee of the Office of the Secretary of Defense - Policy, Professor John Logsdon of George Washington University, Faith Chandler of NASA's Office of the Chief Technologist (OCT), and Jeff Foust of Futron all gave input from their perspective on the landscape of CST.

For roughly 8 hours at each workshop there were breakout discussions where the large group broke into 4 smaller groups centered on each research theme. Some spent time in several different themes' discussions, while others focused on a single discussion group. The tasks set for them were:

- Finding an organizational principle or mission statement
- Correcting (if needed) the structure of the theme as defined by FAA AST
- Documenting the main research sub-areas
- Identifying important next-steps
- Prioritizing research topics

The groups were not necessarily able to complete all these tasks, but all made considerable progress towards the goals. After the breakout discussions, their work was summarized in a set of presentations given to the plenary group and accompanied by group discussion.

Chairs for each breakout group were chosen in advance as experts in their fields (Table 1).

Table 1. Breakout Group Chairs for 2011 Workshops

	Workshop 1	Workshop 2
Theme 1	Kelvin Coleman (FAA AST) & Karl Bilimoria (NASA Ames)	Mike McElligott (FAA AST)
Theme 2	Dr. Dan Rasky (NASA Ames) & Dr. Juan Alonso (Stanford U.)	Nick Demidovich (FAA AST)
Theme 3	Dr. Jon Clark (Baylor College of Medicine)	Dr. Mark Weyland (NASA JSC)
Theme 4	Ken Davidian (FAA AST)	René Rey (FAA AST)

In the intervening time since the original research roadmap was completed, the commercial space transportation landscape has evolved in numerous ways and therefore an updated research roadmap was required. In the summer of 2014 a new COE task was funded to accomplish this update with a charter of: "Update the original research roadmap and build on it in order to increase its usefulness to the community and to the FAA COE CST." This included three main components:

- Revisiting the 2011 research roadmap and updating as necessary
- Identifying and differentiating near term (1-3 years), medium term (3-6 years), and far term (> 6 years) research tasks
- Defining research priorities to the extent possible

In contrast to the first road mapping task, where broad workshops were held with plenary sessions that covered the full range of research areas within the COE, during this second effort workshops were organized with specific focus areas. Between September of 2014 and February 2015, five events were held that each focused on a single research theme. Note that Theme 1 was broken into 1a and 1b to reflect a natural division within the research theme. Table 2 describes the dates and locations of the workshops.

Principal investigators who were experts in the domain were chosen as lead PIs and given control over the workshop format and invitees (Table 2). The goal of this organizational structure was to reflect the significant variety of research endeavors within the COE, from structures and materials to biomedicine to economics. The PIs invited a wide range of both industry and government stakeholders as well as members of the academic research community.

Table 2. 2014-2015 Workshop Information

Research Theme	Lead PI	Location	Date
1A. Space Traffic Management	Juan Alonso	Stanford University	February 11 & 12, 2015
1B. Spaceports	Patricia Hynes	New Mexico State University	November 17, 2014
2. Vehicle Technologies	Farrukh Alvi	Florida State University	November 3, 2014
3. Human Spaceflight	Jim Vanderploeg	University of Texas Medical Branch at Galveston	September 24 & 25, 2014
4.Industry Viability	Tristan Fiedler (Co-PI Scott Benjamin)	Lockheed Martin Global Vision Center, Crystal City, VA	December 2 & 3, 2014

Figure 2. Adobe Connect screenshot

The lead PIs were able to design these workshops in a way that best fit the needs and availabilities of their respective communities, and resulted in a variation in workshop format. Generally, all the meetings included a mixture of presentations and open discussions. In order to facilitate collaboration with as many people as possible, videoconferencing technology was incorporated to allow remote participation at all workshops via the Adobe Connect software package. Figure 2 shows a screenshot of the attendees' view using Adobe Connect from the Theme 3 workshop on human spaceflight. Informal assessments of the Adobe connect tool after the meetings indicated that for this type of workshop, a virtual environment could be utilized successfully.

In the first round of research road mapping workshops, representatives of the Stanford team were present in each breakout group to directly capture the discussions and later synthesize the results into the first research roadmap. In contrast, during the second round of workshops the lead PIs compiled and distilled the input and delivered it to the Stanford research road mapping team.

COMMERCIAL SPACE TRANSPORTATION: A STRATEGIC OVERVIEW

Overview of the Industry

The commercial space transportation industry has many sectors: orbital and suborbital launch vehicles, space tourism, spaceports, and numerous subsectors that support them including everything from pressure vessel manufacturers to software developers.

Much of the industry is driven by the end-customer. For orbital launches this is often the communications industry or the military, which uses satellites for surveillance, communications, and sensing applications. NASA and universities use orbiting platforms for Earth sensing and astronomy, but they also use the vehicles to launch probes out of Earth orbit to the moon, sun, and other planets in the solar system.

There are very few manufacturers of orbital launch vehicles due to the massive development and operational costs associated. Currently United Launch Alliance, Orbital Sciences, and SpaceX are the only companies who are offering orbital launch services in the USA. With the notable exception of SpaceX, all of these vehicles were developed with close partnership with government agencies or the DoD.

The suborbital launch industry has traditionally been limited to small sounding rockets used for microgravity, atmospheric, and astronomical research. However there are several companies currently developing vehicles which would also (or primarily) be used for suborbital tourism. These companies include Virgin Galactic, Sierra Nevada Corporation, XCOR, Blue Origin, Armadillo Aerospace, and Masten Space Systems.

These demands for suborbital and orbital launch vehicles drive the development of the vehicles themselves, which in turn drives the development of subsystems and support systems.

The Role of FAA AST

The FAA's Office of Commercial Space Transportation (FAA AST) has mandates to both regulate and encourage the commercial space transportation (CST) industry. AST regulates the operation of both spaceports and vehicles. AST does not regulate launches by and for the US government (for example, a Delta IV launching an NRO payload or NASA launching a science mission).

Reusable suborbital vehicles may obtain an experimental permit instead of a license. Permits have the advantage of fewer vehicle specification and safety requirements, but they are much more limited in scope; the operations must be for the non-commercial purpose of research & development, gathering data for a license, or crew training.

Licenses are required by all other vehicle launches in the US that exceed the limits for amateur rocketry, and are applicable either to a specific launch or can be used for up to 5 years, depending on the specifics of the license. US companies launching payloads anywhere in the world and foreign companies launching within the US are all regulated by the FAA AST. This requirement stems from the 1967 United Nations International Outer Space Treaty whereby the nationality of the launch operator and the nation in which the launch occurs are responsible for any subsequent damage that occurs.

Obtaining a vehicle license or permit requires five steps: policy review (national security and foreign policy), payload review (payload safety issues), maximum probable loss determination (dollar amount due to bodily injury or property damage), an environmental determination (impact of launch on environment), and a safety review (range and launch site safety issues).

Launch or reentry sites (commonly referred to as spaceports) must obtain licenses, however the process is slightly different. The steps are: policy review (national security and foreign policy), launch site location review (ground boundaries, flight corridors, and risk assessments), agreements (airspace and marine), an explosive site plan (minimum safe distances), and an environmental impact review (based on any hazardous materials). In addition, spaceports must have plans in place for accident response and investigation.

The second mandate for FAA AST is to encourage, facilitate, and promote the CST industry. Tasks that support this mandate include generating a series of industry reports such as launch forecasts, economic impact reports, Year in Review reports, Developments and Concepts reports, and others. In addition FAA AST conducts research and development outside of the COE to further technologies that would be a benefit to the industry as a whole. FAA AST also conducts a CST Grants program, conducts an annual conference and has active international outreach activities.

The Center Of Excellence for Commercial Space Transportation (COE CST), established "in order to identify solutions for existing and anticipated commercial space transportation problems," aids in both mandates by identifying and completing research tasks that are important. These tasks can be geared towards informing regulatory practices or towards developing components and systems that many companies could use in order to reduce engineering and development costs.

RESEARCH THEME 1A.
SPACE TRAFFIC MANAGEMENT

Mission Statement

In this first theme – Space Traffic Management – we focus on research requirements for the safe and efficient utilization of the NAS, including safety-related aspects of transitions above FL600. In general, the work focuses on two major categories:

- Ideas, methods, and operations to safely and equitably share the NAS with minimal disruption caused by commercial space traffic (outbound and inbound), and
- Space situational awareness of resident space objects and the potential safety implications of lack of separation.

Description and Impact

As the frequency, variety, and geographical distribution of commercial space operations all increase over the coming decade, the safe, fair, and equitable use of the NAS will become a significant issue that must be addressed: how can we maintain the necessary separation between commercial air and space vehicles in all phases of flight, without unduly burdening one industry or the other? How can we minimize the impacts of one type of flights on those of the other community? Moreover, since the outcome of a significant portion of future commercial space flights will include a transition to / from orbit, a detailed understanding of the space environment (regarding man-made and naturally-occurring hazards) and the potential impact on commercial space vehicles is needed.

The research in this theme is well positioned to eliminate a number of critical bottlenecks that would impact the core mission of the FAA in the Commercial Space Transportation area: how can we operate orbital and sub-orbital commercial space vehicles safely and without artificially limiting their development and expansion? By devising more effective means of maintaining separation between air and space vehicles, maintaining or

Box 1A. Example Task - Space Debris Mitigation

Principal Investigator: Dr. Norman Fitz-Coy, University of Florida

The objective of this task is to identify and quantify the global growth trends of CubeSat-class satellites, assess the interests of US and international communities for CubeSat applications, and investigate emerging CubeSat products (e.g., Planet Labs constellation of CubeSats). To do this, a survey was conducted regarding the assembly integration and testing practices of these CubeSat developers and utilize that information to investigate the mortality rates of CubeSats. This will allow the assessment of space debris mitigation strategies utilized and implemented by these developers.

Figure 3. Large constellations of CubeSats are being implemented

improving on the traditional levels of safety that the commercial air traffic sector has demonstrated over the past few decades, and by ensuring that risks deriving from the presence of orbital debris can be understood and managed, the FAA will be able to simultaneously meet its mandates (regulation and "encouraging, facilitating, and promoting") regarding the commercial space transportation industry.

Without the completion of this research, the consequences can be substantial. On the one hand, the operation of space vehicles (during both ascent and re-entry) could impose such large restrictions on our commercial air transportation infrastructure that system-level inefficiencies may relegate CST to a national-interest-only role. Moreover, lacking the product of this research, the necessary infrastructure would not be in place at the appropriate time to ensure the development of new types of vehicles and transportation options. Finally, without this research work, operations relating to orbital insertion, in-orbit operations, and de-orbit burns may result in unmanageable risks that prevent widespread use of commercial space transportation alternatives.

Space Traffic Management Research Program Structure

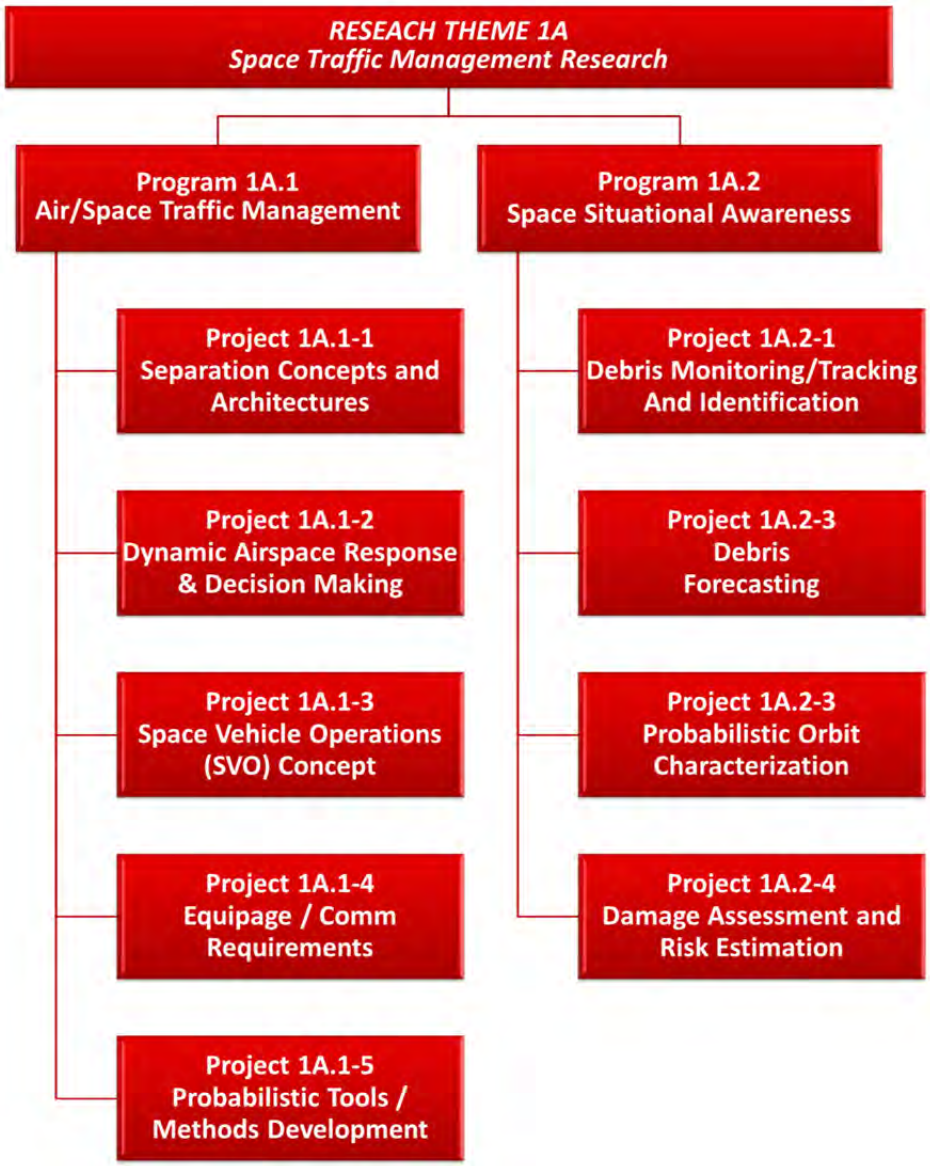
The Space Traffic Management research theme taxonomy is depicted in Figure 4 below. This version of the STM research theme taxonomy is different than the 2011 version. How the latter fully integrates into the former was not addressed, so for the sake of completeness, the 2011 taxonomy for research theme 1 (including 1A and 1B of the 2014-2015 version) is included as Appendix E.

Priority Research Tasks

As has been mentioned previously in this report, the original roadmap (2011) listed a number of key elements envisioned for the Space Traffic Management portion of the research, but did not attempt to reach consensus among the participants regarding the order of priority of such tasks. In the 2014-15 workshop, an effort was made to narrow down the number of tasks and their descriptions and to highlight which were of higher (and lower) priority. Within each of the two subareas (Air/Space Traffic Management and Space Situational Awareness) we present below, in order of priority within each subarea, the research tasks that were found to be most pressing. Note that, during the workshop, the research tasks were laid out along three separate horizons: short term (high hazard / low equipage), medium term (medium hazard / equipage), and far term (low hazard / high equipage). The order of priority described in this document represents the consensus of the workshop participants, but may need to be be altered if the focus and balance of the research program shifts from a mid-to-far term target.

The identification of order of the research tasks in the list below also was also motivated by the perception of the types, locations, and frequencies of space vehicle operations that are expected in the coming years: the underlying assumption is that the research needs to be completed some time prior to the need materializing. It is envisioned that, over the next 3-5 years (near term), the majority of the CST operations will be of the sub-orbital type. The frequency (and geographical diversity) of such sub-orbital flights will continue to grow during the mid-term (5-10 years from now). Finally, the frequency/diversity of suborbital flights will be accompanied by a more substantial presence of orbital and trans-atmospheric flights in the long term (10-20 years from now).

Figure 4. Research Theme 1A. Space Traffic Management Research



Air/Space Traffic Management research tasks:

- Dynamic de-confliction for nominal and off-nominal operations
    - (Short-term priority) Research to inform first-generation implementation of air/space traffic management architectures including: automation tool requirements,

equipage, conveying information to ATC, safety requirements in a high-hazard environment, and utilization of NextGen technologies (4DT and SWIM) to aid with further automation.
    - (Long-term priority) Research to understand the best methods to compute 4D protected space / envelopes, assess reaction times during off-nominal events, incorporate dynamically-changing 4D envelopes into de-confliction algorithms, and utilize de-centralized methods and decision making algorithms to guarantee separation during off-nominal events.
- Integrated procedures above / below FL600
    - (Short term priority) Establishment of procedures and ConOps for re-entry trajectories that unify orbital mechanics and re-entry demands and leverage existing and near-term ATC infrastructure.
    - (Medium to long term priority) Research, development, and evaluation of integrated strategies for seamless transition between NAS and orbit and vice versa.

In addition, participants in the workshop also discussed the importance of the following research topics, in no particular order of priority: development of aircraft vulnerability models; outlining operator (of the Space Vehicle) responsibilities regarding data and communications; progressive re-entry breakup models; ground-based debris tracking requirements.

Space Situational Awareness / Space Debris research tasks:

- Debris monitoring and forecasting methods
    - (Short term priority) Recognizing the ownership of this problem by other government agencies beyond FAA, short-term research focuses on FAA-appropriate work including orbital debris detection and prediction to forecast intersection between known debris fields and potential flight paths (sub-orbital and orbital); modeling of satellite and debris orbit and attitude dynamics to predict long-term evolution for planning.
    - (Medium to long term priority) Orbital debris modeling estimation using probabilistic methods and including space atmospheric characterization and variability, non-gravitational effects, and fusion of tracking data.
- Debris impact modeling and risk assessments
    - (Short term priority) Research directed towards improving understanding of impact of orbital debris on man-made vehicles and satellites; characterization of electromagnetic impacts; risk assessments and risk mitigation strategies.
    - (Medium to long term priority) Modeling of debris-vehicle impacts; probabilistic risk assessments; on-board and 4D options for risk mitigation.

In addition, participants in the workshop also discussed the importance of the following research topics, in no particular order of priority: establishing clear lines of responsibility for debris monitoring and avoidance (what is the role of the FAA? What would FAA do with this information?); policy / international coordination issues; real-time atmospheric characterization; optimizing tasking / JSPOC coordination; establishing guidelines for comparable levels of risk between meteoroids and man-made hazards.

RESEARCH THEME 1B. SPACEPORT OPERATIONS

Mission Statement

The spaceport operations research theme will facilitate the development, utilization, and operation of commercial spaceports. This will be accomplished by developing a framework to capture the body of knowledge for spaceport operation best practices.

Description and Impact

The research theme of spaceports must be approached from the perspective of the FAA statutory goal of protecting public health and safety as well as encouraging private sector launches and related services.

In the next 5 years more launch operators will be flying under commercial licenses at commercially licensed spaceports. In the case of sub-orbital vehicles, there are only a few operating right now, none under a commercial license.

FAA regulation Part 417.9: Launch Site Responsibility provides:

- For a launch from a spaceport licensed under Part 420 of this chapter, a launch operator [vehicle operator] must:
    - Conduct its operations as required by any agreements that the launch site operator [spaceport] has with any Federal and local authorities under part 420 of this chapter; and
    - Coordinate with the launch site operator and provide any information on its activities and potential hazards necessary for the launch operator, person, or property at the launch site as required by the launch site operator's obligations under 420.55 of this chapter.

Currently, all correspondence, agreements and procedures between launch operators and sites is held privately by the parties, not publically disclosed. It is evident that there is a real gap in the knowledge of how launch operators and site operators interact. In order to move forward, the interaction between ground operators and vehicle operators must be studied as a whole and these groups must come together to discuss what they see as

Box 1B. Example Task - Spaceport Operational Framework

Principal Investigator: Dr. Patricia Hynes, New Mexico State University

The Framework for Spaceport Operations is an evolving collection documents and information that represents industry best practices. The collection was created and made accessible by a multi-agency, multi-partner research team led by NMSU. Constructed and maintained by the NMSU Library, the database is available on the web at contentdm.nmsu.edu.

Figure 5. NMSU Framework for Spaceport Operations

milestones that need to be addressed, each cohort making their contributions in relationship to the other.

An online database has been assembled as a way of capturing and maintaining the body of knowledge for spaceport operations. This database currently contains hundreds of documents and links to thousands more. It is available at http://contentdm.nmsu.edu.

Spaceport Operations Research Program Structure

The Spaceport Operations Research Theme is depicted in Figure 6 below.

Figure 6. Research Theme 1B. Spaceport Operations Research

The complete taxonomy of research subjects in this research theme is provided in Appendix D at the end of this document. This version of the spaceport operations research theme taxonomy is different than the 2011 version. How the latter fully integrates into the former was not addressed, so for the sake of completeness, the 2011 taxonomy for research theme 1 (including 1A and 1B of the 2014-2015 version) is included as Appendix E.

Priority Research Tasks

In the 2011 workshop, the attendees identified two priority research tasks: the first was related to identifying vehicle-specific requirements for spaceport operations, and the second was focused on establishing best practices. This second task has become the majority of the research done within Theme 1b in the form of an online database for the body of knowledge. All discussions at the 2014-2015 workshop were related to expansions of the body of knowledge.

From these discussions, 4 priority research projects were identified that would significantly improve the body of knowledge. These were:

1. Provide guidance to spaceport operators and launch operators on emergency response and communications in the event of an incident (currently missing from body of knowledge)

- Locate documents, in particular-NTSB guidelines and when reports become available integrate findings into the digital collection- and develop information to fill this gap
- Continuously update the digital collection

2. Further expand the sections on insurance, indemnification, and waivers
   - Search for documents, rules and regulations pertaining to this topic
   - Populate the body of knowledge digital collection
3. Query the users of the body of knowledge to identify information gaps by using a survey
   - Development of the survey
   - Promotion to people to take the survey
   - Time of librarian and technical staff to work the survey into the website
   - Team members to analyze the survey
   - Write up final results report
4. Encourage more transparency in the agreements that exist between spaceports and launch operators.
   - Develop and administer confidential anonymous surveys to spaceport operators and launch operators. The purpose of the surveys would be to allow these entities to share some of the basic provisions in their agreements without jeopardizing their intellectual property or commercial competitive advantage.
   - The information would then be converted to summary form so that the identity of those participating would not be revealed.
   - Search for documents, rules and regulations pertaining to this topic.
   - Populate the body of knowledge digital collection.

Projects 1 and 2 were identified as near term priorities, while project 4 was classified as a medium-to-long term goal.

RESEARCH THEME 2.
SPACE TRANSPORTATION VEHICLES

Mission Statement

The Space Transportation Vehclias (including Operations, Technologies, and Systems) research theme focuses on enabling and enhancing the safety, reliability, and efficiency of commercial space vehicles.

Description and Impact

The wide span of this research area makes it difficult to define concisely. However, it can be subdivided broadly into two areas: component-level and systems-level research. From there, the best description is via examples.

Component-level research includes developing new thermal protection systems for re-entry, “black boxes” that could be integrated into spacecraft and launch vehicles, and standardized sensors. System-level research includes developing operational procedures, safety analyses, licensing or certification processes, and human-rating standards.

Currently this type of research is pursued by a number of organizations, however it is generally performed with a specific application or customer in mind. As the field of commercial space transportation increases in size it will be beneficial to develop more generic components, systems, procedures, and analyses that can be easily adapted to different applications rather than be re-designed for each new case.

Box 2. Example Task - Nitrous Oxide Composite Case Testing

Principal Investigators: Dr. Warren Ostergren, Dr. Bin Lim, Dr. Andrei Zagrai, New Mexico Tech

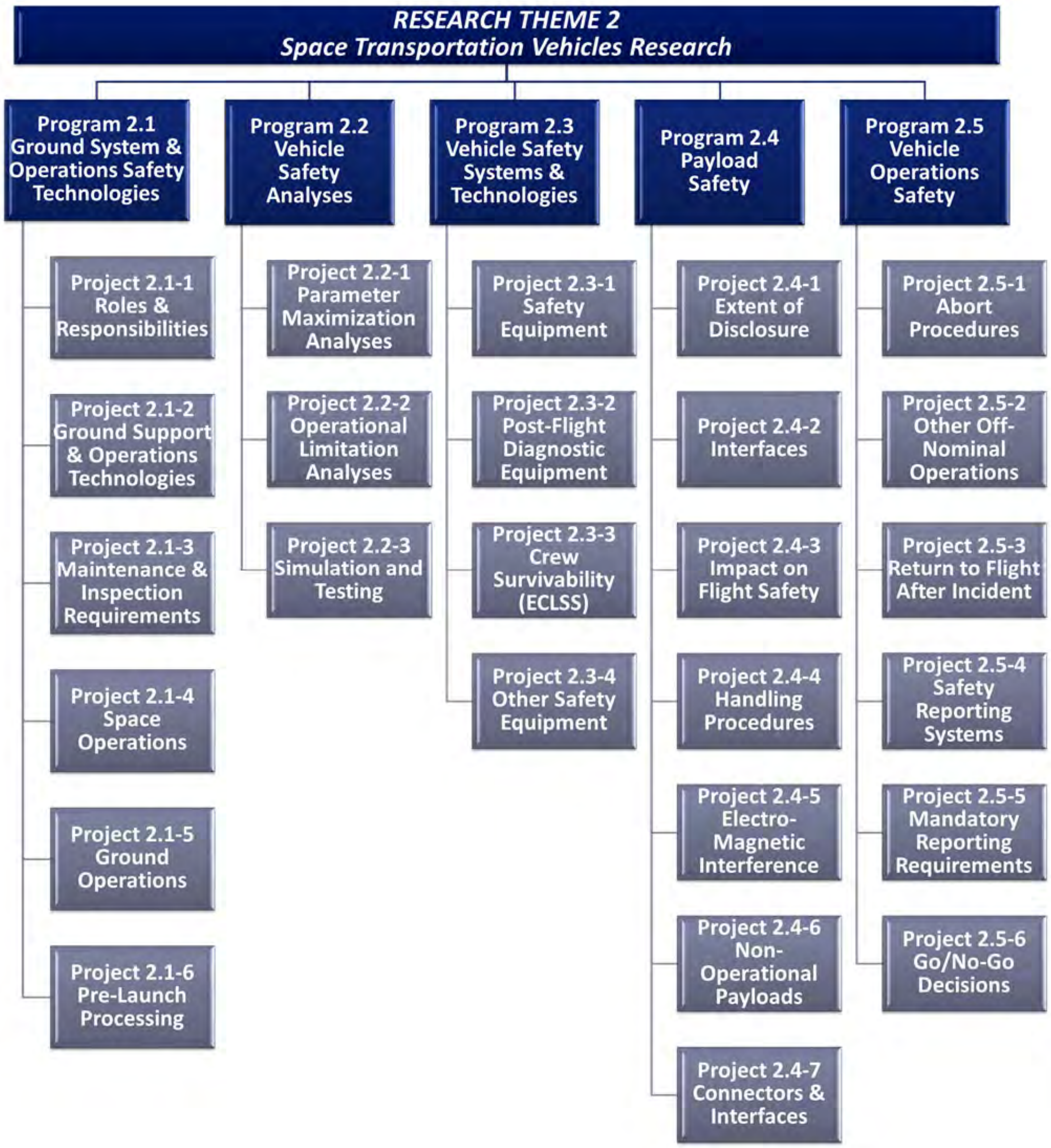
Nitrous oxide is a popular oxidizer for rocket propulsion systems in commercial spaceflight, and is commonly stored in lightweight composite tanks. The purpose of this task is to develop an understanding of fragmentation hazards from such tanks in order to set guidelines for proper safe distances. In the picture below, a composite panel is mounted in a test setup that can produce shock waves.

Figure 7. Test fixture for shock wave loading of composite panels

This research supports the FAA’s mandate of protecting public health and safety by developing technologies, analyses, and operations to both increase the safety of commercial space vehicles and facilitate industry growth.

The Space Transportation Operations, Technologies & Systems research program structure is shown in Figure 8.

Figure 8. Research Theme 2. Space Transportation Vehicles Research



The complete taxonomy of research subjects in this research theme is provided in Appendix D at the end of this document.

Priority Research Tasks

During the 2011 workshops, attendees identified 13 specific high-priority research tasks. These ranged in topic from establishing proper redundancy levels on safety critical systems to the physics of re-entry debris to licensing procedures.

In the 2014-2015 workshop however, the attendees identified 4 broad areas of priority research:

- Devices: Sensors and Actuators for Enhanced Aircraft Safety

- Advanced Materials and Structures
- Aerothermal Environment – Test and Simulation
- Technology Transition

Within these research areas, tasks were divided into levels of prioritization, near-to-mid term priorities and mid-to-long term priorities. In the first category were the following:

- Existing projects in the area of advanced materials, structures, and sensors that have shown promising results
- Research modeling the space vehicle environment via computational and experimental means
- Leveraging the distributed capabilities of the COE members, especially when there are PIs with complimentary expertise

In the mid-to-long term category were the following tasks:

- Identify and fill gaps in the current knowledge base in sciences and tools
- Develop/fabricate advanced materials and structures with embedded sensors
- Support flight or survivability tests for advanced sensors and structures/materials
- Develop/support paths for transitioning technologies to the CST vehicles or systems that would most benefit from their inclusion.

RESEARCH THEME 3. HUMAN SPACEFLIGHT

Mission Statement

The third research theme – Human Spaceflight – is concerned with the physiology, medicine, technology and training that impact safety and performance of both crew and spaceflight participants (SFPs). Within the research areas contained within Theme 3, research is generally focused in two primary areas:

- Protection of the health and safety of crew and spaceflight participants, and
- Identification and reduction of avoidable risks of human spaceflight.

Description and Impact

Research in this theme area is critical to the strategic needs of the FAA as the public comes to expect greater safety from the industry for crew and SFPs. There is historical precedent from spaceflight experience regarding human system risk management and medical events for humans in space, including topics such as space adaptation syndrome, behavioral/psychological issues, acute gastrointestinal conditions, acute pain, serious or incapacitating medical events, and environmental issues (debris, cabin environment, radiation, etc.).

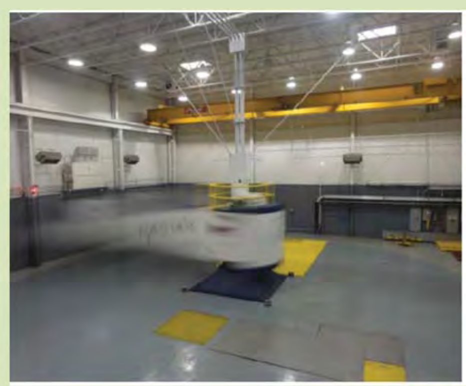
As the industry expands, development of guidelines or standards for protection of a population more diverse and likely less fit, healthy, and trained than the traditional astronaut is imperative. Considerations for examining human system risk management include current limitations in screening, limited access to analog environments for study and training, limited training time, and limited historical data on diverse populations.

Box 3. Example Task - Tolerance of Centrifuge-Induced G-Force by Disease State

Principal Investigator: Dr. James Vanderploeg, University of Texas Medical Branch

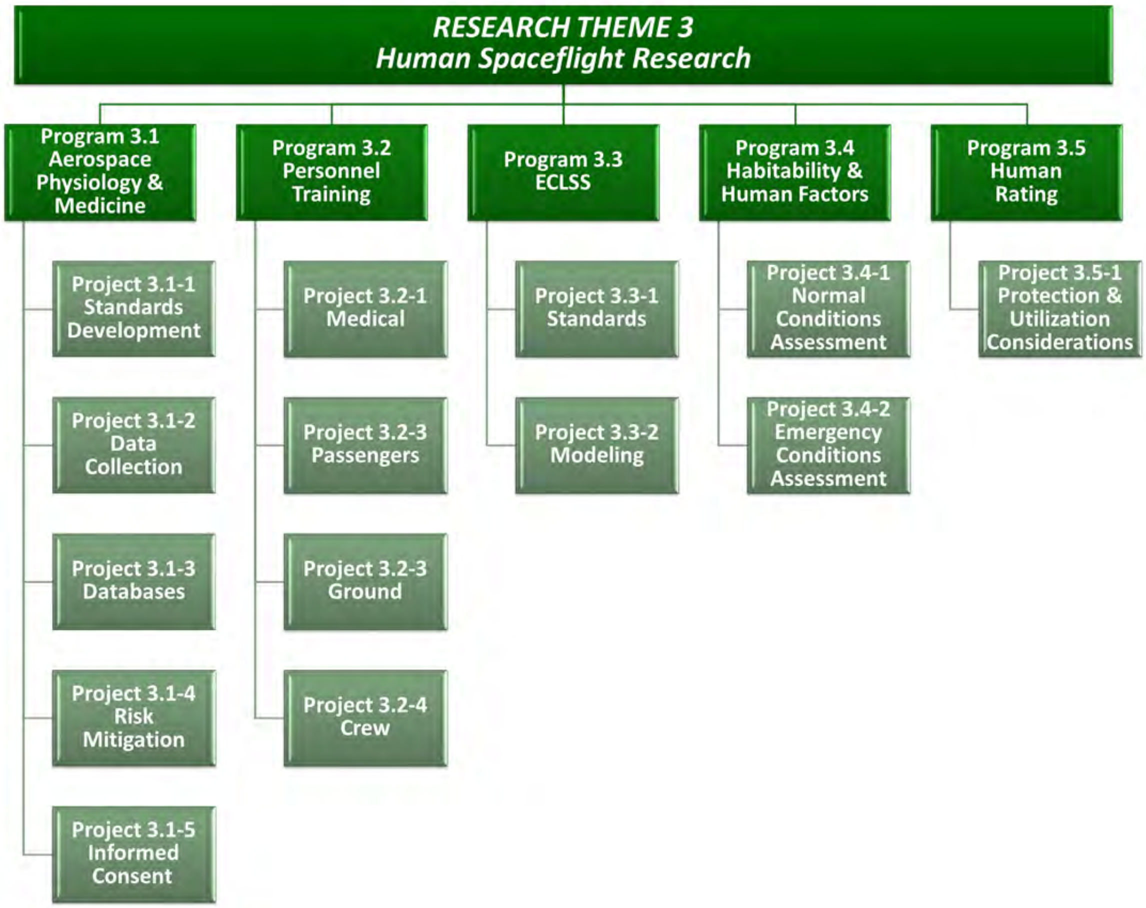
Based on results from previous centrifuge tests, space flight participant (SPF) anxiety may present a significant problem for commercial spaceflight companies. Currently no information about how to train SFP's for mental/physical challenges related to the spaceflight environment. This task will identify triggers for anxiety, possible mitigation approaches, and optimum training methods. The goal is to mitigate anxiety and enhance SFP enjoyment..

Figure 9. The NASTAR centrifuge simulates the forces of suborbital flight



The Human Spaceflight research program structure is shown in Figure 10.

Figure 10. Research Theme 3. Human Spaceflight Research



The complete taxonomy of research subjects in this research theme is provided in Appendix D at the end of this document.

Priority Research Tasks

In the 2011 workshop, there was no consensus opinion on prioritization of research tasks. However, in the 2014-2015 workshop a detailed prioritization of both areas and tasks was produced. This workshop identified the following six areas as being of particular importance:

- Vehicle life support and survivability
- Medical standards for crew and acceptance criteria for spaceflight participants
- Training and adaptation
- Operational support
- Physiological monitoring
- Data analysis and database repository

Within these six areas, a total of 30 priority tasks were identified and characterized as being either short-term or medium/long term priorities. The division was generally between research relating to suborbital versus orbital flight due to the apparent proximity that some suborbital commercial space transportation companies are to beginning commercial operations. Orbital tourism on the other hand were perceived as likely to be many years from flight. A sampling of these priority tasks are given in Table 3 below.

Table 3. Short-, Mid-, and Long-Term Research Human Space Research Priorities

Areas	Short-Term	Mid- to Long-Term
Vehicle life support and survivability	Research leading to recommendations for interior cabin design to enhance occupant safety and facilitate emergency egress.	Research leading to recommendations for food, water, personal hygiene, sleep stations, and toilet facilities.
Medical Standards (crew), Acceptance Criteria (HSPs)	Investigate performance effects and crew member fatigue with multiple spaceflights within the same day or same week.	Research to establish advisability for preflight quarantine.
Training and adaptation	Research directed toward answering the question of what is the optimum SFP training versus what is the minimum training necessary for suborbital spaceflights.	Gather data to examine inflight psychosocial incidents and compare with training experiences to determine which training models are most effective, such as group vs individual.
Operational support	Determine the best means of mitigating the risk of in-flight psychological events, particularly those with an elevated predisposition to anxiety-related events. Determine if anxiolytics are an option to reduce anxiety to a safe and flyable level.	Define the parameters of risk disclosure and informed consent. Evaluate the relationship between the informed consent process with reasonable customer expectations and appropriate levels of understanding of the true risks of their spaceflight.
Physiological monitoring	Research to determine the highest risk medical conditions which would require more data and need monitoring.	Determine if flights dedicated to individuals with physical disabilities are achievable, and what preparation would be desired with these individuals?
Data analysis and database repository	Research needed to define which parameters would be included in a database; finding a set of common recommended elements for data gathering and analysis.	Provide a high fidelity plan to the FAA on implementing a database repository.

RESEARCH THEME 4.
SPACE TRANSPORTATION INDUSTRY VIABILITY

Mission Statements

The purpose of the Industry Viability research theme is to support effective policy decision-making in the accomplishment of the dual regulatory and promotional missions of FAA AST. Studies of the industry will reveal the importance and effects of various economic, legal, legislative, regulatory, and market variables. These data will then be used to maximize both regulatory cost-effectiveness and industry growth.

Description and Impact

The research conducted in Theme 4 and its interaction with the other research themes is foundational to the overall viability of commercialization of the industry. As the FAA continues to expand or contract its role as setting regulatory standards governing human space flight and commercial space transportation, information related to the appropriate level of involvement is pivotal. The research generated by Theme 4 seeks to provide a better understanding of the relationship of governmental policy and innovation adoption. As the commercial space transportation industry matures, the FAA needs to make prudent decisions so that regulations neither stifle technology development nor expose the crew or space flight participants to avoidable risks as the public comes to expect greater safety for crew and space flight participants from the industry. This delicate balance between regulation and innovation needs to be approached both comparatively by making institutional comparisons with other industries as well as empirically driven in order to guide regulatory decision making based on statistical conclusions.

The Space Transportation Industry Viability research program structure is shown below in Figure 12.

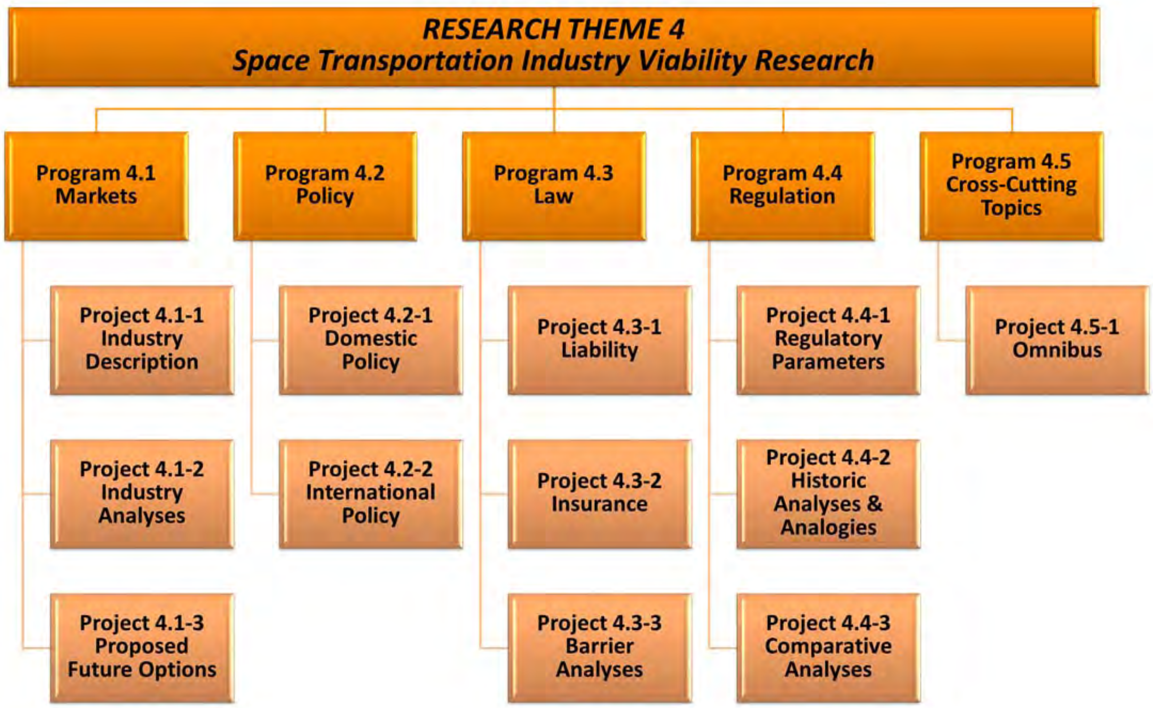
Box 4. Example Task - Suborbital Transportation Industry Analysis

Principal Investigator: Dr. Scott Benjamin, Florida Institute of Technology

In order to create a comprehensive evaluation of the impacting factors that will aid or hinder the adoption of commercial space transportation, indutsry structure and international competitiveness frameworks were implemented for the evolving suborbital space transportation industry. This research will provide a macro-level investigation of the factors that impact these adoption processes and overlay these concepts with the adoption of a radically different industry paradigm.

Figure 11. Current competitors in suborbital space transportation

Figure 12. Research Theme 4. Space Transportation Industry Viability Research



The complete taxonomy of research subjects in this research theme is provided in Appendix D at the end of this document.

Priority Research Tasks

In the 2011 workshops, attendees were able to construct a list of 7 priority research tasks. 4 of these tasks were mentioned again in the outcome of the 2014-2015 workshop and will be noted later. The 3 topics that were not reproduced were:

- Workshop of industrial organization economists looking at CST industry
- Liability limitation: history, issues, and options
- Barrier analysis of existing regulations

In the 2015 workshop, the attendees not only identified research projects of importance but described them thoroughly with a set of specific tasks within each. Included in the description were a desired time scale of the project (near, medium, or long term) and also a level of priority (low, medium, high). These projects are:

- What defines an industry and does the commercial space transportation have an accepted definition of the industry? What is the current segmentation within the industry? (Short term, low priority)

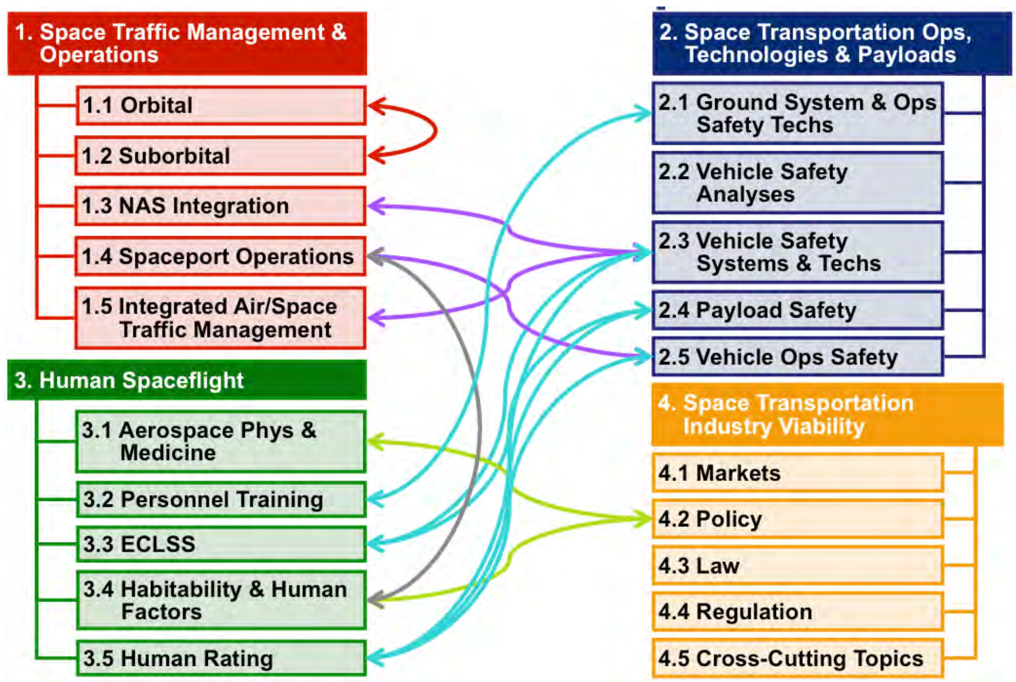
- Compare and contrast the adoption of commercial space transportation and the adoption of the aviation industry. (Medium term, high priority, related to a topic from 2011 roadmap)
- Evaluate the cross-over of aviation and space transportation regulatory authority domestically and internationally. (Medium term, medium priority, related to a topic from 2011 roadmap)
- Industry access to public data and lessons learned for human space flight may be important to hastening the industry life cycle adoption process. How do we create a clearinghouse for information between industry and the Center of Excellence? (Long term, low priority)
- Identify macro level trends across multiple industries that consistently effect rapid industry proliferation. Compare and contrast these variables against the current adoption of commercial space transportation. (Medium term, medium priority, related to a topic from 2011 roadmap)
- What is an appropriate amount of government regulation that will stimulate growth in the industry while achieving the objective of protection of public safety? (Long term, high priority, mentioned in 2011 roadmap)
- What government regulatory structure will minimize cost to the industry while maximizing safety concerns? (Long term, high priority)

CROSS-CUTTING TASKS AND INTEGRATION

There are many research tasks that fall under more than one research theme. In some cases the interaction is two-way, where both research groups will need varying degrees of input from each other. This could range from full collaboration to simple periodic information transfers. In other cases the interaction is only in one direction, with one research group simply requiring the output or knowledge base of another.

Below, some of the specific cases of interaction that were emphasized in our workshops are shown graphically in Figure 13.[2] In addition these interactions are listed and detailed below the figure.

Figure 13. Research Area Dependencies



Dependencies between Communications, transponders, and beacons, NAS integration & Air and Space Traffic Management

- Inputs for the design of transponders, beacons, and communications systems (Theme 2.3) are needed from the researchers developing air and space traffic management strategies (Theme 1.3 and 1.4).

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[2] This section was included without changes from the previous version of the research roadmap document. That is why the four research areas shown in Figure 13 are not the same as the updated set shown earlier in Figure 1.

Dependencies between Flight diagnostic equipment & ECLSS

- Inputs from the ECLSS experts (Theme 3.2) are needed in order to design flight diagnostic equipment (Theme 2.3) that measures parameters related to ECLSS functionality.

Dependencies between Payload Safety & Occupant protection capabilities

- Interaction between the payload safety researchers (Theme 2.4) and those from the occupant protection capabilities group (Theme 3.4) is required in order to establish any possible dangers to the spaceflight participants from particular payloads.

Dependencies between Vehicle safety operations & Spaceport operations

- Interaction between the vehicle safety operations (Theme 2.5) group and the spaceport operations group (Theme 1.4) is required in order to establish:
    - Guidelines for contingency operations.
    - Off-nominal operation protocols
    - Determine what equipment is needed
    - Desired interaction between the FAA and the vehicle operator to solve problems

Dependencies between Pre-flight care & Policy

- Interaction between the pre-flight care group (Theme 3.1) and the policy group (Theme 4.2) is needed to develop drug and alcohol testing standards for the CST industry.

Dependencies between Passengers & Space Transportation Operations, Technologies & Payloads

- Inputs are needed from Theme 2 for the development within Theme 3.2 of standardized training templates for spacecraft and/or missions.

Dependencies between ECLSS & Policy

- In order to provide a starting point for work in ECLSS (Theme 3.3), inputs from the policy group (Theme 4.2) are needed in order to review, analyze and summarize information on existing regulations and policies for ECLSS.

Dependencies between Habitability & human factors, Spaceport Operations & Space Transportation Operations, Technologies & Payloads

- Interaction is needed between the habitability & human factors group (Theme 3.4), the spaceport operations group (Theme 1.4), and Theme 2 in order to develop databases related to accidents and incidents. This will also include an anonymous reporting system to notify authorities of applicable events. Procedures for assessing the human factors associated with such an event must also be developed.

Dependencies between Human Rating / Vehicle Safety Systems & Technologies/ Vehicle Operations Safety

- Research into human rating procedures and standards will require extensive work between the human rating group within Theme 3.4 and the vehicle safety systems & technologies group (Theme 2.3) and the vehicle operations safety group (Theme 2.5).

FAA AST PORTFOLIO OF "APPLIED" RESEARCH IDEAS

In calendar year 2015, an activity within the FAA Office of Commercial Space Transportation (AST) was conducted to identify areas of potential research in support of four critical areas as presented to the FAA Research, Engineering, and Design Advisory Committee (REDAC). The correlation between the four research themes preseted in this report and the critical areas are shown in Table 4 below:

Table 4. Applied Research Ideas

Roadmap Research Theme/Program	REDAC Critical Area
1A. Space Traffic Management 1.1 Air/Space Traffic Management	Safe integration into the National Air Space
1A. Space Traffic Management 1.1 Air/Space Traffic Management	Advanced Safety Assessment Methods (first two bullets shown below)
2. Space Transportation Operations, Technologies & Systems 2.2 Vehicle Safety Analyses	Advanced Safety Assessment Methods (last three bullets shown below)
2. Space Transportation Operations, Technologies & Systems 2.2 Vehicle Safety Analyses 2.3 Vehicle Safety Systems & Technologies	Advanced Vehicle Safety Technologies and Methodologies
3. Human Spaceflight 3.1 Aerospace Physiology & Medicine	Human Space Flight Safety

Below are research project ideas for each of the four REDAC critical areas.

"Safe and Efficient Integration" Research Ideas

- Improving integration of launch and reentry sites into the NAS and its system of airports, including sites in the vicinity of major airports or complex airspace.
- Exploring the development of separation standards for improved airspace management of launch/reentry vehicles during non-explosive phases of flight.
- Improving approaches to monitor launch/reentry vehicle operations for airspace integration, to decrease the amount of airspace closed to regular air traffic operations and expedite response to off-nominal scenarios.
- Developing and validating improved noise models for commercial space launch operations at inland launch sites, including spaceports co-located with airports.
- Improving methods for launch and reentry collision avoidance analysis to produce more efficient launch and reentry planning and NAS integration.

“Advanced Safety Assessment Methods” Research Ideas

- Exploring advanced commercial human space flight data sharing and mining capabilities to inform safety assessments and identify emerging safety issues.
- Improved safety analysis methods to assess and manage hazards to dynamic population clusters, such as for the public in recreational areas and on roads and rail.
- Improved understanding of aircraft vulnerability to space-vehicle-breakup debris, including model development and refinement to reduce over-conservatism applied to airspace “keep out” areas used to protect against a launch or reentry vehicle failure.
- Improved methods to evaluate failure probabilities for launch and reentry vehicles.
- Improved methods to evaluate debris generated by launch and re-entry vehicle failures

“Advanced Vehicle Safety Technologies and Methodologies” Research Ideas

- Exploring the repetitive use considerations for high utilization reusable space vehicles, to include assessing the use of integrated vehicle health monitoring technologies and reentry breakup recorders when applicable.
- Improved understanding of emerging autonomous flight safety systems and exploring mitigation factors to address their potential vulnerabilities.

“Human Space Flight Safety” Research Ideas

- Identifying best practice considerations for crew human factors for small winged commercial spaceflight vehicles.

CONCLUSIONS

Through our series of workshops representative of more than 50 organizations with a stake in the CST industry were able to gather and discuss what they see as important research. These discussions have been transcribed into a detailed roadmap that the COE CST can use to achieve its goal of identifying solutions for existing and anticipated commercial space transportation problems.

The highest priority research items are summarized below:

- Theme 1. Space Traffic Management (STM) and Spaceport Operations
  - A minimum safe corridor for launches and re-entries must be identified.
- Theme 2. Space Transportation Vehicles
  - Further effort is required to identify top research objectives from the technological landscape, but the overriding issue is safety of flight.
- Theme 3. Human Spaceflight
  - Extensive data on the risks of various medications and conditions in the space environment are required.
- Theme 4. Space Transportation Industry Viability
  - Identifying and verifying the suborbital and orbital microgravity commerce and research opportunities is of prime importance.

While this roadmap and these research priorities have been developed with the COE as its main user, there is no true limit to its applicability. The views represented are a consensus view from many perspectives within the industry and the result is information that is if value to any organization that seeks to further CST in the US.

These research tasks contained within the roadmap will significantly benefit the industry by informing forthcoming regulations from the FAA and by using academic research to develop solutions to key problems retarding progress in the industrial sectors. Without sufficient funding for this research, however, this progress will be delayed needlessly.

In 2010, there were 4 licensed or permitted launches. In 2011 there were a total of 5. However, combining commercial satellite launches with COTS and CRS flights, OCT's Flight Opportunities Program, and Virgin Galactic's SpaceShipTwo there could easily be more than 40 in 2012. In 2013 that number could climb to 100 or above.

There are some who are skeptical of the predicted growth in CST, and for good reason. The industry is plagued by delays and it's not uncommon for launch dates to be postponed months or even years. Nevertheless, it is quite clear that commercial launch frequency will be increasing dramatically in the coming years and, in order to keep pace with this acceleration, AST will need to grow simply to maintain current licensing and permitting operations.

As milestones are reached and passed in the CST industry, new problems will arise and different priorities may result for research tasks. Therefore, this research roadmap will be updated on an annual or biennial basis. By cultivating a living document we will not only serve its original purpose for the COE, but also maintain it as a standard that other organizations may utilize.

APPENDIX A. 2011 COE CST RESEARCH ROADMAP WORKSHOP 1

Center of Excellence for Commercial Space Transportation
Research Roadmap Workshop I, April 6-7, 2011
Stanford University, Stanford CA

Attendee List

First	Last	Organization
Doc	Aguilar	Air Force Research Laboratory
Juan	Alonso	Stanford University
Farrukh	Alvi	Florida State University
Jim	Ball	NASA Kennedy Space Center
Herb	Bachner	CSSI, Inc.
Karl	Bilimoria	NASA Ames Research Center
Gary	Chambers	Cimarron, Inc.
Brad	Cheetham	University of Colorado
Jon	Clark	Baylor College of Medicine
Kelvin	Coleman	FAA AST
Ken	Davidian	FAA AST
Diane	Dimeff	Center for Space Entrepreneurship
Paul	Eckert	The Boeing Company
Carl	Ehrlich	SpaceWorks Engineering
Norm	Fitz-Coy	University of Florida
Jeff	Forrest	Metropolitan State College of Denver
Jeff	Foust	Futron Corporation
Paul	Guthrie	The Tauri Group
William	Hoffman	Webster University
Scott	Hubbard	Stanford University
Pat	Hynes	New Mexico State University
Richard	Jennings	University of Texas Medical Branch
Jay	Kapat	University of Central Florida
Barry	King	Dynetics

First	Last	Organization
Dan	Kirk	Florida Institute of Technology / Starfighters, Inc.
Dave	Klaus	University of Colorado
Glenn	Law	Aerospace Corporation
Mark	Leifeste	NASA White Sands Test Facility / Jacobs Technology, Inc.
John	Logsdon	George Washington University
Alan	Lovell	Air Force Research Laboratory
Will	Marshall	NASA Ames Research Center / International Space University
Charles	Miller	NASA Headquarters
Diane	Murphy	WMP Communications
Scott	Norris	Lockheed-Martin
Lori	Paulin	Hewlett-Packard Laboratories
Dan	Rasky	NASA Ames Research Center
Larry	Richardson	United Launch Alliance
Van	Romero	New Mexico Institute of Mining & Technology
Merri	Sanchez	Sierra Nevada Corporation
Jay	Santee	OSD Policy
Chris	Smith	Wyle
David	Spencer	Penn State University
James	Stanley	QinetiQ NA
Gerrit	van Ommering	Space Systems Loral
John	West	Draper Laboratory
Mark	Weyland	NASA Johnson Space Center

Agenda

Center of Excellence for Commercial Space Transportation
Research Roadmap Workshop
April 6-7, 2011
at Stanford University, Paul Brest Hall, Munger Conference Center

DAY I : Wednesday, 6 April 2011

Time	**Topic**	**Key Speaker or Panel Moderator**
8:00 - 8:30 a.m.	Coffee and continental breakfast	
8:30 – 8:45	Welcome, announcements and logistics	Prof. Scott Hubbard, Stanford
8:45 - 9:00	FAA Welcome	Mr. Ken Davidian, FAA
9:00 – 9:30	Agenda Overview and Workshop Charter	Prof. Scott Hubbard
9:30 – 10:15	Overview of Research Theme 1: **Space Traffic Management and Launch Operations**	Mr. Kelvin Coleman, FAA
10:15 - 10:30	Break	
10:30 - 11:15	Overview of Research Theme 2: **Launch Vehicle Systems, Payloads, Technologies, and Operations**	Dr. Dan Rasky, NASA
11:15 – 11:35	Commercial Space Transportation and the DoD Perspective	Brig. Gen Jay Santee, USAF
11:35 – 12:00	International Collaboration and Commercial Space Transportation	Prof. John Logsdon, GWU
12:00 – 1:00 p.m.	Lunch	On your own at Munger Center
1:00 – 1:45	Overview of Research Theme 3: **Human Space Flight**	Dr. Jon Clark, Baylor College of Medicine
1:45 - 2:30	Overview of Research Theme 4: **Industry Viability**	Mr. Ken Davidian, FAA
2:30 – 2:45	Break	
2:45 – 5:00	1st Breakout Sessions	Parallel Sessions on Themes 1 - 4
6:00 – 8:00 p.m.	Reception and Dinner	Stanford Faculty Club

DAY II: Thursday, 7 April, 2011

8:00 – 8:30 a.m.	Coffee and breakfast	
8:30 – 9:00	Plenary Session, Announcements, Logistics	Prof. Scott Hubbard
9:00 – 10:00	Breakout Sessions	
10:00 – 10:15	Break	
10:15 – 12:00	Breakout Sessions	
12:00 – 1:00 p.m.	Lunch	On your own at Munger
1:00 - 2:00	Breakout Sessions	
2:00 – 2:30	Presentation on **Space Traffic Management and Launch Operations**	Mr. Kelvin Coleman
2:30 – 3:00	Presentation on **Launch Vehicle Systems, Payloads, Technologies, and Operations**	Dr. Dan Rasky
3:00 – 3:15	Break	
3:15 – 3:45	Presentation on **Human Space Flight**	Dr. Jon Clark
3:45 – 4:15	Presentation on **Industry Viability**	Mr. Ken Davidian
4:15 – 5:00	Group discussion	
5:00	Adjourn	

APPENDIX B. 2011 COE CST RESEARCH ROADMAP WORKSHOP 2

Center of Excellence for Commercial Space Transportation
Research Roadmap Workshop II, August 15-17, 2011
Lockheed Martin Global Vision Center, Washington DC

Attendee List

First	Last	Organization
Doc	Aguilar	AFRL
Eleanor	Aldrich	AIAA
Juan	Alonso	Stanford University
David	Anhalt	Space Systems/Loral
Herb	Bachner	CSSI, Inc.
Jim	Ball	NASA KSC
Stephanie	Bednarek	SpaceX
Haym	Benaroya	Rutgers State University
Dan	Brockway	United Space Alliance
Francisco	Capristan	Stanford University
Faith	Chandler	NASA Headquarters
Brad	Cheetham	University of Colorado
Tom	Colvin	Stanford University
Ken	Davidian	FAA AST
Craig	Day	AIAA
Nick	Demidovich	FAA AST
Dominic	DePasquale	SpaceWorks Commercial
Michael	Draper	OSD Policy
Paul	Eckert	The Boeing Company
Carl	Ehrlich	SpaceWorks Engineering
Edward	Ellegood	ERAU & Cape Canaveral Spaceport
Tristan	Fiedler	FIT
Norm	Fitz-Coy	University of Florida
Jeffrey	Forrest	Metropolitan State College of Denver
Jeffrey	Foust	Futron Corporation
John	Gedmark	CSF
Jan	Gou	UCF
Nicolas	Guerra	NASA IVVF
Paul	Guthrie	The Tauri Group
Brienna	Henwood	NASTAR Center
William	Hoffman	Webster University
Scott	Hubbard	Stanford University
Patricia	Hynes	NMSU
Matt	Isakowitz	CSF
Richard	Jennings	UTMB

First	Last	Organization
Kelly	Kabiri	FAA AST/NASA HQ
Jay	Kapat	UCF
Barry	King	Dynetics
Dan	Kirk	FIT
David	Klaus	CU & BioServe Space Technologies
Rajun	Kumar	Florida State University
Glenn	Law	Aerospace Corporation
Mark	Leifeste	Jacobs Technology Inc.
John	Logsdon	GWU
Alan	Lovell	AFRL
Mike	Machula	NASA
Nicole	Maillet	FIT
Vernon	McDonald	Wyle
Mike	McElligott	FAA AST
Brian	Meade	FAA AST
Karin	Nilsdotter	Spaceport Sweden
Scott	Norris	Lockheed Martin Space Systems Company
Rene	Rey	FAA AST
Larry	Richardson	United Launch Alliance
Van	Romero	NMT
Jay	Santee	OSD Policy
Samantha	Segall-Anderson	SAIC
Audrey	Schaffer	OSD Policy
David	Spencer	Penn State University
James	Stanley	QinetiQ North America
Ken	Stroud	SNC
Jim	Van Laak	FAA AST
James	Vanderploeg	UTMB
Nathaniel	Villaire	FIT
Justin	West	Cimarron Inc
Mark	Weyland	NASA JSC
Richard	Wolf	NASA IVVF
Jonah	Zimmerman	Stanford University

Agenda

Day 0: Monday, 15 August 2011

Time	Topic	Key Speaker or Panel Moderator
1:00 – 2:00 p.m.	Overview of AST and Commercial Space Industry	Ken Davidian
2:00 – 3:30	Overview of ELV and RLV Licensing	Phil Brinkman
3:30 – 5:00	Overview of Permits and Safety Applications	Sherman Council

Day 1: Tuesday, 16 August 2011

Time	Topic	Key Speaker or Panel Moderator
8:00 – 8:30 a.m.	Coffee and breakfast/snacks	
8:30 – 8:45	Welcome, announcements and logistics	Scott Hubbard
8:45 – 9:00	FAA Welcome	Jim Van Laak
9:00 – 9:15	NASA Welcome	Faith Chandler
9:15 – 9:45	Commercial Space and the DoD Perspective - update	Maj. Gen. Jay Santee
9:45 – 10:15	Market Studies	Jeff Foust
10:15 – 10:30	Break	
10:30 – 11:15	Breakout Session Overview and Charter	Scott Hubbard / Ken Davidian
11:15 – 11:45	Overview of Research Theme 1: Space Traffic Management and Operations	Mike McElligott
11:45 – 1:00	Lunch	
1:00 – 1:30	Overview of Research Theme 2: Space Transportation Operations, Technologies, and Payloads	Nick Demidovich
1:30 – 2:00	Overview of Research Theme 3: Human Spaceflight	Mark Weyland
2:00 – 2:30	Overview of Research Theme 4: Space Transportation Industry Viability	René Rey
2:30 – 2:45	Break	
2:45 – 4:45	Breakout Sessions	
4:45 – 5:00	Regroup for end of day 1 and outlook for day 2	
5:00 – 7:00	Reception at the GVC sponsored by AIAA	

Day 2: Wednesday, 17 August 2011

Time	Topic	Key Speaker or Panel Moderator
8:00 – 8:30 a.m.	Coffee and breakfast/snacks	
8:30 – 9:00	Plenary Session, Announcements, Logistics	Scott Hubbard
9:00 – 10:00	Breakout Sessions	
10:00 – 10:15	Break	
10:15 – 12:00	Breakout Sessions	
12:00 – 1:00	Lunch	
1:00 – 2:00	Breakout Sessions	
2:00 – 2:30	Presentation on Space Traffic Management and Operations	Mike McElligott
2:30 – 3:00	Presentation on Space Transportation Operations, Technologies, and Payloads	Nick Demidovich
3:00 – 3:15	Break	
3:15 – 3:45	Presentation on Human Spaceflight	Mark Weyland
3:45 – 4:15	Presentation on Space Transportation Industry Viability	René Rey
4:15 – 5:00	Group discussion	
5:00	Adjourn	

APPENDIX C. 2014-2015 COE CST RESEARCH ROADMAP WORKSHOPS

Theme 1a: Space/Air Traffic Management and Operations

Theme 1: Space/Air Traffic Management and Operations
FAA COE CST Road-mapping Workshop
February 11-12, 2015

N. Hoff Conference Room, Durand Building, Room 450
Department of Aeronautics & Astronautics
Stanford University
Stanford, CA 94305

And virtually hosted via GoToMeeting. Details to be forwarded. ***All times Pacific.***

Wednesday, February 11

8:00 am - 8:15 am	Introductions & Objectives of Workshop
8:15 am - 9:00 am	Kevin Hatton, FAA ANG, SVO ConOps and HITL Results
9:00 am - 9:30 am	Karl Bilimoria, NASA Ames, Space Transition Corridors / Space Traffic Alternatives
9:30 am - 10:00 am	Juan J. Alonso / Tom Colvin, Stanford University, 4D Compact Envelopes, Probabilistic Analyses, System-Level Simulations
10:00 am - 10:30 am	Break and Informal Discussions
10:30 am - 11:00 am	Dan Scheeres, Univ. of Colorado, Space Traffic Situational Awareness
11:00 am - 11:30 am	Sigrid Close, Stanford University, Debris Impacts / Locations
11:30 am - 12:00 pm	Initial Team Discussions. What are the leading research opportunities that we need to focus on?
noon - 1:00 pm	Lunch (served in room, possibly with ongoing discussions)
1:00 pm - 2:00 pm	Discussions on air/space traffic deconfliction: challenges and opportunities. What has changed since last roadmap?
2:00 pm	Adjourn
Afternoon / evening	**Further discussions with on-site participants. Group dinner.**

Thursday, February 12

8:00 am - 8:15 am	Planning for discussions / breakout sessions.
8:15 am - 10:00 am	Breakout sessions (virtual): session #1 on air/space traffic (led by Juan J. Alonso); session #2 on space situational awareness / debris (led by TBD). Locations: Durand 450 and Durand 464.
10:00 am - 10:15 am	Break and Informal Discussions
10:15 am - 10:45 am	Report-out of Air/Space Traffic breakout session
10:45 am - 11:15 am	Report-out of Space Situational Awareness / Debris breakout session
11:15 am - 12:00 pm	Next Steps, writing contributions, final report planning and timeline
2:00 pm	Adjourn

Questions/comments, please contact jjalonso@stanford.edu

Theme 1b. Spaceport Operations

Workshop description

This workshop was hosted by Professor Patricia Hynes of New Mexico State University in Las Cruces, NM. It consisted of a 2 hour teleconference call on November 17, 2014 and combined with a questionnaire sent to participants before the workshop in order to help identify areas of importance and interest to the community that could be discussed during the workshop. Much of the workshop focused on the body of knowledge, an online database of information concerning all aspects of spaceport operations, and additionally a survey was used to assess its use and effectiveness.

In total, 14 participants attended the call, including representatives of universities, local and state government, NASA, spaceports, and other commercial space transportation companies. Also note that this workshop occurred shortly after the widely publicized failures of the Orbital Sciences Antares launch vehicle and the Virgin Galactic SpaceShipTwo and these were an important focus area for discussions but also limited attendance from personnel who were involved in the resulting investigations.

Agenda for the FAA Center of Excellence for Commercial Space Transportation (FAA COE-CST) Road Mapping

Monday, November 17, 2014 at 10:00am (MST)
Call In: (712) 432-0180, Access code: 898876#

The Agenda

The **outcome** from this 2 hour meeting is to capture the discussion among ourselves regarding the commercial spaceport industry and relationships that are anchors to the future of commercial spaceports, launch operations and spaceport users and stakeholders. We are taking a snapshot of the industry at the time of the meeting in relationship to the topics below.

At **1 hour and 45 minutes** into the meeting we will **stop** and determine if we want to re-convene; whether members of the group are interested in writing further on any of the topics; who else might we involve, and when our work will be completed.

My job will be to keep us moving through the topics below. Anyone is free to submit topic for future discussion should the group want to reconvene. Thank you again for this service to the Center of Excellence for Commercial Space Transportation (COE-CST).

Discussion Topics:

- Regarding the agreements and relationships between spaceport & launch operators: The delta between what is public information and IP is especially critical in the areas of spaceport operations, procedures and policies. Any guidance for the FAA on this will be useful. Is the current status good for the industry going forward?

- Regarding emergency response and communications with media in light of the recent accidents at Mid Atlantic Regional Spaceport and Mojave Air and Space Port: How did the two spaceports, launch operators and their related support community do when two accidents occurred in 1 week?
- Do we understand the impact of these 2 accidents on the FAA AST yet?
- Do we see regulations that may emerge because of these accidents?
  In both cases, it does not appear the spaceports were involved in either accident. Agree/Disagree/Too early to know.
- Regarding Research and Development Activities vs Commercial Operations:
- The launch license does not cover for those on board. Commercial Space Launch Amendment does not indemnify any spaceflight participants. So, the next tier of people we will engage will be the insurance companies. Anyone have comment here?
- Question posed by the FAA for this group: What does the industry envision a spaceport to be?
- What else might they be doing to encourage, facilitate, and promote the industry? These are unique functions for the FAA AST Division.
- When do we think the FAA's role will evolve beyond what it currently is?

Background:

- What does the FAA currently do to regulate and work with spaceports?
- Spaceport licensing, vehicle permitting and licensing.
- Part 420 Regulation for operation of a launch site.
- FAA supports Safety Inspectors to attend each permitted or licensed launch; they provide safety inspection of each launch site.
- They are currently involved in the 2 NTSB investigations related to accident investigations that happened on commercial spaceports on October 28th and 31st, 2014.

Theme 2. Space Transportation Vehicles

Workshop Description

This workshop was hosted by Professor Farrukh Alvi of Florida State University in Tallahassee, FL. It was formatted as a one day meeting on November 3, 2014 with both in person and virtual attendees. After an overview and description of the road mapping effort, the day was broken into two sessions. During each, presentations were given by PIs currently researching tasks within or related to the research theme. Following that, an open discussion was held concerning the theme's structure, possible topics, and research task prioritization. The first session focused on sensors and propulsion systems and the second focused on advanced materials, structures, and systems.

In total, there were 18 participants including 4 virtual attendees utilizing the Adobe Connect software package. Attendees primarily came from universities, with two FAA representatives in attendance as well.

Roadmap 2.0- Theme 2.
Vehicle Operation, Technologies, and Payloads

November 3, 2014 - Hosted by FCAAP

SESSION 1 – Sensors and Propulsion Systems
Session Chairs: W. Oates & R. Kumar

Time	Title	Speaker	Affiliation
11:20-11:40	Magneto-Elastic Sensing for SHM (Task 228)	A. Zagrai	NMT
11:40-12:00	High Temp Pressure Transducers (Task 241)	M. Sheplak/W. Oates	UF & FSU
12:00-12:20	Low-Mass/Cost CO/CO2 Sensors (Task 311)	S. Vasu	UCF
12:20-12:40	Rocket Nozzle Thrust and Noise	R. Kumar	FSU
12:40- 1:20	Discussion, Review and Session Wrap UP. Propose a **List of Topics & Priorities** for the next 5 years	Moderated by Session Chairs	

SESSION 2 – Advanced Materials, Structures and Systems
Session Chairs: J. Kapat & A. Zagrai

Time	Title	Speaker	Affiliation
2:30-2:50	UHT Composites Thermal Protection Systems (Task 253)	J. Guo and J. Kapat	UCF
2:50-3:10	Reduced Order Non-Linear Structural Modeling (Task 293)	K. Miller	NMT
3:10-3:30	Integration & Evaluation of ADS-B Payloads (Task 298)	P. Hynes	NMSU
3:30-3:50	Tank Testing (Task 299)	W. Ostergren	NMT
3:50-4:30	Discussion, Review and Session Wrap Up Propose a List of Topics & Priorities for the next 5 years		
4:30-5:00	**Meeting Wrap Up: F. Alvi, K. Davidian and S. Hubbard**		

Theme 3. Human Spaceflight

Workshop description

The human spaceflight workshop was hosted by Professor James Vanderploeg of the University of Texas Medical Branch at Galveston in Galveston, TX. The workshop spanned two days (September 24 & 25, 2014) and included both in person and virtual attendees. In advance of the workshop, a survey was sent to the attendees that asked them to rank the importance of various research areas in order to establish what, if any, consensus opinions about prioritization already existed.

The workshop began with several overview presentations and talks by PIs presenting the results to date on current research projects. Then there were discussions on future research needs and directions for both the near and far term, followed by discussion of prioritization. There were 36 attendees in total, representing 5 universities, 11 companies,

Human Spaceflight Research Roadmap Workshop

AGENDA

September 24th 10:00 AM to 4:00 PM Central Daylight Time

Time	Topic	Presenter
10:00 – 10:15 AM	Welcome & Introductions	Jim Vanderploeg
10:15 – 10:30 AM	Overview of Road Map Process	Scott Hubbard
10:30 – 11:00 AM	Review of 2011 Roadmap for Human Space Flight	Jim Vanderploeg
11:00 – 12:00 PM	Progress Made to Date	Presentations by investigators
12:00 – 1:00 PM	Lunch break	
1:00 – 2:30 PM	Future Research Needs and Directions Near Term (1 – 5 years)	Discussion by attendees
2:30 – 3:00	Break	
3:00 – 4:00	Future Research Needs and Directions Far Term (5+ years)	Discussion by attendees
4:00 PM	Adjourn for the day	

September 25th 10:00 AM to 2:00 PM Central Daylight Time

Time	Topic	Presenter
10:00 – 10:30 AM	Recap from yesterday	Jim Vanderploeg
10:30 – 11:30 AM	Prioritization of near term research directions	Group discussion
11:30 – 12:00 PM	Prioritization of far term research directions	Group discussion
12:00 – 1:00 PM	Lunch break	
1:00 – 1:45 PM	Overall prioritization and next steps	Discussion by attendees
1:45 – 2:00	Wrap Up	Jim Vanderploeg Scott Hubbard
2:00 PM	Adjourn	

Theme 4. Space Transportation Industry Viability

Workshop description

The Space Transportation Industry Viability workshop was hosted by Professor Tristan Fiedler and co-led by Professor Scott Benjamin of the Florida Institute of Technology in Melbourne, FL. The workshop was held on December 2 and 3, 2014 at the Lockheed Martin Global Vision Center in Crystal City, VA in order to make it more convenient for many of the Washington, DC based participants. The workshop was structured primarily around two panel discussions on the needs of the commercial space transportation industry and several open discussions about research priorities and directions.

12/2/2014 (Tue.)	EVENT - Day 1	RESPONSIBLE IND.
10:30:00 AM EST	Lockheed-Martin Global Vision Center Registration	
11:00:00 AM EST	Welcome & Introductions	Tristan Fiedler
11:15:00 AM EST	Roadmap Overview: 2011 & 2014 Markets - Policy - Legislation - Regulation	Scott Hubbard
11:45:00 PM EST	Industry (COMSTAC) Panel Perceived R&D Needs	***** MODERATOR ***** Mike Gold ********** PANELISTS ********** - MARKETS: Clay Mowry (Tentative) - POLICY: Herb Bachner (Honorary COMSTAC member for the day) - LAW: Mike Gold - REGULATION: Jennifer A. Warren
1:15:00 PM EST	Lunch & Networking	
2:00:00 PM EST	Roundtable Discussion	All
2:30:00 PM EST	Potential Short Term (<5 yrs) Research Directions - Discussion	All
	15-minute Break inserted as needed	
3:30:00 PM EST	Potential Long Term (>5 yrs) Research Directions - Discussion	All
5:00:00 PM EST	Day 1 Wrap up & Announcements	Fiedler, Hubbard
12/3/2014 (Wed.)	**EVENT - Day 2**	**RESPONSIBLE IND.**
10:30:00 AM EST	Lockheed-Martin Global Vision Center Registration	
11:00:00 PM EST	NON-COMSTAC Panel Perceived R&D Needs	***** MODERATOR ***** Scott Hubbard PANELISTS - MARKETS: Eric Stallmer - POLICY: John Sloan - LAW: Laura Montgomery - REGULATION: Patti Grace-Smith
12:30:00 PM EST	Lunch & Networking	
1:00:00 PM EST	Potential Short Term (<5 yrs) Research Directions - Discussion	All
2:00:00 PM EST	Potential Long Term (>5 yrs) Research Directions - Discussion	All

APPENDIX D. 2014-2015 CST RESEARCH STRUCTURE

1. SPACE TRAFFIC MANAGEMENT AND SPACEPORT OPERATIONS

1.1 AIR/SPACE TRAFFIC MANAGEMENT

- 1.1.1 Separation concepts and architectures
- 1.1.2 Dynamic airspace response & decision making
- 1.1.3 Space Vehicle Operations (SVO) concept
- 1.1.4 Equipage / Communication requirements
- 1.1.5 Probabilistic tools / methods development

1.2 SPACE SITUATIONAL AWARENESS

- 1.2.1 Debris monitoring /tracking and identification
- 1.2.2 Debris forecasting
- 1.2.3 Probabilistic orbit characterization
- 1.2.4 Damage assessment and risk estimation

1.3 SPACEPORT OPERATIONS

- 1.3.1 Launch and Landing Requirements
- 1.3.2 Interoperability
- 1.3.3 Support Services Requirements

2. SPACE TRANSPORTATION VEHICLES

2.1 GROUND SYSTEMS & OPERATIONS SAFETY TECHNOLOGY

- 2.1.1 Roles & Responsibilities
  - *2.1.1.1 Spaceport Facilities/Infrastructure*
  - *2.1.1.2 Propellant Handling*
  - *2.1.1.3 Licensing Guideline Requirements*
  - *2.1.1.4 Maintenance Technician Certification*
  - *2.1.1.5 Ground Abort/Range Safety*
  - *2.1.1.6 Residual Fluid Handling/Disposal*
  - *2.1.1.7 Personal Protection Equipment*
  - *2.1.1.8 Frequency Spectrum Management*
  - *2.1.1.9 EMC/RF*
    - 2.1.1.9.1 Susceptibility
    - 2.1.1.9.2 Degaussing Procedures
- 2.1.2 Ground Support & Operations Technologies
  - *2.1.2.1 Identification*
  - *2.1.2.2 Development*
- 2.1.3 Maintenance & Inspection Requirements
- 2.1.4 Space Operations Training
- 2.1.5 Ground Operations Training
- 2.1.6 Pre-Launch Processing

2.2 VEHICLE SAFETY ANALYSES

- 2.2.1 Parameter Maximization Analyses
  - *2.2.1.1 Handling*
  - *2.2.1.2 Redundancy*
  - *2.2.1.3 Materials & Propulsion Systems*
  - *2.2.1.4 Analysis Frameworks*
  - *2.2.1.5 Software Safety*
  - *2.2.1.6 Safety Metrics*
    - 2.2.1.6.1 Probability Risk Assessment
    - 2.2.1.6.2 Reliability
    - 2.2.1.6.3 FMEA
  - *2.2.1.7 Reliability Allocation*
  - *2.2.1.8 Guidance, Navigation, and Control*
- 2.2.2 Operational Limitation Analyses
  - *2.2.2.1 Environmental Limits*
  - *2.2.2.2 Life-Cycle Predictions*
  - *2.2.2.3 Regulatory Support*
    - 2.2.2.3.1 Instantaneous Impact Point
    - 2.2.2.3.2 Probability of Failure
    - 2.2.2.3.3 Trajectory
    - 2.2.2.3.4 Debris List
    - 2.2.2.3.5 Debris Dispersion
    - 2.2.2.3.6 Impact Probability
    - 2.2.2.3.7 Vulnerability
    - 2.2.2.3.8 Maximum Probable Loss
- 2.2.3 Simulation and Testing
  - *2.2.3.1 Rapid Prototyping*
  - *2.2.3.2 Hardware*
  - *2.2.3.3 Software*

2.3 VEHICLE SAFETY SYSTEMS & TECHNOLOGIES

- 2.3.1 Real Time Instrumentation
  - *2.3.1.1 Communications / Transponders and Beacons*
  - *2.3.1.2 Flight Termination Systems*
  - *2.3.1.3 Detection Systems*
  - *2.3.1.4 Propellant Monitoring*
  - *2.3.1.5 Integrated Vehicle Health Systems/Fault Detection Isolation and Recovery*
- 2.3.2 Post Flight Diagnostic Equipment
  - *2.3.2.1 Black Boxes*
  - *2.3.2.2 Life Cycle Detection*
- 2.3.3 Crew Survivability (ECLSS)
- 2.3.4 Additional Safety Critical Subsystems / Safety Enabling Technologies

2.4 PAYLOAD SAFETY

2.4.1 Extent of Disclosure
2.4.2 Interfaces
2.4.2.1 Power
2.4.2.2 Communications
2.4.2.3 Storage & Deployment
2.4.2.4 Busses, Plug & Play
2.4.3 Impact on Flight Safety
2.4.3.1 Vehicle
2.4.3.2 Crew
2.4.4 Handling Procedures
2.4.4.1 Fluids
2.4.4.2 Battery
2.4.4.3 Coolant
2.4.5 Electro-Magnetic Interference
2.4.5.1 Programmable Frequency Transmitters
2.4.6 Non-Operational Payloads
2.4.7 Connectors and Interfaces
2.4.7.1 Low Cost
2.4.7.2 Space-Reliable

2.5 VEHICLE OPERATIONS SAFETY

2.5.1 Abort Procedures
2.5.1.1 Handling
2.5.1.2 Size of Dead Zone
2.5.1.3 Environmental Effects
2.5.2 Other Off-Nominal Operations
2.5.2.1 Reentry
2.5.2.2 Abort
2.5.2.3 FTS
2.5.2.4 TTS
2.5.3 Return to Flight Status After Off-Nominal Operation
2.5.4 Safety Reporting Systems
2.5.4.1 Voluntary
2.5.4.2 Mandatory
2.5.5 Mandatory Reporting Requirements
2.5.6 Go/No-Go Decisions
2.5.6.1 Allocation

3. HUMAN SPACEFLIGHT

3.1 AEROSPACE PHYSIOLOGY & MEDICINE

3.1.1 Develop medical standards for crew and develop acceptance criteria for passengers
3.1.2 Data collection
3.1.2.1 Develop methods and procedures to collect and analyze biomedical data from space flight crews and space flight participants to determine any unique medical risks that humans encounter during launch, ascent, on-orbit, reentry, landing and repetitive flights.
3.1.2.2 Investigate novel ways to track health of space crews including DNA analysis for radiation injury, fatigue, and stress. Also, consider options for the use of DNA and other body fluids/tissues in body identification and other environmental exposures in the event of a fatal accident.
3.1.2.3 Physiological sensor hardware utilization
3.1.2.4 Centrifuge evaluation of specific medical conditions
3.1.3 Databases
3.1.3.1 Review all medications that have been used in spaceflight to aid in medical standard development and special issuance procedures for crew on medications.
3.1.3.2 Develop database to track medical outcomes among crewmembers that experience repetitive and frequent spaceflights.
3.1.4 Risk mitigation
3.1.4.1 Pre-flight care
3.1.4.1.1 Support the validation of drug and alcohol testing standards used in the commercial aviation industry for application in the manned commercial space transportation industry (coordinate with Theme 4).
3.1.4.2 In-flight care
3.1.4.2.1 Support the development of medical kits for various suborbital and orbital flight scenarios.
3.1.4.3 Post-flight care
3.1.4.4 Special issuance (waiver) procedures for crew
3.1.4.4.1 In a cooperative effort with NASA and previous commercial spaceflight participants, review outcome of flight experience involving astronauts with commonly occurring medical conditions in order to create an evidence-based approach to special issuance decision-making.
3.1.5 Informed consent

3.1.5.1 Provide input for an Informed Consent Briefing for spacecraft and mission specific profiles.

3.2 PERSONNEL TRAINING

3.2.1 Medical

3.2.2 Passengers

3.2.2.1 Develop a standardized training template for spacecraft and mission specific profiles.

3.2.3 Ground

3.2.3.1 Support the development of human factors standards for aerospace vehicle maintenance to prevent maintenance-related incidents/accidents.

3.2.4 Crew

3.2.4.1 Support the development of appropriate standards for emergency medical kits, equipment, and procedures for use onboard aerospace vehicles. Recommend CPR and basic life support training requirements for space crews. Evaluate and recommend the use of telemedicine systems for the diagnosis, treatment, and monitoring of unexpected medical emergencies during aerospace vehicle operations.

3.3 ECLSS

3.3.1 Review, analyze and summarize existing standards

3.3.2 Coordinate with Theme 2 and A/C Environment COE

3.3.3 Standalone generic ECLSS model

3.3.4 Adapt existing NASA modeling tools for commercial human spaceflight, such as MMOD Model (Bumper) and Cabin Depressurization Model (Killer Press) to allow comparison of tradeoffs and risks.

3.4 HABITABILITY & HUMAN FACTORS

3.4.1 Review, analyze and summarize information on existing regulations and policies

3.4.1.1 Evaluate human factors related to Reusable Launch Vehicles (RLV) cockpit/panel/ layouts, with emphasis on the capability to visually reacquire a runway, spaceport/airport, runway environs i.e. approach lighting requirements, visual approach slope indicators for re-entering vehicles, unique runway marking requirements for suborbital re-entry in visual flight conditions.

3.4.1.2 Support the development of a computerized accident/incident database. In addition, an anonymous incident database similar to NASA's ASRS (Aviation Safety Reporting System) database should also be available for aerospace vehicle operations. Develop appropriate procedures for the assessment of human factors issues in aerospace vehicle accident investigation. Coordinate with Theme 1.

3.4.2 Assess occupant protection capabilities during nominal and emergency conditions

3.4.2.1 Identify hazards

3.4.2.2 Physiological effects under appropriate g-loads of all potential participants across age, gender, anthropometry, etc.

3.4.2.3 Seat design

3.4.2.4 Seat materials

3.4.2.5 Restraint design

3.4.2.6 Suited versus unsuited

3.4.3 Assess pilot performance under sustained G-loads

3.4.3.1 Identify safety-related human-centered automation issues related to the design and operation of aerospace vehicles to determine if ascent profiles and/ or contingency aborts should be automated.

3.4.4 Assess effects of repeat flight on pilot performance

3.4.4.1 Pre-flight pilot condition

3.4.4.2 Develop a risk analysis report on medical incapacitations and situations (e.g. fatigue, anxiety, stress) that might occur in RLV flight crew and space flight participants.

3.4.4.3 Trajectory following

3.4.4.4 Situational Awareness / Spatial Disorientation

3.4.5 Consider performance factors of pilot/ground crew using remote-piloted vehicles

3.4.6 Determine minimum passenger tasks and safety knowledge

3.4.6.1 Nominal

3.4.6.2 Emergency

3.4.6.3 Assess personal carry-on item risk
3.4.6.4 Assess payload materials risk
3.4.6.4.1 Coordinate with Theme 2

3.5 HUMAN RATING

3.5.1 Review, analyze and summarize human rating work and spacecraft lessons learned
3.5.1.1 Close calls
3.5.1.2 Mishaps
3.5.1.3 Recent work
3.5.2 Consider implications of crew versus passenger/ground personnel on protection and utilization
3.5.3 Integrating with launch vehicle team (Coordinate with Theme 2)

4. SPACE TRANSPORTATION INDUSTRY VIABILITY

4.1 MARKETS

4.1.1 Industry Description
4.1.1.1 Description of companies
4.1.1.2 Comprehensive repository for industry resources
4.1.2 Industry Analysis
4.1.2.1 Historical studies
4.1.2.2 Modeling
4.1.3 Future Options
4.1.3.1 Applications of industry description and analysis for future policy directions
4.1.3.2 Prospective analysis of support of transition to multiple customers

4.2 POLICY

4.2.1 International
4.2.1.1 Options for new regulatory initiatives
4.2.1.2 Options for a single international space regulatory regime
4.2.2 Domestic
4.2.2.1 Economic actor, customer (anchor tenant), market analysis, government interaction with commercial sector (transition)
4.2.2.2 Service provider (range safety, debris removal, etc.)
4.2.2.3 Technology research and development support
4.2.2.4 Legal, regulatory actions

4.3 LAW

4.3.1 Liability
4.3.1.1 Historical analogies with other industries
4.3.1.2 Role of government (different than current regime)
4.3.1.3 State vs. federal jurisdiction
4.3.1.4 Assessment of liability risk
4.3.2 Insurance
4.3.2.1 What's the insurance for and how is it relevant to business viability?
4.3.2.2 Kind of insurance required is a policy decision, implemented through laws and regulations
4.3.2.3 Insurance considerations and approaches
4.3.3 Barrier analysis of existing laws

4.4 REGULATION

4.4.1 Regulatory parameters
4.4.1.1 Scope of regulations
4.4.1.2 Characteristics
4.4.2 Historical analyses and analogies
4.4.2.1 Regulatory case studies in aviation, railroad, and maritime transportation to provide historical context on the evolution of US and international regulatory regimes
4.4.3 Comparative analysis
4.4.3.1 Contemporary issues
4.4.3.2 International analysis

4.5 CROSS-CUTTING TOPICS

APPENDIX E. 2011 SPACE TRAFFIC MANAGEMENT AND OPERATIONS RESEARCH THEME STRUCTURE

1. STM & OPS

1.1. ORBITAL STM

- 1.1.1. Services
  - *1.1.1.1. Service Provider Roles and Responsibilities*
  - *1.1.1.2. Space Situational Awareness*
    - 1.1.1.2.1. Surveillance Sensor Technologies
  - *1.1.1.3. Conjunction Prediction Analysis*
  - *1.1.1.4. Real-Time Conjunction Analysis*
  - *1.1.1.5. Collision Avoidance*
- 1.1.2. Guidelines
  - *1.1.2.1. Slot Allocation / Zoning*
  - *1.1.2.2. End of Life / Deorbit (Object Specific)*
  - *1.1.2.3. Certification and Liability (Theme IV Interaction)*
- 1.1.3. Standardization
  - *1.1.3.1. State vector / Ephemeris (eg. Pos, Vel, etc.)*
  - *1.1.3.2. Modeling*
    - 1.1.3.2.1. Space Environment
    - 1.1.3.2.2. Propagation
    - 1.1.3.2.3. Macro Approach
  - *1.1.3.3. Time Systems*

1.2. SUBORBITAL STM

- 1.2.1. Space Environment
  - *1.2.1.1. Space Weather*
  - *1.2.1.2. Debris*
- 1.2.2. Traffic
  - *1.2.2.1. Traffic Above NAS*

1.3. NAS INTEGRATION

- 1.3.1. Takeoff and Landing Requirements
  - *1.3.1.1. STC Demand and Integration with NAS*
  - *1.3.1.2. Spacecraft Escape / Abort Paths*
  - *1.3.1.3. Breakup Debris Models*
    - 1.3.1.3.1. Hazmat Behavior
  - *1.3.1.4. Ascent / Reentry Trajectory Models*
- 1.3.2. Transit Requirements
- 1.3.3. Integration Into NextGen
  - *1.3.3.1. Launch/Landing Traffic Management Modeling*

1.4. SPACEPORT OPERATIONS

- 1.4.1. Spaceport Launch/Landing Requirements
  - *1.4.1.1. Demand Studies*
  - *1.4.1.2. Traffic Modeling*
  - *1.4.1.3. Noise Modeling*
- 1.4.2. Spaceport Interoperability
  - *1.4.2.1. Domestic*
  - *1.4.2.2. International*
- 1.4.3. Support Services Requirements
  - *1.4.3.1. Industry*
    - 1.4.3.1.1. Fuel Farms
    - 1.4.3.1.2. Hazmat Procedures
    - 1.4.3.1.3. Infrastructure
    - 1.4.3.1.4. Safety
  - *1.4.3.2. Passengers*

1.5. INTEGRATED AIR/SPACE TRAFFIC MANAGEMENT

- 1.5.1. Forthcoming

The Research Roadmap Workshops were generously supported by contributions from the following companies:

LOCKHEED MARTIN

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