FAA OFFICE OF COMMERCIAL SPACE TRANSPORTATION RESEARCH ROADMAP

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The Federal Aviation Administration (FAA) Office of Commercial Space Transportation (AST) established a Center of Excellence for Commercial Space Transportation (COE CST) in August 2010. While drafting the Request For Proposal in preparation for the COE CST competition, four research groups were identified with brief descriptions and examples that fit into each grouping. AST's four research areas include:

(i) Space Traffic Management and Operations
(ii) Space Transportation Operations, Technologies and Payloads
(iii) Human Spaceflight
(iv) Space Transportation Industry Viability

During the initial year of COE CST operation, a concerted effort was made to fill in each of the four top-level groupings with details that would:

a) Identify a comprehensive set of research subdivisions
b) Identify a broad spectrum of research opportunities and options
c) Identify specific tasks for the research subdivisions
d) Make an attempt to prioritize the tasks to help AST decide what research to undertake first

The result of this effort is the FAA Research Roadmap that is the guiding document for AST's four research plans. After giving a brief history of the AST Research Roadmap creation, this paper will provide details about each of the four research areas, including a description of how the resulting maps correlate to the fourteen NASA Space Technology Roadmaps.

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I. Center of Excellence Background

The Center of Excellence for Commercial Space Transportation (COE CST) was formed in 2010 with the goal of identifying 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 Federal Aviation Administration (FAA) Office of Commercial Space Transportation (AST) and the U.S. commercial space transportation industry as a whole.

The Center is made up of nine universities: Florida Institute of Technology, Florida State University, New Mexico Institute of Mining and Technology, New Mexico State University, Stanford University, University of Central Florida, University of Colorado at Boulder, University of Florida, and University of Texas Medical Branch at Galveston. Together these universities represent a unique compilation of geographic diversity and connections with CST industry partners.

FAA AST possesses dual mission goals of both regulation and promotion. These stem from the legislation which created FAA AST and are described in Title 51 of US Code, Subtitle V, Chapter 509:

1. Regulate the commercial space transportation industry, only to the extent necessary, to ensure compliance with international obligations of the United States and to protect the public health and safety, safety of property, and national security and foreign policy interest of the United States.

2. Encourage, facilitate, and promote commercial space launches, re-entries, and associated services by the private sector.

These missions are reflected in the research that FAA AST invests in and thus in the Research Roadmap for the COE. The selected research tasks function primarily to increase safety, inform regulation, and/or facilitate development of the industry.

II. Research Roadmap Background and Process

In order to coordinate research tasks towards the COE's goals, developing a roadmap for future research was identified among the first round of research tasks. To generate this roadmap, two workshops were held and numerous interested parties were contacted and invited to send representatives. This includes companies, organizations, research centers, universities, NASA, and the Department of Defense. In all, for each of the two workshops approximately 70 people were in attendance.

The first workshop was held at Stanford University in Palo Alto, CA, April 6-7 2011 and the second was at the Lockheed Martin Global Vision Center in Arlington, VA, August 16-17 2011. The two locations and times allowed us to capture the views of a broad range of geographically diverse researchers, engineers, policymakers, and others with difficult schedules and travel availabilities.

At the 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 attendees broke into 4 smaller groups centered on each research theme. Some spent time in several different themes' deliberations, 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, and are listed in Table 1.

	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)

Table 1: Workshop session chairs

III. Research Roadmap Results

The research theme breakdown structure (Figure 1) was one of the results of these discussions. It began with a structure provided by FAA AST, but was revised to various degrees during both workshops. In addition, deeper levels of substructure were identified, in some cases down to the level of individual research tasks (Figure 2).

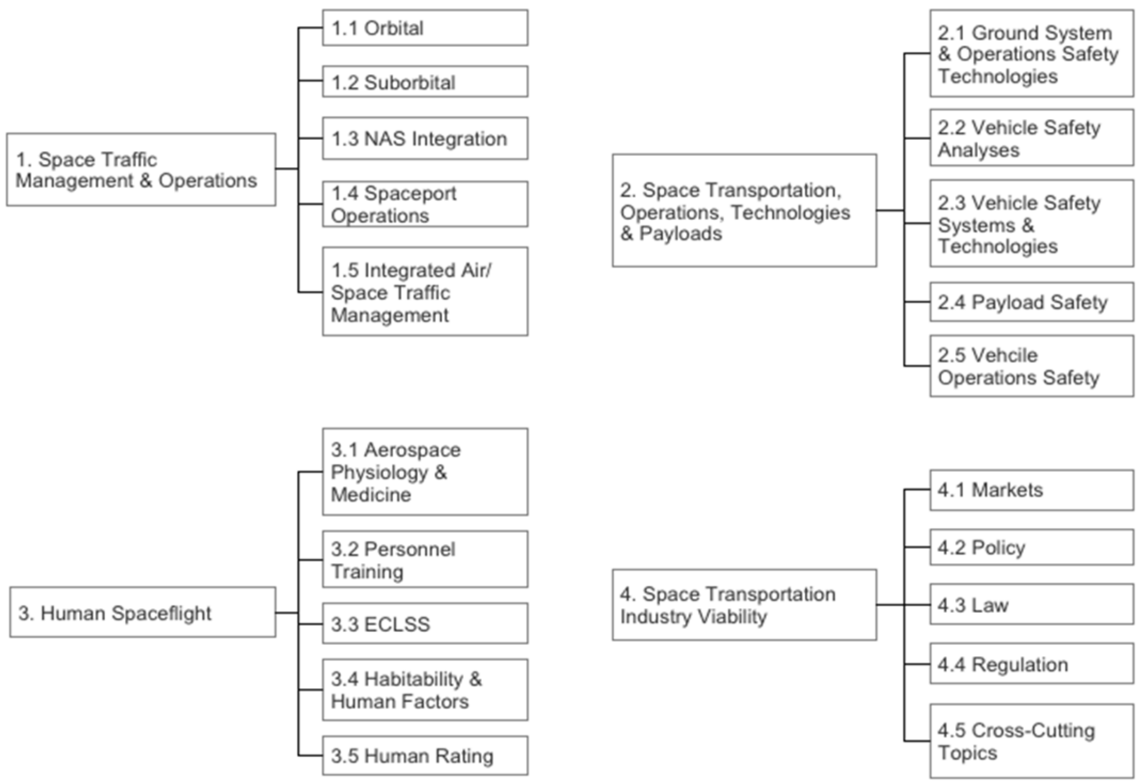

Figure 1: Research theme structure

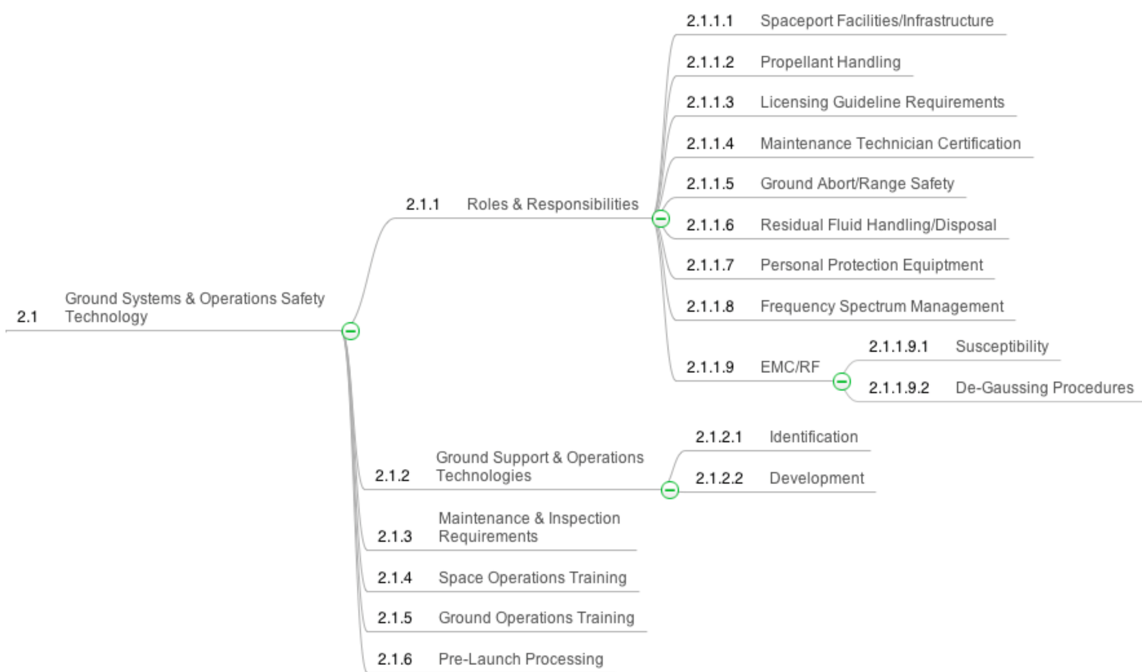

Figure 2: Sample of deeper level structure

Theme 1: Space Traffic Management & Operations

Mission Statement

"Safe Integration of Air & Space Traffic Management, to effectively answer those topics related to the development and optimization of technical and regulatory provisions and processes used to oversee, coordinate, regulate, and promote safe and responsible space all activities between space and Earth (including access to, operations in and return from space to Earth) to avoid physical and/or electromagnetic interference.

It also includes the operational and safety-related design criteria of spaceports, launch and reentry vehicles, and resident space objects, air and space traffic integration, space situational awareness (currently not within AST authority, but listed for the sake of completeness), ground support operations, and other issues which may impact the safe operation of launch, reentry, or on-orbit operations."

Description and Impact

Theme 1 is centered on finding the best way to deal with the traffic associated with the anticipated rapid increase in orbital and suborbital vehicle operations. Several major problems will be engendered by this rise in traffic.

Currently in the US there are roughly 850,000 commercial airline flights per month, while there are rarely as many as 10 commercial rocket launches per month. The FAA requires a large stay-out zone around these launches, but because they are rare occurrences from a handful of locations, the impact on commercial aviation has been minimal. However, in the coming years the number of launch vehicles operating regularly is projected to rise dramatically from an increasing number of launch sites. The net result of this is a logistical and economic impact that could easily become monumental and simply unacceptable.

Aside from the conflict between launch vehicles and airplanes, the current upper limit for air traffic control is 60,000 ft. If the number of vehicles and objects above this limit becomes large, some new form of traffic management will become necessary to reduce the risk of collision.

A third major task involves developing something akin to the operational procedures in place at our nation's airports, but optimized for the requirements of orbital and suborbital launch vehicles.

Research Program Structure

- Program 1.1 Orbital STM Research
  - Project 1.1-1 Orbital STM Services
  - Project 1.1-2 Guidelines
  - Project 1.1-3 Standardization
- Program 1.2 Suborbital STM Research
  - Project 1.2-1 Space Environment
  - Project 1.2-2 Traffic
- Program 1.3 NAS Integration Research
  - Project 1.3-1 Takeoff and Landing Requirements
  - Project 1.3-2 Transit Requirements
  - Project 1.3-3 Integration Into NextGen
- Program 1.4 Spaceport Operations Research
  - Project 1.4-1 Launch and Landing Requirements
  - Project 1.4-2 Interoperability
  - Project 1.4-3 Support Services Requirements
- Program 1.5 Integrated Air/Space Traffic Management Research

Priority Research Tasks

- Airspace
  - Deconfliction between air and space traffic
    - What kind of airspace do we need for the vehicle?
    - Do we need to reserve portions of NAS for rocket traffic?
    - Do we need transition corridors from air to space?
    - Do we need a new class of airspace?
  - How does space transportation interface with NextGen?
- Spaceport Requirements
  - What are the vehicle specific requirements (fueling, servicing, passengers, etc.)?
  - Talk with existing launch sites to determine best practices
- Air Traffic Issues
  - What are the navigational requirements?
  - What are the flight planning requirements?
  - How are anomalies resolved?
  - Who do we tell that we're aborting?
- Weather and Space Weather
  - Triggered lightning
- Command and Control
  - What should be command and control element at spaceports?
  - What are the vehicle specific command and control requirements?
  - What is the integrated concept of operations?
  - Who offers these services?

Theme 2: Space Transportation Operations, Technologies & Payloads

Mission Statement

"Improved vehicle safety and risk management, including knowledge of all safety-critical components and systems of the space vehicles and their operations, so as to better identify potential hazards and to better identify, apply and verify hazard controls."

Description and Impact

The wide span of this research area makes it difficult to define concisely. Generally, It involves the technology development, operations and safety analyses of ground support, vehicle and payload systems and subsystems. For further detail 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 and certification processes, and human-rating standards for vehicles.

Currently this type of work is only performed with a specific application or customer in mind and to optimize functionality and reliability. NASA develops technologies and systems and operations specific to its own vehicles and missions, while space transportation companies do similar work for purposes of customer acceptability and cost.

As the field of commercial space transportation increases in size it will be beneficial to develop more generic components and systems that can be adapted to different applications rather than be re-designed for each new vehicle or mission.

Research Program Structure

- Program 2.1 Ground System & Operations Safety Technologies Research
  - Project 2.1-1 Roles & Responsibilities
  - Project 2.1-2 Ground Support & Operations Technologies
  - Project 2.1-3 Maintenance & Inspection Requirements
  - Project 2.1-4 Space Operations

- Project 2.1-5 Ground Operations
- Project 2.1-6 Pre-Launch Processing

- Program 2.2 Vehicle Safety Analyses Research
  - Project 2.2-1 Parameter Maximization Analyses
  - Project 2.2-2 Operational Limitation Analyses
  - Project 2.2-3 Simulation and Testing
- Program 2.3 Vehicle Safety Systems & Technologies Research
  - Project 2.3-1 Safety Equipment
  - Project 2.3-2 Post-Flight Diagnostic Equipment
  - Project 2.3-3 Crew Survivability (ECLSS)
  - Project 2.3-4 Other Safety Equipment
- Program 2.4 Payload Safety Research
  - Project 2.4-1 Extent of Disclosure
  - Project 2.4-2 Interfaces
  - Project 2.4-3 Impact on Flight Safety
  - Project 2.4-4 Handling Procedures
  - Project 2.4-5 Electro-Magnetic Interference
  - Project 2.4-6 Non-Operational Payloads
  - Project 2.4-7 Connectors & Interfaces
- Program 2.5 Vehicle Operations Safety Research
  - Project 2.5-1 Abort Procedures
  - Project 2.5-2 Other Off-Nominal Operations
  - Project 2.5-3 Return to Flight After Incident
  - Project 2.5- 4 Safety Reporting Systems
  - Project 2.5- 5 Mandatory Reporting Requirements
  - Project 2.5- 6 Go/No-Go Decisions

<u>Priority Research Tasks</u>

- Research and recommend safe, expeditious, and cost efficient processing of reusable manned or unmanned vehicles that are payloads on ELV's.
  - Landing, inspection, modification if needed, transportation, and integration.
- Explore expeditious procedures for licensing and permitting.
  - When minor changes to a licensed spacecraft, consider between having to re-license entire spacecraft or license the specific change.
- Explore expeditious processes to migrate technologies and payloads to be tested in flight.
- Research the physics and impacts of re-entry debris.
- Study how to facilitate small companies to have access to NASA and FAA test facilities (e.g. test chambers).
- Investigate what NASA and FAA do for handling CG locations for aircraft before flight in order to develop a reliable procedure that can be used to process payloads.
- Analyze which safety equipment and systems can be leveraged from aviation, and identify the type of analysis required.
- Study literature on redundancy for safety critical systems to develop guidelines for redundancy levels.
- How much information does a developer/operator need to tell the FAA in order to safely fly a payload (leverage work from NASA FOP program)?
- Case study of a generic deployment of a payload on an RLV, and how to do a safety analysis on this.
- Develop minimum requirements and guidelines for a return to flight after off nominal operation.
- Study interoperability of commercial space safety management system with other FAA and TBD agencies and develop guidelines for vehicles, spaceports, and operators.
- Hazmat template of what information on toxic materials needs to be provided to fire departments to assess resulting fire due to a vehicle crash.

<u>Theme 3: Human Spaceflight</u>

<u>Mission Statement</u>

"Ensure human safety of those onboard during space vehicle operation and those involved with spaceport operations."

<u>Description and Impact</u>

Since the beginning of manned spaceflight in 1961 and with very few exceptions since then, humans sent to space have gone through intensive physical training and screening. In the near future companies like Virgin Galactic, XCOR, Sierra Nevada Corporation and others may begin flying tourists on suborbital or even orbital flights. These tourists are unlikely to be prepared and screened to the levels to which astronauts or cosmonauts are accustomed.

This presents a host of medical issues, including unknowns about how medications and medical conditions will be affected by the space environment.

Research Program Structure

- Program 3.1 Aerospace Physiology & Medicine Research
  - Project 3.1-1 Standards Development
  - Project 3.1-2 Data Collection
  - Project 3.1-3 Databases
  - Project 3.1-4 Risk Mitigation
  - Project 3.1-5 Informed Consent
- Program 3.2 Personnel Training Research
  - Project 3.2-1 Medical
  - Project 3.2-3 Passengers
  - Project 3.2-3 Ground
  - Project 3.2-4 Crew
- Program 3.3 ECLSS
  - Project 3.3-1 Standards
  - Project 3.3-2 Modeling
- Program 3.4 Habitability & Human Factors Research
  - Project 3.4-1 Normal Conditions Assessment
  - Project 3.4-2 Emergency Conditions Assessment
- Program 3.5 Human Rating Research
  - Project 3.5-1 Protection & Utilization Considerations

Priority Research Tasks

Throughout the two workshops, there wasn't a consensus opinion on research prioritization.

Theme 4: Space Transportation Industry Viability

Mission Statement

"Increase industry viability, including economic, legal, legislative, regulatory, and market analysis & modeling."

Description and Impact

One of the largest unanswered questions in the commercial space transportation industry is "what is the market?" Different companies have vastly different opinions about what will happen to demand in the coming decades. In Theme 4, answering this question is one of the primary goals.

Other topics that require detailed research and planning include domestic and international policies, legalities, and regulation.

Research Program Structure

- Program 4.1 Market Research
  - Project 4.1-1 Industry Description Research
  - Project 4.1-2 Industry Analyses
  - Project 4.1-3 Proposed Future Options
- Program 4.2 Policy Research
  - Project 4.2-1 Domestic Policy Research
  - Project 4.2-2 International Policy Research
- Program 4.3 Law Research
  - Project 4.3-1 Liability
  - Project 4.3-2 Insurance
  - Project 4.3-3 Barrier Analyses
- Program 4.4 Regulation Research
  - Project 4.4-1 Regulatory Parameters
  - Project 4.4-2 Historic Analyses & Analogies
  - Project 4.4-3 Comparative Analyses
- Program 4.5 Cross-Cutting Topics Research
  - Project 4.5-1 Omnibus

Priority Research Tasks

- Markets
  - CST demand market research
  - Retrospective analysis of:
    - Transition from government to private customers
    - Commercial failures
  - Workshop of industrial organization economists looking at CST industry
- Policy
  - Options of a single international space regulatory regime
- Law
  - Liability limitation: history, issues, and options
- Regulation
  - Barrier analysis of existing regulations

IV. Example tasks

Here, a handful of ongoing tasks are described to illustrate the types of projects that have already been selected as COE CST research tasks. These examples are meant to be illustrative but not exhaustive and as such should not convey any limitations on the types of research conducted by the COE. One task is given for each of the four research themes.

Theme 1: Unified 4-D Trajectory Approach for Integrated Traffic Management

Principal Investigator: Dr. Juan Alonso, Stanford University

The projected growth in demand for the use of the traditional airspace by commercial space transportation entities will make it increasingly difficult to accommodate launches on a Special Use Airspace basis. The purpose of this project is to use 4-D time-space probabilistic trajectories and safety assessments to develop the foundation of a plausible Integrated Airspace Management System. Some sample results showing these modeled trajectories are shown in Figure 3 below.

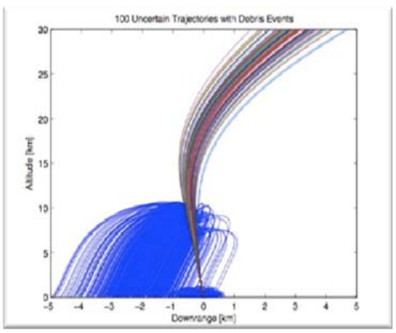

Figure 3: Possible trajectories, including debris

Theme 2: Magneto-Elastic Sensing for Structural Health Monitoring

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

Structural health monitoring of modern satellites is very expensive and time-consuming. Future spacecraft require sensing technologies that are reliable, multi-purpose, durable, and long-lived. These sensors need to perform a multitude of tasks, such as: detect and characterize impact damage from space debris, assess structural integrity of the spacecraft, provide information on structural interfaces, explore spacecraft electrical signature, enable reusable component requalification for flight, and possibly conduct non-contact inspection in space. The purpose of this task is to develop innovative magneto-elastic sensing technologies for structural diagnosis of space vehicles. A schematic showing a sample design of these sensors is shown below in Figure 4.

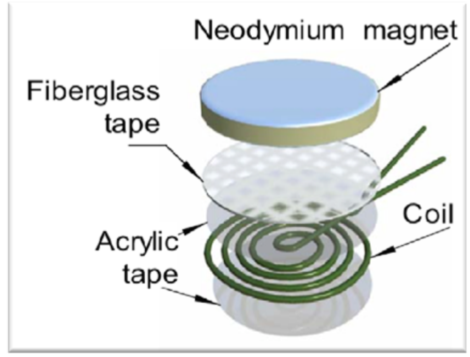

Figure 4: Diagram of magneto-elastic sensor

Theme 3: Wearable Biomedical Monitoring Equipment for Passengers on Suborbital & Orbital Flights

Principal Investigator: Dr. Richard Jennings, University of Texas Medical Branch

Collection of biomedical data from the diverse population of commercial spaceflight participants (SFP's) will greatly enable the FAA in developing relevant regulations for SFP's. The purpose of this task is to identify the gaps between current technologies and the medical data needs for SFP's, and then develop sensors that could be used by the CST industry to fill those gaps. In the photo below, Dr. Richard Jennings undergoes centrifugal testing at the NASTAR Center.

Figure 5: Dr. Richard Jennings at the NASTAR Center

Theme 4: Defining the Future by Engaging Emerging Leaders

PI: Dr. George Born, University of Colorado at Boulder

The FAA COE program has three primary goals: research, training, and outreach. This activity emphasizes COE CST's outreach goal by engaging students in graduate seminar activities, conference attendance that emphasizes commercial space topics, and the execution of specific research work for presentation at professional space conferences in commercial space paper sessions. In Figure 6, students are shown at the first Emerging Space Industry Leaders Conference.

Figure 6: ESIL-01 Conference in Boulder, CO

V. Connections to NASA Space Technology Roadmaps

In 2011 NASA's Office of the Chief Technologist (OCT) published a set of Space Technology Roadmaps outlining technology development strategies to enhance the US's current capabilities in space. These extensive documents were designed to be an input to the National Research Council (NRC), who used them as a starting point to develop space technology research priorities. The fourteen Technology Areas (TA's) of the NASA Space Technology Roadmaps include:

- TA01 (Launch Propulsion Systems)
- TA02 (In-Space Propulsion Systems)
- TA03 (Space Power and Energy Storage)
- TA04 (Robotics, Tele-Robotics and Autonomous Systems)
- TA05 (Communication and Navigation)
- TA06 (Human Health, Life Support, and Habitation Systems)
- TA07 (Human Exploration Destination Systems)
- TA08 (Science Instruments, Observatories and Sensor Systems)
- TA09 (Entry, Descent and Landing Systems)
- TA10 (Nanotechnology)
- TA11 (Modeling, Simulation, Information Technology and Processing)
- TA12 (Materials, Structures, Mechanical Systems and Manufacturing)
- TA13 (Ground and Launch Systems Processing)
- TA14 (Thermal Management Systems)

Given the similar purposes behind the COE Research Roadmap and NASA's Space Technology Roadmaps, it is beneficial to compare the two in order to identify possible areas of collaboration.

It must be first noted that NASA and FAA AST have strategic goals that are similar and provide for some overlap but are nonetheless distinct. The FAA AST Research Roadmaps define a pathway towards informing commercial space transportation regulations, increasing safety, and facilitating the industry. While not always the focus, space technology research plays a part in many tasks within these missions. An overview of the correlation between the two roadmaps is given below in Figure 7.

In particular, AST Research Area 2 (Space Transportation Operations, Technologies, and Payloads) has the strongest direct connections to NASA Technology Areas. Program 2.3 (Vehicle Safety Systems and Technologies) by its nature is heavily centered on space technology and can be directly connected to:

- TA01 (Launch Propulsion Systems),
- TA02 (In-Space Propulsion Systems),
- TA03 (Space Power and Energy Storage),
- TA05 (Communication and Navigation),
- TA09 (Entry, Descent and Landing Systems),
- TA10 (Nanotechnology),
- TA12 (Materials, Structures, Mechanical Systems and Manufacturing) and
- TA14 (Thermal Management Systems).

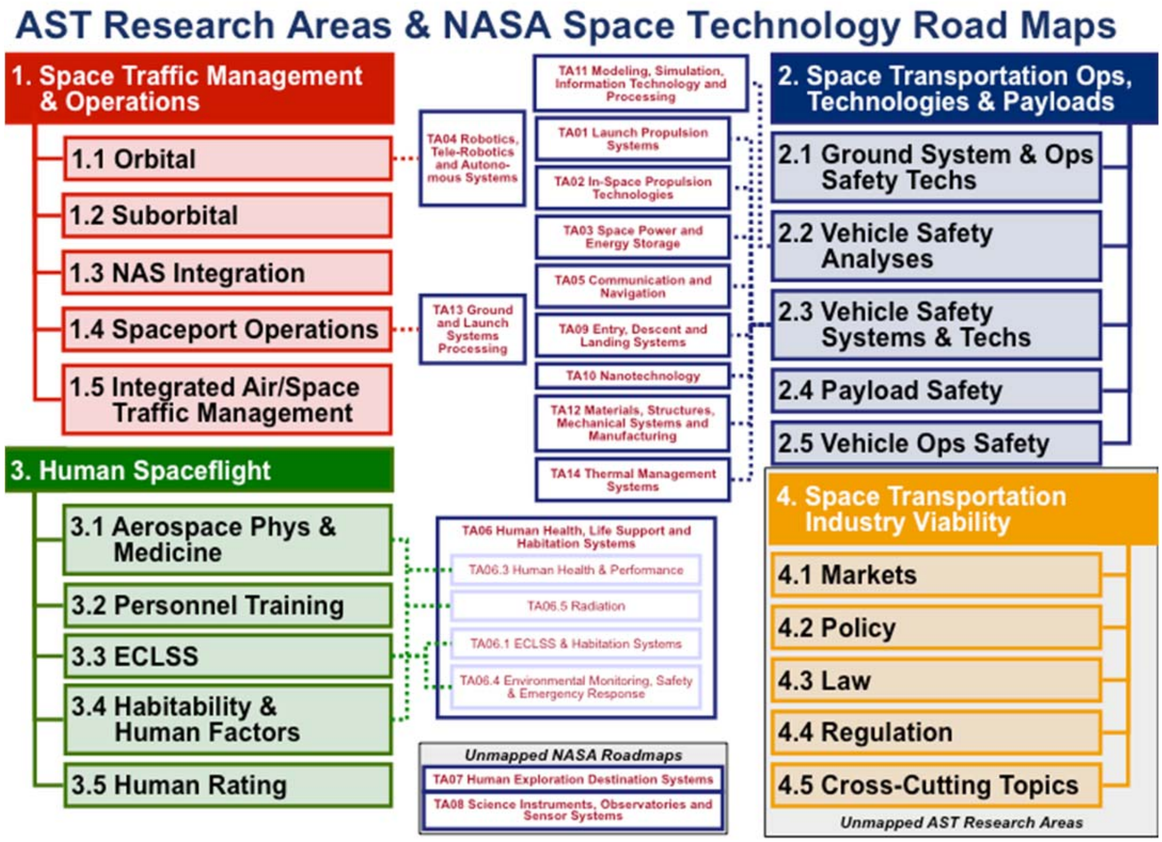

Figure 7: AST Research Area (RA) and NASA Space Technology Roadmap Technology Area (TA) interconnections

As an example of the overlap, the NRC identified TA09.4.6 (Instrumentation and Health Monitoring) as a high-priority research item and includes the development of sensors that could be used to both validate TPS design algorithms by comparing simulation and flight test results and provide evidence that vehicle systems are operating properly prior to re-entry. The development of such technology would clearly be of interest to FAA AST and corresponds directly to research within RA 2.3.1.3 (Detection Systems) and 2.3.1.5 (Integrated Vehicle Health Systems).

Elsewhere within AST RA 2, TA11 (Modeling, Simulation, Information Technology and Processing) shows some overlap with Program 2.2 (Vehicle Safety Analyses) due to the significant amount of modeling and simulation required for many advanced safety analyses. Within this TA, the NRC identified TA11.3.1 (Distributed Simulation) as a high-priority research item that would be undoubtedly useful for AST research within RA 2.2.3.3 (Simulation and Testing Software).

AST Research Area 3 (Human Spaceflight) overlaps extensively with NASA Technology Area 05 (Human Health, Life Support and Habitation Systems), and individual areas within the TA Breakdown Structure show direct connection to the Programs within the AST RA. For instance, Programs 3.1 (Aerospace Physiology and Medicine) and 3.4 (Habitability & Human Factors) correspond to TA06.3 (Human Health & Performance) and TA06.5 (Radiation). Additionally, Program 3.3 (ECLSS) can be easily tied to TA06.1 (ECLSS & Habitation Systems) and TA06.4 (Environmental Monitoring, Safety & Emergency Response).

Due to concerns about long-duration space travel, the NRC identified several priority research tasks within TA6.5 (Radiation). All of these are of interest to AST for predicting and mitigating risks to crews and spaceflight participants in suborbital and orbital flight. As an example, TA6.5.3 (Radiation Protection Systems) corresponds directly to AST research within RA 3.1.4 (Risk Mitigation for Aerospace Physiology & Medicine).

AST Research Area 1 (Space Traffic Management and Operations) is less focused on specific technologies and thus there are fewer connections to the NASA Roadmaps, although some connections can be made with TA04 (Robotics, Tele-Robotics, and Autonomous Systems), TA09 (Entry, Descent, and Landing), and TA13 (Ground and Launch Systems Processing).

The NRC identified TA9.4.5 (EDL Modeling and Simulation) as a high priority research item that overlaps heavily with one of the priority research tasks for AST Program 1.3 (NAS Integration), which focuses on determining the corridor required by a re-entering space vehicle.

Research Area 4 (Space Transportation Industry Viability) is completely separate from the NASA Roadmaps and is an illustrative example of how the differing missions of the two roadmaps affects their research priorities. The FAA uniquely has both regulatory and industrial promotion goals, necessitating the inclusion of research that is based on economics, management, policy, and law. This includes tasks such as market demand research, investigating methods for liability limitation, and novel ideas for international space regulatory regimes. NASA would likely be interested in some of these research tasks, but that interest would not be reflected in its Space Technology Roadmaps.

Similar to AST RA 4, there are NASA Technology Areas that do not directly correspond to any AST Research Area. This includes TA07 (Human Exploration Destination Systems) and TA08 (Science Instruments, Observatories and Sensor Systems). Both of these follow NASA's exploration and science mission goals and represent a departure from research of interest to FAA AST. Examples of research within these TA's include food production/processing/preservation, surface mobility, in situ instruments and sensors, and high-efficiency lasers.

Given this extensive overlap between the two roadmaps, collaboration between NASA and the FAA would be an ideal way to leverage the buying-power of federal research dollars.

VI. Conclusions

Through our series of workshops representatives 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 Operations**
  - A minimum safe corridor for launches and re-entries must be identified.
- **Theme 2 - Space Transportation Operations, Technologies, and Payloads**
  - 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 inherent limitation of its applicability. Within the roadmap are consensus views from many perspectives within the industry and the resultant information is of value to any organization that seeks to further commercial space transportation.

These research tasks contained within the roadmap will benefit the industry by leveraging academic research in order to inform forthcoming regulations from the FAA and to develop solutions to key problems impeding industrial progress. Without sufficient funding for this research, however, this progress will no doubt be delayed.

Identifying overlap with NASA’s space technology work will be instrumental in ensuring rapid progress by harnessing research opportunities available from both agencies. While the goals of NASA and FAA AST may differ, their research of interest contains numerous parallels and in this paper we have identified many intersections of NASA’s Technology Areas and FAA AST’s Research Themes. We hope that in the future this work will be expanded upon in order to coordinate research efforts from the two agencies.

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 CST, but also maintain it as a standard that other organizations may utilize.

VII. Acknowledgements

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