COE CST Fifth Annual Technical Meeting

# Research Roadmapping Workshops

Task 193

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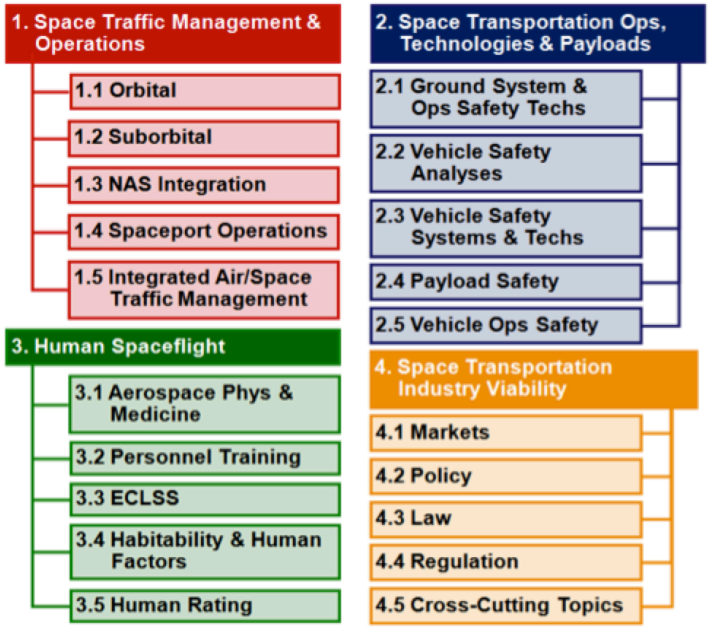
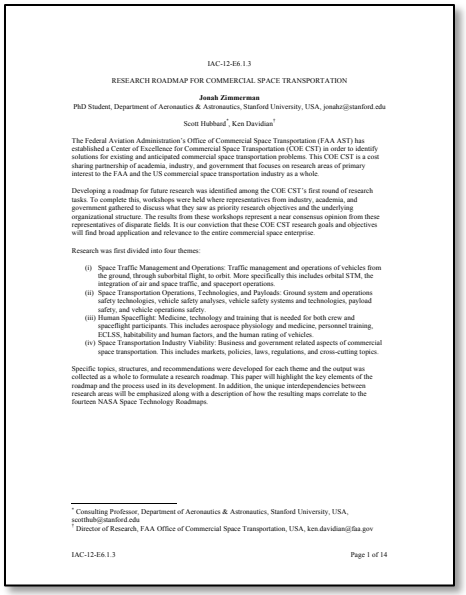
# Background

In 2010, FAA established the FAA COE CST to identify research solutions to existing and anticipated CST problems. In addition:

- A research roadmap was identified as one of the first research tasks
- Workshops were held with representatives of industry, government, and academia
- A notional decomposition / program structure was created
- Results including research tasks (without prioritization) were compiled into a report in 2011

In 2015, it was recognized that the CST industry had undergone significant transformation and a revision of the roadmap (with prioritization in the research tasks) was needed.



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RESEARCH ROADMAP FOR COMMERCIAL SPACE TRANSPORTATION

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The Federal Aviation Administration's Office of Commercial Space Transportation (FAA AST) has 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 US 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 represent a near consensus opinion from these 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 enterprise.

Research was first divided into four themes:

(i) Space Traffic Management and Operations: Traffic management and operations of vehicles from the ground, through suborbital flight, to orbit. More specifically this includes orbital STM, the integration of air and space traffic, and spaceport operations.
(ii) Space Transportation Operations, Technologies, and Payloads: Ground system and operations safety technologies, vehicle safety analyses, vehicle safety systems and technologies, payload safety, and vehicle operations safety.
(iii) Human Spaceflight: Medicine, technology and training that is needed for both crew and spaceflight participants. This includes aerospace physiology and medicine, personnel training, ECLSS, habitability and human factors, and the human rating of vehicles.
(iv) Space Transportation Industry Viability: Business and government related aspects of commercial space transportation. This includes markets, policies, laws, regulations, and cross-cutting topics.

Specific topics, structures, and recommendations were developed for each theme and the output was collected as a whole to formulate a research roadmap. This paper will highlight the key elements of the roadmap and the process used in its development. In addition, the unique interdependencies between research areas will be emphasized along with a description of how the resulting maps correlate to the fourteen NASA Space Technology Roadmaps.

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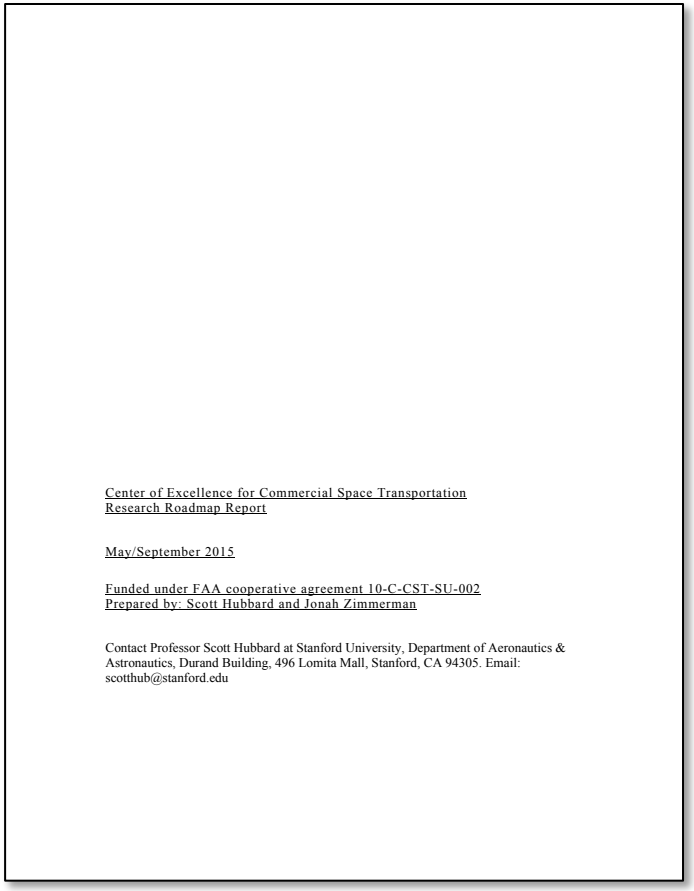
# Statement of Task

A summary of the updated (2015) research roadmap is described in this presentation

- It covers the same 4 major areas but modifications to the program structure were made
- Represents the consensus of experts in a host of interdisciplinary fields
- Revisits the prioritization of research tasks and includes near-term, high importance items
- Consensus achieved via discussion during five workshops held at different locations around the country, as well as virtually

The outcome represents the efforts of Prof. Scott Hubbard and (almost) Dr. Jonah Zimmermann, with the help of many.



Center of Excellence for Commercial Space Transportation
Research Roadmap Report

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# Research Themes

The basic structure of the research themes was taken from the 2011 roadmap and did not change significantly:

- Research Theme 1a: Space Traffic Management
- Research Theme 1b: Spaceport Operations
- Research Theme 2: Space Transportation Operations, Technologies & Systems
- Research Theme 3: Human Spaceflight
- Research Theme 4: Space Transportation Industry Viability

- Cross-Cutting Tasks and Integration

# High-Priority Research

*Sample*, near-term high-priority research tasks in each of the themes:

- **Space Traffic Management**: Dynamic de-confliction for nominal and off-nominal operations and integrated procedures above / below FL600.
- **Spaceport Operations:** Provide guidance to spaceport operators and launch operators on emergency response and communications in the event of an incident
- **Space Transportation Operations, Technologies & Systems:** Develop, test, and refine promising flow control methods to reduce flow unsteadiness in rocket plume interactions with launch pad structures.
- **Human Spaceflight:** Research to determine the highest risk medical conditions that would require more data and need monitoring
- **Space Transportation Industry Viability:** Determine the government regulatory structure that will minimize cost to the industry while maximizing safety.

# Research Theme 1a: Space Traffic Management

Focuses on two major areas:

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

Priority Research Tasks

Air/Space Traffic Management:

- Dynamic de-confliction for nominal and off-nominal operations
- Integrated procedures above / below FL600

Space Situational Awareness / Space Debris:

- Debris monitoring and forecasting methods
- Debris impact modeling and risk assessments

***Example of a Current Research Task***

Task 185: Unified 4-D Trajectory Approach for Integrated Traffic Management

Principal Investigator: Dr. Juan J. 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. In the figure below, an example is shown of a compact envelope for a suborbital commercial spaceflight vehicle.

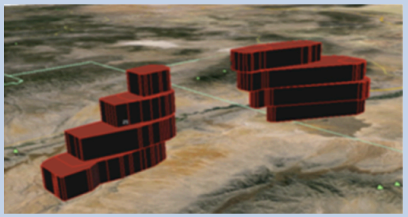


**Figure 3. Example of a compact envelope for a Lynx-like vehicle**

# Research Theme 1b: Spaceport Operations

Facilitate the development, utilization, and operation of commercial spaceports by developing a framework to capture knowledge for spaceport operation best practices.

Priority Research Tasks

- Guidance to spaceport and launch operators on emergency response and communications in the event of an incident
- Expand the sections on insurance, indemnification, and waivers
- Query the users to identify information gaps by using survey techniques
- Encourage transparency in the agreements between spaceports and launch operators

***Example of a Current Research Task***

Task 220: Spaceport Operational Framework

PI: Pat Hynes, New Mexico State

The commercial space industry has not assembled a body of knowledge for commercial spaceports. The purpose of this task is to develop a framework for the body of knowledge, encompassing the activities conducted at a commercial spaceport. Below, the top level breakdown of the framework is shown.

| Reference | Topic |
|---|---|
| 1.0 | AIRFIELD & LAUNCH OPERATIONS |
| 2.0 | SITE SECURITY |
| 3.0 | EMERGENCY RESPONSE |
| 4.0 | VISITOR MANAGEMENT |
| 5.0 | GROUND AND FLIGHT SAFETY |
| 6.0 | ENVIRONMENTAL MANAGEMENT |
| 7.0 | MISSION READINESS |
| 8.0 | ITAR REQUIREMENTS |
| 9.0 | INTERNATIONAL COORDINATION AMONG SPACEPORTS |
| 10.0 | SELF-INSPECTION |

**Figure 4. Top level breakdown of the commercial spaceport framework**

# Research Theme 2: Space Transportation Operations, Technologies & Systems

Focuses on enabling and enhancing the safety, reliability, and efficiency of commercial space vehicles.

Priority Research Tasks / Areas

- Devices: Sensors and Actuators for Enhanced Aircraft Safety
- Advanced Materials and Structures
- Aerothermal Environment – Test and Simulation
- Technology Transition

Including (near term): advanced materials, structures, and sensors that have shown promising results; modeling the space vehicle environment; leveraging the distributed capabilities of the COE members.

***Example of a Current Research Task***

Task 299: Nitrous Oxide Composite Case Testing

PIs: Warren Ostergren, Robert Abernathy, Michael Hargather, 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 5. Test fixture for shock wave loading of composite panels**

# Research Theme 3: Human Spaceflight

Concerned with the physiology, medicine, technology and training that impact safety and performance of both crew and spaceflight participants (SFPs). Research is in two primary areas:

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

Priority Research Tasks / Areas

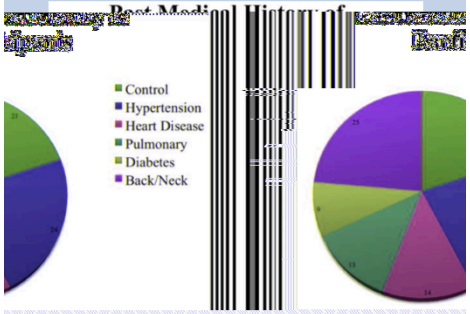
- Vehicle life support and survivability
- Medical standards for crew and acceptance criteria for spaceflight participants
- Training and adaptation
- Operational support
- Physiological monitoring
- Data analysis and database repository

***Example of a Current Research Task***

Task 256: Tolerance of Centrifuge-Induced G-Force by Disease State

PI: James Vanderploeg, University of Texas Medical Branch

There is currently little to no data on how individuals with chronic diseases will perform in a high-performance environment such as commercial spaceflight. The purpose of this task is to produce such data by testing participants with various common medical conditions in the NASTAR centrifuge and use these resulting data to develop risk mitigation strategies. Below, the types of medical conditions tested are shown.




**Past medical rticipants in the tudy** **Figure 6. history of pa s**

# Research Theme 4: Space Transportation Industry Viability

Support effective policy decision-making in the accomplishment of the dual regulatory and promotional missions of FAA AST. Includes economic, legal, legislative, regulatory, and market effects.

Priority Research Tasks / Areas

1. What defines an industry and does the commercial space transportation have an accepted definition of the industry?
2. **Adoption of CST and the adoption of the aviation industry.**
3. Cross-over of aviation and space transportation regulatory authority domestically and internationally
4. Industry access to public data and lessons learned for human space flight.
5. Identify macro level trends across multiple industries that consistently effect rapid industry proliferation.
6. What is an appropriate amount of government regulation that will stimulate growth in the industry while achieving the objective of protection of public safety?
7. **What government regulatory structure will minimize cost to the industry while maximizing safety concerns?**

***Example of a Current Research Task***

Task 193: Role of COE CST in EFP

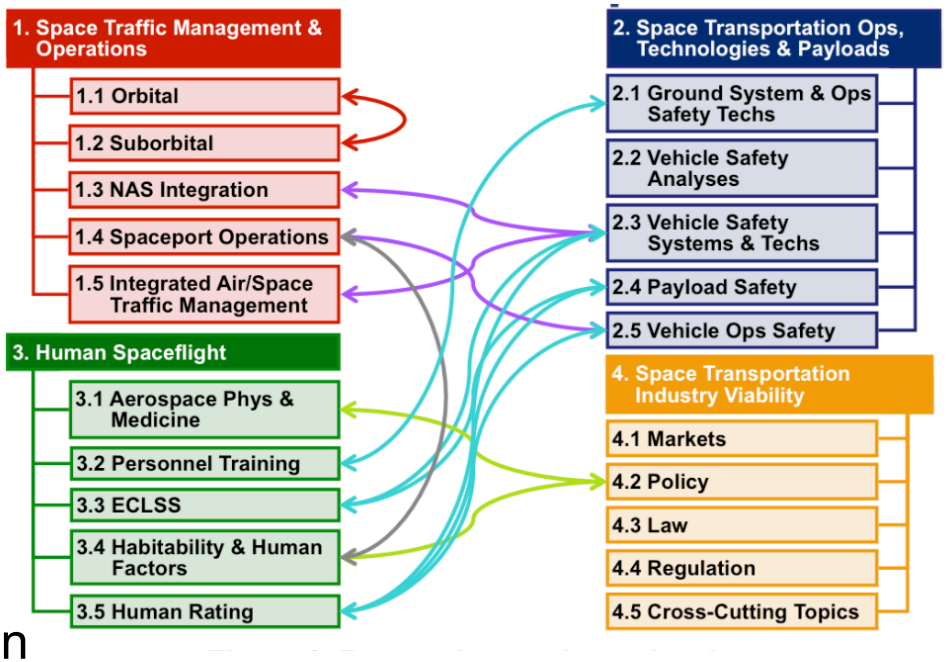
PI: George Born, CU Boulder

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 5, students are shown at the first Emerging Space Industry Leaders Conference.

**Figure 7. ESIL-01 Conference in Boulder, CO**

# Cross-Cutting Tasks & Integration

- Multiple tasks belong under more than one theme
- Interaction may be one-way or two-way.
- Different paradigms for interaction




Some examples:

- Equipage and STM
- Flight diagnostics & ECLSS
- Payload safety & occupant protection
- SV safety & spaceport ops
- ECLSS & Policy
- Human rating & vehicle/ops safety
- Passengers and space transportation operations, technologies and payloads

# Acknowledgements

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- **Research Roadmap PM**: Ken Davidian
- **PI:** Scott Hubbard, SU with help from Jonah Zimmermann
- **Workshop Theme 1a:** Juan J. Alonso, SU
- **Workshop Theme 1b:** Patricia Hynes, NMSU
- **Workshop Theme 2:** Farrukh Alvi, FSU
- **Workshop Theme 3:** Jim Vanderploeg, UTMB Galveston
- **Workshop Theme 4:** Tristan Fiedler / Scott Benjamin, FIT

… and the participation and contributions of nearly 70 experts from academia, government, and industry.

Thanks!