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Center of Excellence for
Commercial Space Transportation

**Federal Aviation Administration
Center of Excellence for
Commercial Space Transportation**

Year 8 Annual Report

Executive Summary

December 31, 2018

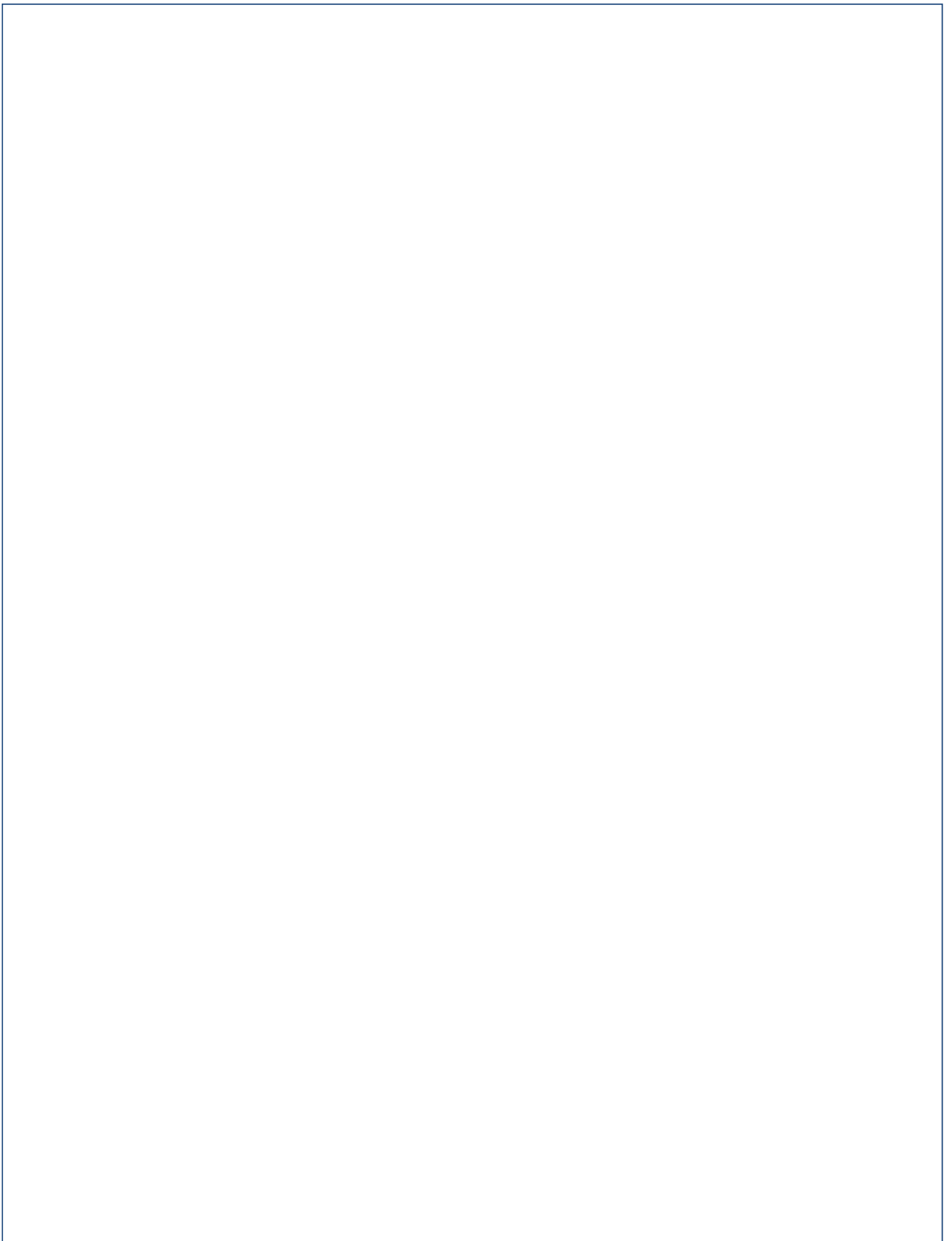




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LETTER FROM THE EXECUTIVE DIRECTOR

As the Center of Excellence for Commercial Space Transportation (COE CST) moves into its 9th year of operation, our research portfolio continues to expand and mature across the 10 core member university consortium along with some two dozen affiliates, associates, subcontractors, and other interested parties actively participating in the pursuits. The accomplishments and advances described in this 8th Annual Executive Summary report serve to illustrate the variety of multidisciplinary topics being addressed by the COE CST.

2018 produced a number of significant spaceflight milestones, with over 100 orbital launches occurring globally during the year. SpaceX continues to not only routinely launch rockets at a record cadence, but to progressively perfect returning the boosters intact as well. Especially notable was the first launch of the Falcon Heavy in February with its rather unique payload of 'Starman' in a Tesla Roadster, which is now traveling on a heliocentric orbit slightly beyond that of Mars. Meanwhile, NASA's OSIRIS-REx spacecraft is orbiting the Bennu asteroid, with a planned sample return in 2023. And NASA's InSight lander successfully touched down on Mars, where it is sending back key scientific data pertaining to the interior structure and composition of the Red Planet. On that same mission, NASA also sent the first CubeSats into deep space, with the twin satellites called Mars Cube One, or MarCO, trailing InSight to serve as data relays during the Lander's entry and descent. Closer to home, Virgin Galactic's VSS Unity took two veteran pilots from the Mojave Air & Space Port up beyond the 50-mile mark defined by the US government as the edge of space, further advancing the onset of commercial space tourism. Blue Origin also successfully carried a suite of commercial payloads on a suborbital trajectory to an altitude of over 100 km, the internationally recognized border of space, aboard the New Shepard, including the test dummy 'Mannequin Skywalker' which conducted astronaut telemetry and science studies.

Providing a reminder that spaceflight does not come without risk, however, the Soyuz rocket intended to send the Expedition 57 crew to ISS in October failed to reach orbit when a booster anomaly occurred during ascent, but the abort system did its job to safely put the crew on a ballistic entry profile back to Earth. Less than two months later, Soyuz returned to flight, delivering the Expedition 58 crew to ISS as planned. While hazards cannot be designed out, risk mitigation strategies can be implemented to reduce the potential for catastrophic failures, which is a focus of our COE CST research. Along those lines, NASA and the US Air Force are conducting tests of astronaut survival systems for the Orion module, which will carry humans to the moon or Mars in the coming years. And finally, NASA's Commercial Crew Program has test flights of Boeing's CST-100 Starliner and SpaceX's Crew Dragon on the calendar for 2019, with astronauts being assigned for these missions this past August.

An exciting year in spaceflight indeed, with the collective successes drawing on contributions from government, industry and academia to meet the shared goals of deep space exploration, ISS crew transport, and space tourism. It is a privilege to participate in these endeavors through the COE CST in support of the FAA Office of Commercial Space Transportation, along with our government and industry partners. We look forward to continuing to help blaze the trail to space for all of humanity.



David Klaus, PhD
Professor, Aerospace Engineering Sciences
Executive Director, COE CST



PREFACE

The Federal Aviation Administration (FAA) Office of Commercial Space Transportation (AST) is pleased to release this FAA Center of Excellence for Commercial Space Transportation (COE CST) Year Eight Annual Report Executive Summary.

The COE CST is now a collection of ten incredible universities, supplemented by affiliate and associate members, and complemented by numerous private organizations and research institutions. Of course, within each of these entities are the people that make the COE CST what it is; the principal investigators, the students, the financial officers, the contractors, the business women (and men), the executives, the administrators, and the government researchers. It is the collective effort of these individuals that makes the research possible, provides matching cash and in-kind contributions, posts the extensive technical and financial data for government-required reports, and fundamentally makes the overall system function efficiently through their individual actions.

The first years of operation (2010-2015) were focused on building the various types of relationships (e.g., research, administrative, financial, personal, etc.) between the many individuals at each of the original nine universities and government offices. Although the budget of the center may be relatively small, the complexity of the relationship network makes the smooth operation of this center a challenge. Despite this complexity, the COE CST has successfully emerged as a fully functional, cohesive unit. Year six began the second half of the ten-year program (2016-2020). During this phase of the organization, the COE CST placed a major emphasis on raising its profile with industry members, to better understand the needs of the evolving commercial space marketplace, and to be better understood by the major marketplace actors.

The success of the COE CST would not have been possible, however, without the leadership of certain important individuals. Specifically, Dr. George Nield, Associate Administrator of FAA AST (until his retirement in March 2018), and Dr. Patricia Watts, National Program Director of the FAA COEs, are two individuals without whose support the COE CST could not function today. The COE CST recognizes them as driving forces for any success the COE CST has attained.

All the COE CST individuals, representing the dozens of participating organizations and institutions, cannot be given enough words of thanks or acts of appreciation in recognition for their contributions of time, effort, and treasure.

For more information about the content of this report, please visit the COE CST web site at www.coe-cst.org. Please address any questions or corrections to Dr. Ken Davidian, 202-267-7214, ken.davidian@faa.gov.

- December 31, 2018

INTRODUCTION

This executive summary accompanies a more detailed annual report of the FAA COE CST. The annual report volume will be available on the COE CST web site, www.coe-cst.org. The full report provides a description of the FAA COE CST including its research, structure, member universities, funding, and research tasks, a comprehensive set of presentation charts of each research task, and a comprehensive set of notes and links to recordings from all FAA COE CST teleconferences and face-to-face meetings.

The Executive Summary begins with overviews of the FAA Office of Commercial Space Transportation (the sponsoring organization), the FAA COE Program and the COE CST. The COE CST became operational on August 18, 2010, with nine members. It has subsequently added an additional core



university, as well as numerous Affiliate and Associate organizations, representing both academia and industry.

Brief introductions and general descriptions are provided for each of the COE CST Member Universities, the Affiliate Members, and the FAA Technical Monitors for the COE CST research tasks.

Next, this document describes the overall scope of COE CST research areas, and lists each of the research tasks initiated, conducted and concluded by the COE CST during the eighth year of operation. Finally, the report provides summary information about each task in the form of quad charts.

The Executive Summary concludes with a listing of the COE CST students, the partnering institutions from industry, the research organizations, and the technical publications delivered during the year.

OVERVIEWS

FAA OFFICE OF COMMERCIAL SPACE TRANSPORTATION

Despite its relatively small size, the FAA Office of Commercial Space Transportation (AST) has an important set of responsibilities as described in their mission and defined in the Code of Federal Regulations, Title 51 US Code Subtitle V, Ch. 509. The two main goals of AST are:

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

FAA CENTER OF EXCELLENCE PROGRAM

The FAA Air Transportation Centers of Excellence (COE) program was established by the Omnibus Budget Reconciliation Act of 1990, PL 101-508, Title IX, Aviation Safety and Capacity Expansion Act. The text of this legislation is provided on the inside back cover of this report.

COEs are intended to be multi-year, multi-disciplinary partnerships of academia, industry, and government to combine world-class resources that will address current and future challenges for the aviation and aerospace communities, including commercial space transportation. The main goals of every COE include research, training & education, and technology transfer & outreach.

The absolute uniqueness of the program partnerships is the mandatory one-to-one matching requirement for every federal dollar granted to a COE university to establish, operate and conduct research. The matching requirement can be satisfied through direct or in-kind contributions from any non-federal funding source, including industry, universities, or state and local government organizations. COE efforts which are jointly supported provide the U.S. citizens a return on their tax dollars. To date, the COE members have generated more than \$312M in matching contributions to offset the research costs incurred by the government organizations.

In addition to the COE CST, there are currently five more active FAA COEs, including:

- **The Center of Excellence for Technical Training and Human Performance (TTHP)** (on the web at coetthp.org), was established in 2016. The core focus of the COE for TTHP includes curriculum architecture, content management and delivery, simulation and part task training, human factors, analytics, safety, and program management. Core members include Auburn University, Drexel University, Embry-Riddle Aeronautical University (technical co-lead), Inter American University, Oklahoma State University, Purdue University, Tennessee State University, the Ohio State University, the University of Akron, the University of Oklahoma (technical co-lead), Tulsa Community



College, University of Nebraska-Omaha, University North Dakota, University of Wisconsin – Madison, Western Michigan University, and Wichita State University (administrative lead).

- **The Center of Excellence for Unmanned Aircraft Systems (UAS)**, aka the “Alliance for System Safety of UAS through Research Excellence” (ASSURE, on the web at www.assureuas.org), was established in 2015. The core focus of the COE UAS includes air traffic integration, airworthiness, control and communication, detect and avoid, human factors, and low altitude operations safety. Core members include Mississippi State University (Lead), Drexel University, Embry-Riddle Aeronautical University, Kansas State University, Montana State University, New Mexico State University, North Carolina State University, Oregon State University, University of Alabama – Huntsville, University of Alaska – Fairbanks, University of California Davis, University of Kansas, University of North Dakota, The Ohio State University, Wichita State University, and Auburn University.
- **The Center of Excellence for Alternative Jet Fuels and Environment (AJFE)**, also known as the “Aviation Sustainability Center, (ASCENT, on the web at ascent.aero), was established in 2013. The core focus areas of ASCENT include alternative jet fuels: feedstock development, processing and conversion, regional supply and refining infrastructure, environmental benefits analysis, aircraft component deterioration and wear, fuel performance testing, environment: aircraft noise and impacts, aviation emissions and impacts, aircraft technology assessment, environmentally and energy efficient gate-to-gate aircraft operations, and aviation modeling and analysis. Core members include Washington State University (Lead), Massachusetts Institute of Technology (Co-lead), Boston University, Georgia Institute of Technology, Missouri University of Science & Technology, Oregon State University, Pennsylvania State University, Purdue University, Stanford University, University of Dayton, University of Hawaii, University of Illinois – Champagne Urbana, University of North Carolina – Chapel Hill, University of Pennsylvania, University of Tennessee, and the University of Washington.
- **The Center of Excellence for General Aviation**, aka the “Partnership to Enhance General Aviation Safety, Accessibility and Sustainability” (PEGASAS, on the web at www.pegasas.aero), and established in 2012. Major areas of focus include the enhancement of general aviation safety, accessibility, and sustainability by partnering the FAA with a national network of world-class researchers, educators, and industry leaders. Core members include Purdue University (lead), Florida Institute of Technology, Georgia Institute of Technology, Iowa State University, the Ohio State University, and Texas A&M University.
- **The Joint Center for Advanced Materials, (JAMS)**, in operation since 2003, works closely with industry and government agencies on safety and certification initiatives that are related to existing and near- and long-term applications of composites and other advanced materials and manufacturing processes to aircraft applications, including large transport commercial aircraft, general aviation and unmanned aircraft system products. The overall goal is to ensure safe and reliable use of these materials in aircraft applications. Lead universities are Wichita State University and the University of Washington supported by University of Utah, Oregon State University, Florida International University, and University of California, San Diego.

Other COEs established by the FAA, who have completed their ten-year agreements and phased out of operation, include:

- The Joint Center for Computational Modeling of Aircraft Structures, 1992 to 1996.
- The Center of Excellence for Airport Technology (CEAT), established 1995.
- The National COE for Aviation Operations Research (NEXTOR), operated from 1996 to 2008.
- The Airworthy Assurance COE (AACE) operated from 1997 to 2007.
- The COE for General Aviation Research (CGAR), in operation from 2001 to 2013.



- The Partnership for Aircraft Noise & Aviation Emissions Mitigation Research (PARTNER), in operation from 2003 to 2014.
- The Airliner Cabin Environment and Intermodal Research (ACERite) Center, in operation from 2004 to 2014.

FAA CENTER OF EXCELLENCE FOR COMMERCIAL SPACE TRANSPORTATION

Below is a quick look at the major highlights and special mentions of COE CST year eight. The basic metrics of COE CST performance has also been updated to reflect the most recent events and activities.

COE CST YEAR 8 HIGHLIGHTS

The following are the major milestones for the FAA COE CST during its eighth year:

- **The Eighth Annual Administrative Meeting (AAM8)** was held in Washington, DC, on February 5, 2018. During this meeting, many administrative topics were discussed. Most notably, Dr. Jim Vanderploeg (from the University of Texas Medical Branch at Galveston) stepped down as the COE CST Executive Director, and a vote was taken that replaced him with Dr. Dave Klaus (from the University of Colorado Boulder).
- **New Space** (the official journal of the COE CST) completed its sixth year, featuring a wide range of topics pertaining to non-governmental aspects of space activities. *New Space* volume 6, issue 1 consisted entirely of COE CST research publications (cover shown in figure right).
- **Research Area Workshops** – A new initiative for 2018 was the execution of separate workshops that focused on each of the four research areas. During the 2018 calendar year, these meetings were conducted for research area 1 (Space Traffic Management & Spaceport Operations), 2 (Space Transportation Vehicles Technologies), and 3 (Human Spaceflight). Despite extensive planning, the workshop for research area 4 will be held during the 2019 calendar year due to unavoidable scheduling conflicts.



COE CST YEAR 8 METRICS

Every year, COE CST performance is tracked through the measurement of basic metrics, including the number of active research tasks (a function of the level of funding available from the FAA AST), the number of principal investigators (an indicator of COE CST's research diversity), the number of students (an indicator of COE CST's impact), the number of publications (an indicator of the degree of COE CST knowledge creation). The number of unfunded tasks, research partners, industry partners, affiliate members, and associate members, are all a function of how well member universities are partnering with non-member research organizations. Finally, the amount of funding is provided for each fiscal year.

In year 8 of COE CST operation, 22 principal investigators (PIs) and 38 students conducted 27 research tasks, resulting in 34 technical publications (and patents not reported in previous COE CST Executive Summaries). This Executive Summary presents summary charts (aka "quad charts") for each research task, and then provides a complete list of students and the publications resulting from this work.

Due to changes in the funding concurrence processes, no awards of research funding appropriated in fiscal year 2018 (FY18) were made. The table below, therefore, shows only the total funding through



COE CST Metrics	Year 1 (FY10)	Year 2 (FY11-12)	Year 3 (FY13)	Year 4 (FY14)	Year 5 (FY15)	Year 6 (FY16)	Year 7 (FY17)	Year 8 (FY18)
Active Tasks	34	24	28	28	36	22	14	27
Unfunded Tasks	34	22	22	11	6	5	2	5
Principal Investigators	27	28	29	25	31	22	21	22
Students	31	37	55	47	61	28	23	38
Publications	0	38	28	22	29	19	36	34
Affiliate Members	0	1	6	6	6	6	8	10
Associate Members	-	-	-	3	6	3	3	8
Funding Profile	\$2M	\$2.4M	\$1.1M	\$1.1M	\$1M	\$1M	\$1.4M	NA
Administrative Overhead	13.6%	20.0%	9.9%	27.0%	19.7%	16.4%	15.1%	NA

FY17. Two rows of information included in previous years, Research Partners and Industry Partners, were omitted this year, due to an increasingly uncertainty of how to categorize specific organizations in one category or the other. Over these first eight fiscal years, the average annual administrative costs were just under 15% of the total budget. On the basis of six operating years (since year 2 is a combination of two fiscal years), the average is under 18%. The observed uneven distribution of administrative costs over the course of eight years stems from the timing of actual payments (e.g., paying for three bi-annual meetings from a single fiscal year's budget, instead of two).

All information presented in this report is accurate as of the date of publication (February, 2019). Any corrections identified after this date will be included in the comprehensive COE CST Annual Report and on the COE CST web site.

FAA AST TECHNICAL MONITORS

FAA AST Technical Monitors (TMs) are the links between FAA's research requirements and the work being performed by COE CST member universities. Below is a listing of the FAA COE CST TMs who contributed to the research efforts of the COE CST in year 8:

- Dr. Ken Davidian, Program Manager¹
- Mr. Nickolas Demidovich¹
- Mr. Steph Earle¹
- Mr. Henry Lampazzi²
- Ms. Karen Shelton-Mur¹
- Mr. John Sloan³
- Mr. Gunther Smiley⁴
- Dr. Paul Wilde¹

COE CST MEMBER ORGANIZATIONS

The COE CST member organizations include three categories of organizations: member universities, affiliate member organizations, and associate member organizations. Member universities in 2018 include the Baylor College of Medicine (BCM), Florida Institute of Technology (FIT, or Florida Tech), Florida State University (FSU), New Mexico Institute of Mining and Technology (NMT, or New Mexico Tech), New Mexico State University (NMSU), Stanford University (SU), University of Central Florida (UCF), University of Colorado at Boulder (CU), University of Florida (UF), and the University of Texas Medical Branch at Galveston (UTMB).

¹ FAA AST Office of Advanced Programs and Innovation

² FAA AST Licensing & Evaluation Division

³ FAA AST Office of Strategic Operations

⁴ FAA AST Space Transportation Development Division



MEMBER UNIVERSITIES

The COE CST member universities provide a comprehensive distribution of geographical coverage representing the entire Commercial Space Transportation industry, including the top four civil space states (California, Colorado, Texas, and Florida) and New Mexico, the state leading the suborbital industry as well as having a significant level of military space activity. As a single entity, the COE CST member universities bring complementary strengths together for the benefit of the overall COE. FAA finds that each team member provides highly respected and accomplished experiences that directly address the research and study needs of the commercial space industry. Combined, the universities bring a large number of government, industry, and academic organizations into the COE CST network as research partners.

THE BAYLOR COLLEGE OF MEDICINE (BCM)

The Baylor College of Medicine (BCM) is home to the Center for Space Medicine (CSM). The CSM is the only academic department/center in space medicine at any university or medical school. Established in 2008, it has over 70 members and 15 interdisciplinary faculty members. It offers a unique and popular four-year Space Medicine Track and awarded (with Neuroscience) its first Ph.D. in space medicine in 2015. BCM CSM was awarded a \$246M NASA cooperative agreement in 2016 to lead a 12-year Translational Research Institute in collaboration with Caltech and MIT. BCM CSM is recognized as the leading academic space medicine research and education program in the world. Expansion plans for BCM CSM include a new Initiative called the Aerospace Medicine (ASM) program within the CSM. The CSM-ASM program will include membership in the FAA COE CST, new aerospace medicine clinical activities, enhanced educational activities, and expanded research programs. The result will be an unprecedented cutting-edge international center of excellence, combining research, education and clinical practice in aviation and space medicine. BCM CSM will be the go-to place in the world where space and medicine come together.



FLORIDA INSTITUTE OF TECHNOLOGY (FLORIDA TECH)

Florida Institute of Technology performs doctoral research and undergraduate and graduate education through its six academic colleges and schools with emphases on aviation, aeronautics, science, technology, engineering and mathematics. Research at Florida Tech focuses on mechanical and aerospace engineering, software and hardware resilient systems, biomedical engineering, space resource utilization, corrosion and space-related engineering, cloud physics and space weather, space traffic management and launch operations, vehicle and payload analysis and design, thermal systems, propulsion, and commercial space industry viability. Florida Tech serves as the primary COE CST liaison to industry for research partnership, and affiliate membership to the government, the private sector as well as academia. Historically known as FIT, Florida Tech's preeminent research centers and institutes include the Buzz Aldrin Space Institute, the FAA Center of Excellence for General Aviation Research (PEGASAS), the FAA Center of Excellence for Commercial Space Transportation (COE CST), the School of Human-Centered Design, Innovation & Arts, the Harris Institute for Assured Information, and more.



FLORIDA STATE UNIVERSITY (FSU)

FSU brings a range expertise and unique infrastructure and unparalleled testing facilities in many areas relevant to the COE CST. These include but are not limited to: cryogenics, thermal management, vehicle aerodynamics and controls, sensors, actuators, system health monitoring and high-performance simulations including multi-physics mechanics and flow surface interactions. We have substantial expertise in

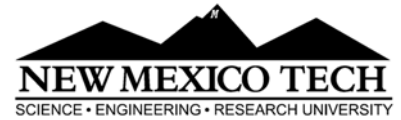




simulating, experimentally and numerically, the Vehicle Launch Environment and the associated challenges in aeroacoustics and aero-structures.

NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY (NMT)

NMT is a science, math and engineering university that has more than a dozen research divisions that work with private industry, government agencies and other universities. The research divisions include the Petroleum Research and Recovery Center, the Institute for Complex Additive Systems Analysis, the Energetic Materials Research Testing Center, the world’s largest lending library of seismology equipment, the Magdalena Ridge Observatory, the National Center for Genome Resources, the National Cave and Karst Research Institute, and the Langmuir Laboratory for Atmospheric Research.



NEW MEXICO STATE UNIVERSITY (NMSU)

NMSU and its Physical Sciences Laboratory have led space and aerospace research in areas of suborbital investigations from the time of Robert Goddard and Werner von Braun to the current era of commercial sub-orbital space transportation with Spaceport America and its operators, Virgin Galactic, UP Aerospace, and EXOS Aerospace. New Mexico Space Grant Consortium, the 21st Century Aerospace Space Group and related aerospace research focuses on annual access to space for student and faculty experiments, unmanned aerial vehicles, and cube-satellite development.



STANFORD UNIVERSITY (SU)

SU brings a 50-year history of aerospace research excellence and a broad scope of expertise to the COE CST, including the optimization and autonomous operation of complex systems, strategic research planning, organizational integration and distributed administration experience.



UNIVERSITY OF CENTRAL FLORIDA (UCF)

UCF, as partners of Florida Center for Advanced Aero-Propulsion (FCAAP) and the Center for Advanced Turbines & Energy Research (CATER), offers its experience and expertise in thermal protection system, propulsion system components, cryogenic systems and materials, composites, sensors and actuators, and guidance and control.



UNIVERSITY OF COLORADO AT BOULDER (CU BOULDER)

CU offers the COE CST their experience in spacecraft life support systems and habitat design, spaceflight risk assessment, human factors engineering analysis, payload experiment integration, and expertise in space environment and orbital mechanics.



UNIVERSITY OF FLORIDA (UF)

UF has been performing aeronautical and aerospace research since 1941, with current emphasis in the Department of Mechanical and Aerospace Engineering on research in space systems, MEMS, computational sciences, structural dynamics, controls, gas dynamics, and propulsion.



UNIVERSITY OF TEXAS MEDICAL BRANCH (UTMB)

UTMB has a long history of medical support and human spaceflight physiological research with NASA. UTMB doctors have been involved in the commercial orbital





and suborbital spaceflight industry, supporting space flight participant visits to the ISS, and preparing passengers and crew for suborbital space flights.

Two universities are currently working with COE CST member universities as “subcontractor researchers.” These universities are listed and described below.

UNIVERSITY OF SOUTHERN CALIFORNIA (SUBCONTRACTED TO FLORIDA TECH)



The University of Southern California, Lloyd Greif Center for Entrepreneurial Studies, within the Marshall School of Business, offers a wide range of courses in entrepreneurship designed for students who want to start or own a high-growth business, join an emerging business or participate in an entrepreneurial venture in a mature corporation (intrapreneurship). Students can develop an entrepreneurial mindset, gain confidence that they can be successful entrepreneurs, learn about the entrepreneurial process and enhance their conceptual and practical skills to pursue new business opportunities. Wide exposure is given to all types of entrepreneurs and industries. The highly experiential courses span the entrepreneurial process from opportunity discovery to venture initiation, growth and exit, and are designed to teach relevant frameworks and theory as well as to develop an entrepreneurial mindset and skills through hands-on application. The Greif Center also offers co-curricular programs such as venture competitions, speaker events and a new venture incubator, and it actively provides contact with and support for its alumni. More information can be found on the web at the following URL: www.marshall.usc.edu/departments/lloyd-greif-center-entrepreneurial-studies

UNIVERSITY OF TEXAS AT AUSTIN (SUBCONTRACTED TO NMSU)



The Cockrell School of Engineering at The University of Texas at Austin is a top-ranked epicenter of engineering education, and knowledge creation and distribution. Comprised of renowned educators, researchers and thought leaders, the Cockrell School addresses the grand challenges of the world, drives economic progress and improves quality of life. The Cockrell School educates future engineering leaders who think creatively, work collaboratively, and push technological boundaries; develops innovative solutions through groundbreaking research; and improves lives throughout the world by leveraging the school’s entrepreneurial ecosystem and partnerships with industry to translate research into practice. More information can be found on the web at the following URL: <http://www.engr.utexas.edu/about>

Affiliate & Associate Members

With a limited budget and ever-tightening budget pressures on all federal agencies, the COE CST sponsoring organization, FAA AST, cannot provide funding to all the research universities and organizations that deserve it. In recognition of all the meaningful work being done outside the COE CST membership, two different mechanisms were developed to encourage membership in the COE CST without incurring any additional budget obligations. The two different mechanisms that encourage a growing membership roster are called Affiliate and Associate membership. Each of these is described below.

AFFILIATE MEMBER ORGANIZATIONS

To become a COE CST Affiliate Member, an organization must (a) be conducting research that is self-funded, or is funded by some organization other than FAA AST, that fits within the commercial space transportation road map framework (discussed below), and that can be openly disclosed at COE CST public meetings, such as the Annual Technical Meeting (ATM), (b) partner with one of the current COE CST member universities who will act as the Affiliate’s ‘host,’ and (c) voluntarily pay for all costs



associated with attendance at the ATM. In exchange for these commitments, the COE CST will (a) welcome the organization as an Affiliate Member, (b) provide the Affiliate Member with “podium time” at the ATM, equal to that provided to any full COE CST member. The strategy of Affiliate Membership is to gain benefits derived from being part of the overall COE CST research network. As the network grows, so do the possible benefits that can be gained.

To date, there have been a number of COE CST Affiliate Members. Some joined in the early years of COE CST operation, and have been inactive in recent years, some have been active since the program began, and some are just now “knocking on our door,” ready to become members in the near future. Below is a brief description of these Affiliate Member organizations.

CARMINATI LAW PLLC (AFFILIATED WITH CU BOULDER)

Carminati Law, PLLC, is a Denver-based law firm whose practice includes space law. Its head, Dr. Maria-Vittoria Carminati, is head of the American Bar Association’s space law committee. She obtained her JD from the University of Houston, and her LLM in space, cyber, and telecommunications law from the University of Nebraska-Lincoln. More information can be found on the web at the following URL: legaltalknetwork.com/guests/dr-maria-vittoria-carminati

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY (AFFILIATED WITH NMSU)

Embry–Riddle Aeronautical University (ERAU) is a private university offering associate through doctoral degrees in arts and sciences, aviation, business, engineering, computer programming, cyber security and security and intelligence. It is the largest, fully accredited university system specializing in aviation and aerospace, with main campuses in Daytona Beach, Florida and Prescott, Arizona. More information can be found on the web at the following URL: erau.edu



MCGILL UNIVERSITY (AFFILIATED WITH FLORIDA TECH)

McGill University’s Institute of Air and Space Law (IASL) is the world’s premier academic setting for teaching and research in the dual disciplines of international air law and space law. Having celebrated its 65th year of continuous existence in 2016, the Institute is now on course to consolidate and enhance its record of achievement in the five years leading to its 70th anniversary in 2021, the same year that McGill University itself will turn 200. More information can be found on the web at the following URL: www.mcgill.ca/iasl/



ETC NASTAR (AFFILIATED WITH UTMB)

Environmental Tectonics Corporation’s (ETC) National Aerospace Training and Research (NASTAR) Center (est. 2007) is the premier commercial air and space training, research, and educational facility. It combines state-of-the-art flight simulation with physiology-based courseware to optimize human performance in extreme environments. ETC’s NASTAR Center is unique in that it serves as the only non-government (commercial use) facility for the application of acceleration and G force exposure in the world and specializes in replicating high-performance flight environments and characteristics of aerial vehicles. This exclusive capability is ideal for safely modeling nominal and off-nominal (emergency) trajectories and evaluating human performance for military, commercial aviation, and spaceflight clients. The NASTAR Center actively collaborates with numerous agencies including NASA, FAA, JAA, etc. to promote safety in flight.. More information can be found on the web at the following URLs: www.etcusa.com and www.nastarcenter.com





IMMORTAL DATA (AFFILIATED WITH NEW MEXICO TECH)

Immortal Data is targeting the aerospace field, where ruggedness, reliability and high data rates for bulk data are more important than fancy GUIs. They are designing the central nervous system of a ship or engines under test or in harsh, real world environments containing huge volumes of high rate data. Accomplishing this means that, for the most part, they do not sell software on its own; they sell it as a pre-installed hardware/software appliance, preferably as part of a systems solution. More information can be found on the web at the following URL: www.immortaldata.net

OHIO STATE UNIVERSITY (AFFILIATED WITH FLORIDA TECH)

The Aerospace Engineering Program at Ohio State offers BS, MS, and PhD degrees in Aeronautical and Astronautical Engineering (AAE). The AAE program, which was originally founded in 1948, has gained national visibility in the aerospace engineering community. The program is designed to prepare students for successful careers in a variety of specialty areas associated with the application aeronautical and astronautical engineering. Ohio State is centrally located in relation to three major national aerospace powerhouses: NASA Glenn Research Center, the Air Force Research Laboratory, and GE Aviation. More information can be found on the web at the following URL: mae.osu.edu/aerospace



**THE OHIO STATE
UNIVERSITY**

BATTELLE CENTER FOR SCIENCE, ENGINEERING, AND PUBLIC POLICY (AFFILIATED WITH FLORIDA TECH)

The Battelle Center was established at the John Glenn College of Public Affairs in 2006 through the generosity of Battelle, the world's largest non-profit research and development organization and long-time neighbor to The Ohio State University.

Originally the Battelle Center focused on improving education in science, technology, engineering, and mathematics disciplines. In 2011, it pivoted toward the challenges of encouraging innovation and economic development. In 2016, the partnership between Battelle and the Glenn College was strengthened with the inclusion of Ohio State's College of Engineering in the center. Today, these organizations and Ohio State's Government Affairs Office provide advice and support to the center's director. Click here to read more about some of our activities. More information can be found on the web at the following URL:



**THE OHIO STATE
UNIVERSITY**

BATTELLE CENTER FOR SCIENCE,
ENGINEERING, AND PUBLIC POLICY

SOLSTAR (AFFILIATED WITH NMSU)

Solstar's vision is to become the space based internet service provider of choice (ISP) bringing the Internet of Things to every machine and person in Earth orbit and beyond.

Solstar's mission is to build/create the tools necessary to enable 24/7 secure, economical, convenient, two-way, internet-based communications with every "thing" in space, to be the ISP of choice in Earth Orbit and beyond. Our tools and services include: Harnessing the power of the very best existing infrastructure to facilitate constant communication with space assets such as SmallSats, astronauts, LEO platforms, suborbital/orbital spacecraft, and eventually Lunar and Mars exploration; Revolutionizing the way people on Earth communicate and interact with their payloads in space; Professionalizing the way the results of space research are communicated and conducted from space to the ground and back again; Protecting valuable space assets through enhanced two-way communication opportunities for troubleshooting, diagnosing, and resolving issues; Providing reliable emergency backup communications for people and things in space; and Providing 24/7 customer service to payloaders/researchers previously not available to the market.



Solstar Space Co.



SOVARIS AEROSPACE (AFFILIATED WITH CU BOULDER)

Sovaris Aerospace is among those leading the advancement of personalized medicine in human spaceflight, with a focus on suborbital, LEO, Lunar, and Mars. As a clinical support organization, Sovaris applies the tools of complex molecular analytics to develop personalized countermeasures that are tailored to each individual entering an extreme environment. Our team has refined these methods via deployment with military Special Forces, S.W.A.T., wilderness medicine, high altitude ascent, Olympic training environments, and others. As a clinical research organization, the Sovaris team incorporates genomics, epigenomics, transcriptomics, proteomics, metabolomics, and microbiomics into the study of humans in space (e.g. NASA Twins Study) or space analog conditions, with a goal of developing novel countermeasures for future spaceflight. More information can be found on the web at the following URL: www.sovaris-aerospace.com



UNIVERSITY OF NORTH FLORIDA (AFFILIATED WITH NMSU)

Established in 1972, the University of North Florida has grown significantly in size and prominence - particularly in recent years. Today, UNF has an annual economic impact of more than \$1 billion and works closely with community leaders and officials to continue to enhance the significant role it plays in the region. The UNF campus, which includes a nature preserve, beautiful lakes and nature trails, is located between downtown Jacksonville and the Atlantic Ocean in a bustling section of Jacksonville. It includes award-winning buildings filled with state-of-the-art equipment that support innovation and excellence. The University is home to six colleges, and routinely ranks high for quality and value on national lists published by U.S. News & World Report, Forbes, the Princeton Review, Wall Street Journal and more. UNF holds the prestigious Carnegie Classification for Community Engagement recognizing our commitment to our community and beyond. More information can be found on the web at the following URL: www.unf.edu



ASSOCIATE MEMBER ORGANIZATIONS

Associate Members are much more loosely associated with the COE CST, but their contributions can be very significant. During the eighth year of operation, the COE CST was proud to have the following institutions as Affiliate Members.

ASTM INTERNATIONAL

Committed to serving global societal needs, ASTM International positively impacts public health and safety, consumer confidence, and overall quality of life. They integrate consensus standards, developed with our international membership of volunteer technical experts. Over 12,000 ASTM standards operate globally. Defined and set by ASTM International, the standards improve the lives of millions every day. More information can be found on the web at the following URL: www.astm.org



COMMERCIAL SPACEFLIGHT FEDERATION

The Commercial Spaceflight Federation (CSF) is the leading voice for the commercial spaceflight industry. Founded in 2006, CSF and its 80+ members are laying the foundation for a sustainable space economy and democratizing access to space for scientists, students, civilians, and businesses. CSF members are responsible for the creation of thousands of high-tech jobs driven by billions of dollars in investment. Through the promotion of technology innovation, CSF is guiding the expansion of Earth's economic sphere, bolstering U.S. leadership in aerospace, and inspiring America's next generation of engineers and explorers. The mission of the Commercial Spaceflight Federation (CSF) is to promote the development of commercial human





spaceflight, pursue ever-higher levels of safety, and share best practices and expertise throughout the industry. More information can be found on the web at the following URL: www.commercialspaceflight.org

GERMAN AEROSPACE CENTER (DLR)

The German Aerospace Center (DLR) is the national aeronautics and space research center of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport, digitalization and security is integrated into national and international cooperative ventures. In addition to its own research, as Germany's space agency, DLR has been given responsibility by the federal government for the planning and implementation of the German space program. DLR is also the umbrella organization for one of Germany's largest project management agencies. DLR has approximately 8000 employees at 20 locations in Germany. DLR also has offices in Brussels, Paris, Tokyo and Washington D.C. More information can be found on the web at the following URL: www.dlr.de



EXOS AEROSPACE SYSTEMS & TECHNOLOGIES

EXOS Aerospace Systems & Technologies, Inc. has taken the skills from more than a decade of practical lessons learned, and millions of dollars' worth of development and flight experience gained by their team, and moved into the commercial space race, ahead of the game. Over the past decade, the team at EXOS has led the way to some of the most impressive private, commercial, reusable rockets designs and concepts in the world today. They have developed, flown and retrieved for re-use, rockets that are reliable, reusable, better for the environment and easier on your budget. They have successfully designed, built and flown rocket engines used in manned flight. They have fulfilled multiple contracts with NASA. Through all of this, the EXOS team has developed and tested over a hundred rocket engines and dozens of flying vehicles. EXOS is a leading developer and operator of reusable space vehicles. More information can be found on the web at the following URL: exosaero.com



MIT LINCOLN LABS

MIT Lincoln Laboratory researches and develops a broad array of advanced technologies to meet critical national security needs. What sets them apart from many national R&D laboratories is their focus on building operational prototypes of the unique systems they design. MIT Lincoln Labs have stretched the capabilities of technology ever since the Laboratory's establishment in 1951 as a federally funded R&D center managed by MIT for the Department of Defense. During the 1950s development of the nation's first air defense system, their researchers pioneered the use of computers for data analysis and transformed the future of computing. Today, they continue to explore new applications of technology that can help keep our nation safe and aid in international humanitarian efforts. More information can be found on the web at the following URL: www.ll.mit.edu



THE MITRE CORPORATION

As a not-for-profit organization, MITRE works in the public interest across federal, state and local governments, as well as industry and academia. MITRE operates federally funded research and development centers, FFRDCs, unique organizations that assist the United States government with scientific research and analysis; development and acquisition; and systems engineering and integration. MITRE also has an independent research program that explores new and expanded uses of technologies to solve our sponsors' problems. More information can be found on the web at the following URL: www.mitre.org



NASA (HEADQUARTERS AND AMES RESEARCH CENTER)

NASA Headquarters, in Washington, provides overall guidance and direction to the agency, under the leadership of the Administrator. Ten field centers and a variety of installations around the country conduct the day-to-day work in laboratories, on air fields, in wind tunnels, and in control rooms. To implement NASA's Mission, NASA Headquarters is organized into five principal organizations called Mission Directorates: Aeronautics, Human Exploration and Operations, Science, Space Technology, and Mission Support. NASA Ames Research Center, one of ten NASA field centers, is located in the heart of California's Silicon Valley. For more than 75 years, Ames has led NASA in conducting world-class research and development in aeronautics, exploration technology and science aligned with the center's core capabilities. More information can be found on the web at the following URL: www.nasa.gov and www.nasa.gov/ames



Below is a map of all the COE CST member universities, affiliate members, and associate members.



2018 Map of COE CST University, Affiliate, and Associate Membership

AWARDS AND RECOGNITION

The FAA is delighted to highlight the accolades given to our researchers as they work on projects related to the commercial space transportation industry.

2018 DARPA YOUNG FACULTY AWARD RECIPIENT: DR. SUBITH VASU⁵

University of Central Florida Engineering Professor Subith Vasu was recently awarded a \$1 million DARPA Young Faculty Award to help first responders and military personnel do their jobs while keeping them safe.

The three-year Defense Advanced Research Projects Agency grant will allow Vasu to develop a device that may look like a cross between a Star Trek phaser and a radar gun used to clock baseballs, based on early sketches. But this device would be used to detect deadly toxins that pose a threat to national security.



⁵ Text quoted from UCF Today news, by Zenaida Gonzalez Kotala, dated Wednesday, June 27, 2018. Full text is available on the web at the following URL: <https://today.ucf.edu/85621-2/>



The intelligent mobile sensor based on THz spectroscopy will be able to detect fentanyl and Carfentanyl, which are opioids that are 50-10,000 times more potent than heroin. When dispersed in the air, the chemicals can kill, even if the exposure is minimal. The sensor would be able to detect similar toxins, sometimes released in fires or explosions, which pose threats to first responders. These toxins can also be used in chemical warfare.

COE CST RESEARCH AREAS, GOALS, AND TASKS

All research activity sponsored by the FAA Office of Commercial Space Transportation is directed by the following goal statement: “Operators are fully capable and responsible to safely perform all aspects of commercial space transportation.” To achieve this goal, COE CST activity is defined by a framework defining different academic areas for every research task. Generally speaking, the four research areas encompass four distinct research domains: operational activities, the physical and engineering sciences, the biological and medical sciences, and the social sciences. A Commercial Space Transportation Research Road Map, last updated in 2015, is available on the web at www.coe-cst.org, and was created to provide a detailed framework within each of these discipline areas. This section provides a brief introduction to the four research areas, identifies the goals associated with each, and then lists the tasks that were conducted in each research area during the eighth year of COE CST operation.



UPDATED COE CST RESEARCH AREAS

As mentioned above, the research conducted within FAA AST is broken into four major academic disciplines. Each discipline is identified by a distinct research theme: Aerospace Access & Operations (formerly referred to as “Space Traffic Management & Spaceport Operations,” and formerly designated by the color red), Aerospace Vehicles (formerly referred to as “Space Transportation Vehicles Technologies,” and colored blue), Human Operations & Spaceflight (formerly referred to as “Human Spaceflight,” and colored green), and Industry Innovation (formerly referred to as “Space Transportation Industry Viability,” and designated by the color orange). Each of these research areas is divided into programs, and these are further divided into projects, topics, and tasks. The number of tasks conducted in each program can vary from year to year, and research is not necessarily conducted in all programs every year. Some research programs may have some number of tasks every year, and other programs may have never had



a research task funded over the entire life of the COE CST. The priorities of FAA AST are evaluated every year to make the final funding decisions.

Each research area has multiple goals, and these have been revisited during the past year. In FY17, research goals have been identified for each research area that correspond to each of the two AST mission goals (i.e., public safety, or industry promotion).

COE CST RESEARCH GOALS

The goals of the four commercial space transportation research areas are listed below in tabular form. The color scheme introduced above is adopted for the table of research goals, but with a subtle distinction: The darker shade of each color is associated with the public safety research goals, and the lighter shade of each color is associated with the promotional research goals.

Research Goals Applicable to AST's Public Safety Mission	Research Goals Applicable to AST's Industry Promotion Mission
Research Area 1. Aerospace Access & Operations	
<ul style="list-style-type: none"> Improved analytical and computational methods to evaluate safety of uninjured public and property. Situational awareness and understanding of risk posed by resident space objects. 	<ul style="list-style-type: none"> Safe and equitable sharing of the NAS by air and space transportation operators, with minimal disruption caused by commercial space traffic (outbound and inbound). Improved spaceport interoperability and development of necessary spaceport industry infrastructure resources.
Research Area 2. Aerospace Vehicles	
<ul style="list-style-type: none"> Improve vehicle safety and risk analyses and management, including knowledge of all safety-critical components and systems of the space vehicles and their operations. 	<ul style="list-style-type: none"> Improve the manufacturability, assembly, and operational efficiencies of space transportation vehicles, systems, and subsystems.
Research Area 3. Human Operations & Spaceflight	
<ul style="list-style-type: none"> Identification and reduction of avoidable risks of human spaceflight. 	<ul style="list-style-type: none"> Facilitate the continuous improvement of the operational safety of human-carrying vehicles (during both launch and reentry) and spaceports.
Research Area 4. Industry Innovation	
<ul style="list-style-type: none"> Develop improved criteria for evaluating public safety, such as performance based requirements for the protection of public property and critical assets. 	<ul style="list-style-type: none"> Encourage the growth of evolving space industry sectors through relevant economic, legal, legislative, regulatory, and market analyses & modeling. Support effective policy decision-making in the accomplishment of the dual regulatory and promotional missions of FAA AST. Provide a better understanding of the relationship of governmental policy, innovation adoption, and industry growth.



COE CST YEAR 8 RESEARCH TASKS

COE CST research tasks conducted in fiscal year 2018 in each of the four research areas are listed below and shown in the quad charts that follow. Most of the tasks were funded by the FAA AST to COE CST member universities, but also listed are research tasks conducted during this period by COE CST Affiliate and Associate members. (NB: Research tasks are frequently referred to by their task number, because the titles listed below and the titles given on the summary quad charts may not match exactly. Also, some tasks do not have an associated summary quad, and these are denoted with an asterisk.)

Research Area 1. Aerospace Access & Operations

- 186-CU, Mitigating Threats Through Space Environment Modeling & Prediction, Dr. Timothy Fuller-Rowell
- 186-SU, Space Environment Meteoroid and Orbital Debris Modeling & Prediction, Dr. Sigrid Close
- 331-SU, Advanced 4D Special Use Airspace, Dr. Mykel Kochenderfer
- 354-SU, Research Area 1 Workshop, Dr. Mykel Kochenderfer
- 367-CU, CubeSat Deployment Tracking, Dr. Penina Axelrad
- 371-NMSU-UTA, Ontology-based Space Object Database, Dr. Moriba Jah
- 372-CU, Resident Space Objects, Dr. Dan Scheeres
- 375-DLR (Associate), Interoperable Air and Space Traffic Management, Mr. Sven Kaltenhäuser
- 380-NMSU, Spaceport Operations Online Reference Guide, Dr. Patricia Hynes

Research Area 2. Aerospace Vehicles

- 241-FSU, High Temperature, Optical Sapphire Pressure Sensors, Dr. Billy Oates
- 253-UCF, Ultra-high Temperature Composites Thermal Protection Systems, Drs. Jan Gou & Jay Kapat
- 299-NMT, Nitrous Oxide Composite Case Testing, Drs. Bin Lim & Andrei Zagrai
- 307-NMSU/SolStar (Affiliate), Commercial Satellite Communications, Mr. Brian Barnett
- 311-UCF, Advancement of LED-Based Hazardous Gas Sensors for Space Applications, Dr. Subith Vasu
- 323-NMT, Structural Health Monitoring Framework, Dr. Andrei Zagrai
- 325-FSU, Optical Measurements of Rocket Nozzle Thrust and Noise, Drs. Rajan Kumar, Farrukh Alvi, & Jonas Gustavsson
- 359-NMSU/UNF (Affiliate), Relaying Communications from LEO to Earth Using GEO CommSats, Dr. Brian Kopp
- 368-UCF, Research Area 2 Workshop, Dr. Subith Vasu

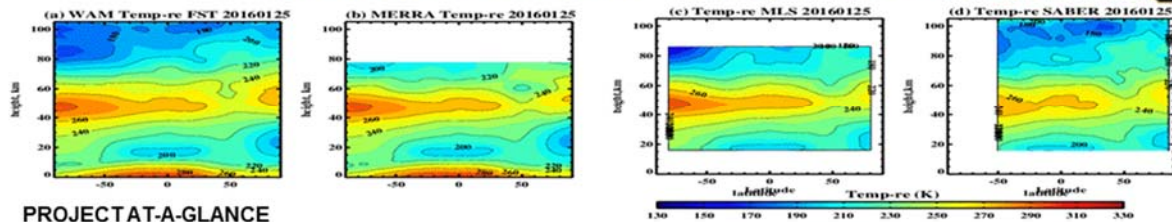
Research Area 3. Human Operations & Spaceflight

- 308-UTMB, Suborbital SFP Anxiety Assessment, Drs. James Vanderploeg, Rebecca Blue, Tarah Castleberry, Charles Mathers, and Johene Vardman
- 309-UTMB, Suborbital Pilot Training Assessment, Drs. James Vanderploeg & Tarah Castleberry
- 310-UTMB, Increasing Cabin Survivability in Commercial Spacecraft, Drs. Charles Mathers, James Vanderploeg, Tarah Castleberry, Rebecca Blue, & Leigh Speicher
- 353-CU, Design and Operational Considerations for Occupant Safety, Dr. David Klaus
- 353-FIT, Design & Operational Considerations for Occupant Safety, Dr. Ondrej Doule
- 373-CU, Research Area 3 Workshop, Dr. David Klaus

Research Area 4. Industry Innovation

- 376-MU-FIT (Affiliate), Legal Issues of Cross-Border Suborbital Flights, Dr. Ram Jakhu
- 378-FIT-USC, Commercial Space Research Center Initiative, Dr. Greg Autry

Task 186. Mitigating Threats Through Space Environment Modeling & Prediction



PROJECT AT-A-GLANCE

- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. Tim Fuller-Rowell
- AST RDAB POC: Karen Shelton-Mur

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- An integrated air and space traffic management system requires real-time knowledge of environmental conditions and their impact on flight conditions from the ground to 600 km altitude, including:
 1. Neutral density variability and structure for on-orbit collision avoidance, spacecraft drag, and atmospheric re-entry, and forecast of near-surface and space weather conditions
 2. Plasma density, D-region absorption, total electron content, ionospheric structure and irregularities, for impact on communications, navigation, and safety in flight

STATEMENT OF WORK

- Develop a seamless atmosphere-space model from the ground to 600 km altitude to fill gap between conventional weather and space weather conditions
- Develop terrestrial and space weather products tailored to suborbital and commercial space transportation needs
- Integrate terrestrial and space weather forecasts from one coordinated source

STATUS

- Past year's goal was to improve gravity wave parameterization and extend GSI data assimilation to 50-120 km altitude, to provide realistic winds, temperature, and density fields to predict the track of debris at sub-orbital and re-entry altitudes
- Gravity Wave (GW) physics and dynamics were tuned to bring seasonal/latitude thermal budget and temperature structure in agreement with observations
- NWS Gridpoint Statistical Interpolation (GSI) data assimilation scheme was extended to 100 km altitude with AURA MLS and SABER observations of temperature and composition to constrain WAM above the stratopause

FUTURE WORK

- Update real-time system, 2-way WAM-IPE coupling, optimize IPE and remove dependence on SMS, validate self-consistent electrodynamic, and use WAM/IPE fields to support CST.



Task 186. Space Environment Meteoroid and Orbital Debris Modeling & Prediction



PROJECT AT-A-GLANCE

- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR(S): Dr. Sigrid Close
- Co-I: Dr. Nicolas Lee
- STUDENT(S): Lorenzo Limonta

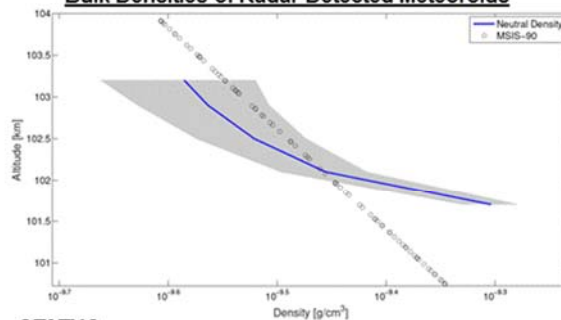
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- An integrated air and space traffic management system requires knowledge of the threat to objects in and entering Low Earth Orbit (LEO). LEO spacecraft are routinely struck by impactors, both human-made (space debris, posing a mechanical threat) and natural (meteoroids, posing a mechanical and electrical threat). Characterizing the impactor population through data analysis and modeling will help predict meteoroid and orbital debris (MOD) threat to the launch and operation of commercial LEO spacecraft.

STATEMENT OF WORK

- The research improves the current probability density functions that estimate the human-made and natural space debris and meteoroid environment by characterizing the meteoroid and orbital debris population. Research is conducted to determine the meteoroid bulk density function, identify scattering patterns based on the FDTD models, and determine neutral densities using meteoroids. Research on orbital debris includes filtering methods for larger satellite constellations, and the determination of debris propagation using near real time density data. Results from these activities are combined into a new threat assessment model.

Bulk Densities of Radar-Detected Meteoroids



STATUS

- Developed neutral density determination algorithm
- Developed improved ablation models to determine ionization efficiency
- Correlated ionization probability with luminous efficiency for improved meteoroid mass estimates
- Refined FDTD scattering model

FUTURE WORK

- Continue to improve fragmentation and ablation models to determine ionization and luminous efficiency
- Continue to develop orbit determination algorithms to correlate bulk density with source
- Develop probabilistic models for risk assessment



Task 331. Advanced 4D Special Use Airspace

PROJECT AT-A-GLANCE

- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR(S): Mykel J. Kochenderfer
- STUDENT(S): Rachael E. Tompa

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- During launches, a large segment of the airspace must be cleared to minimize safety risk, which has a significant impact on efficiency of commercial flights in the region, especially as launches become more frequent. One important challenge is minimizing the impact on commercial air traffic.

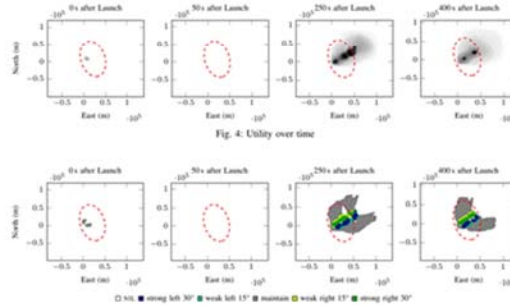
STATEMENT OF WORK

- Use a Markov decision process to create optimal rerouting policies for an aircraft during a commercial space launch.
- Use an inclusive and representative debris model to capture the inherent uncertainty of launch anomalies and provides encompassing rerouting regions.
- Simulation studies across diverse scenarios for various operational and safety metrics
- Introduce metering aircraft "in time" to avoid the launch hazard.
- Measure success against past aircraft rerouting and nominal aircraft trajectories using NASA's FACET.

STATUS

- Discretized framework is complete
- Debris model is robust
- Deep learning transition is ongoing

Rerouting Aircraft During a Launch



ECONOMIC IMPACT

- During the Falcon Heavy launch on Feb. 6, 2018, 563 flights were rerouted, estimated to cost airlines over \$300K.
- Each rerouted flight is estimated to result in a few thousand dollars of additional expenses in fuel, labor, and missed connections.

FUTURE WORK

- Complete deep learning transition to take advantage of the scalability capabilities
- Investigate metering action space

Task 354. Research Area 1 Workshop



Workshop hosted and co-sponsored by the MITRE Corporation

PROJECT AT-A-GLANCE

- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR(S): Mykel J. Kochenderfer
- STUDENT: Rachael E. Tompa

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- This workshop was conducted to educate the audience and stakeholders on current research the COE CST Research Area 1 while fostering discussion about new research ideas and collaboration.
- Research Area 1 focuses on safe and equitable sharing of the NAS by air and space vehicle operators, improved spaceport interoperability & development of spaceport industry infrastructure, situational awareness and understanding of risk by resident space objects, and increased understanding of the space environment.

STATEMENT OF WORK

- To ensure a comprehensive review of this research area is accomplished, representation will be solicited from various academic, industry and government partners working across the different topics noted above.
- The workshop was held at the MITRE Corporation with local and virtual attendance options.



STATUS

- The workshop, held February 6, 2018, was hosted by Prof. Kochenderfer and co-organized with Karen Shelton-Mur (FAA).
- The workshop was separated into a morning Session focused on Space Traffic Management and the Space Environment and an afternoon session focused on National Airspace/Commercial Space Integration and Spaceports.
- A total of 93 individuals from academia, government and industry responded to the invitation with interest in the event.

FUTURE WORK

- The results of this workshop will be used by the FAA to inform future research needs and strategic directions.

Task 367. CubeSat Deployment Tracking



Estimation of 88 clustered CubeSats

PROJECT AT-A-GLANCE

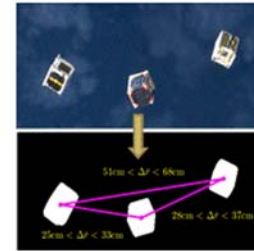
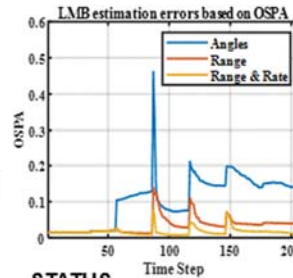
- UNIVERSITY: University of Colorado Boulder
- PRINCIPAL INVESTIGATOR(S): Penina Axelrad
- STUDENT(S): John Gaebler

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Clustered CubeSat deployments, where multiple CubeSats are released over a short time span will become more common as primary launch opportunities
- Rapid detection, tracking, and identification of individual CubeSats within the cluster presents new challenges
- Prompt establishment of accurate orbit estimates reduces the number of conjunction notices generated and provides longer mission life for the satellites.

STATEMENT OF WORK

- Focus on overall tracking and detection methodology including filtering algorithms, sensor scheduling, data fusion, navigation aids, and deployment strategies
- Preliminary simulations modeled after Indian PSLV-C37 mission launched in Feb 2017
- Various sensor configurations to be studied: sensor distribution, measurement types, quality and quantity
- Probabilistic multi-target filtering algorithms including the Cardinalized Probability Hypothesis Density (CPHD) and the Labeled Multi-Bernoulli (LMB) will be assessed



STATUS

- Enhanced simulations created using actual pre-launch and ground tracking data.
- LMB filter implemented and tested on this scenario.
- Work in progress for rigorous incorporation of observations with satellite identifiers and on-orbit imaging from deployer

ECONOMIC IMPACT

- Reducing the time to establish orbits/TLE's for CubeSats allows operators to more quickly begin their missions.
- In LEO, where lifetimes are measured in months, additional weeks/days contribute meaningfully to overall utility.
- Better orbit predictions, after closely spaced deployments, allow for more informed conjunction assessments, reducing unnecessary maneuvers and expenditure of limited fuel.

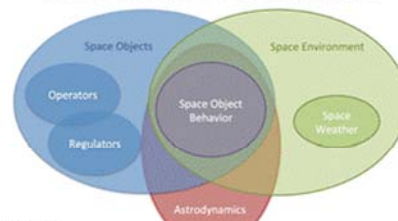
FUTURE WORK

- Demonstrate integrated filter w/ ambiguous & tagged meas.
- Demonstrate improvement expected with observations from deployer

Task 371. Ontology-based Space Object Database



Space Object and Event Behavior



PROJECT AT-A-GLANCE

- UNIVERSITY: University of Texas at Austin
- PRINCIPAL INVESTIGATOR(S): Moriba Jah, Ph.D., Maria Esteva, Unmil Karadkar
- STUDENT(S): Shiva Iyer, Jennie Wolfgang, Kathleen Kryusher, Michael Slovenski, Drew McNeely, Joseph Strassman

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Big data science and analytics solution to space traffic management.

STATEMENT OF WORK

- Take the initial steps to develop, implement, and federate a Space Traffic Management/Orbital Safety Data Lake. Set up an online searchable Digital Collection of these documents that is similar in capability to the Framework for Spaceport Operations.
- Motivate "citizen Science" where people can donate their own sensor/telescope data. Leverage Blockchain technology as a method of STM "cryptocurrency", authentication/identification, and transparent transaction records
- Put together a collection of Open Source Software that can be used to support and enable space traffic management and orbital safety analyses and products. Gather tools like GMAT, Orekit, Tensor Flow, and others that are currently Open Source and leverage those to serve the needs of STM/Orbital Safety

STATUS

- Autonomously retrieves and processes multiple sources of information and updates a knowledge graph database accessible on the web at: <http://astria.tacc.utexas.edu/AstriaGraph>
- Implemented in NEO4J
- Developed open-source orbit determination capability within OREKIT

ECONOMIC IMPACT

- Strive to provide an open and accessible layer of orbital safety service to the global community (like GNSS) upon which space activities and commerce can thrive.

FUTURE WORK

- Incorporating Computation Behavioral and Social Science for Cultural Context and Competency
- Implement more realistic uncertainty quantification
 - Difference between parameter knowledge driven by randomness versus ignorance



Task 372. Resident Space Object System Mechanics



Accurate fit of large spin period fluctuations in defunct GOES-8 satellite by modeling solar radiation pressure effects

PROJECT AT-A-GLANCE

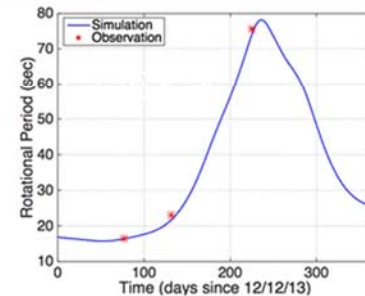
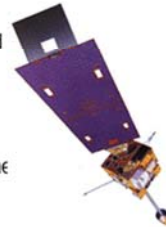
- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. Dan Scheeres
- STUDENT RESEARCHERS: Recent PhD students supported by this task: CK Venigalla, M. Pellegrino, and J. Greaves.

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Orbit debris remains a fundamental issue for all aspects of space utilization. Specific challenges remain in performing long-term forecasts for specific pieces of orbit debris. While the population of debris is relatively well understood — research advances continue to open new windows on this population.

STATEMENT OF WORK

- Effective space situational awareness faces the challenge of bringing together observations from disparate sensors and sources, developing computationally efficient dynamic propagation schemes for orbits and their uncertainty distributions, and formulating accurate estimation methods for the purpose of quantifying and qualifying space-based activities.
- Maximize the information extracted from usual sources of SSA data (minimize uncertainty)
- Identify how data should be collected to maximize information content (maximize efficiency)
- Recover and predict the space domain with more accuracy
- Timely estimation of the space-based environment to create actionable information.



PREVIOUS WORK

- Graduated two FAA-funded PhD students: Kohei Fujimoto, May 2013 & In-Kwan Park Fall 2015, started work with others
- Have a large combined student team focused on relevant SSA research topics of direct interest to the COE
- Presented over 34 distinct papers at 20 conferences
- Over 13 papers published with more in peer review

CURRENT WORK

- Current stage of direct FAA funded research is focusing on predicting space object orbits accounting for uncertainty, improving models for characterizing their dynamics as subject to non-gravitational forces, and investigating optimal evasion maneuvers given a non-zero impact probability.

Task 375. Interoperable Air and Space Traffic Management



PROJECT AT-A-GLANCE

- DLR German Aerospace Center, Institute of Flight Guidance
- PRINCIPAL INVESTIGATOR: Sven Kaltenhaeuser
- TEAM: Frank Morlang, Tanja Luchkova, Jens Hampe, Dirk-Roger Schmitt
- STUDENT: Niklas Klay

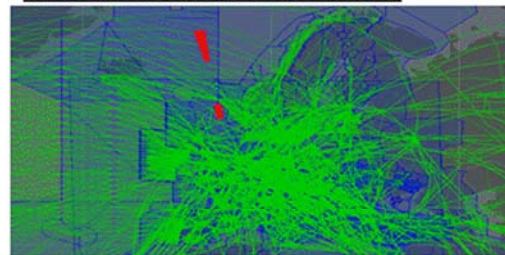
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- With global growth of the commercial space industry there is a developing demand for space flight operations in and over Europe. Air Traffic Management (ATM) is playing a key role to address this challenge.
- The goal is to prepare the European ATM system to enable a safe integration of space vehicle operations (SVO) in a sustainable and efficient way. To enable global operations, interoperability of implemented technologies and procedures is an essential requirement and a specific focus of the DLR work program.

STATEMENT OF WORK

- Categorization of relevant space flight operations and assessing their impact on European airspace using the DLR Space and Air Traffic Management (SATM) testbed.
- Development of measures and procedures for enabling efficient ways to optimize airspace usage for space flight operations while minimizing airspace segregation.
- Development of concepts and prototypes for a seamless, safe and secure implementation of space flight operations into the ATM flight planning and control processes using System Wide Information Management (SWIM) and related open and standard mainstream technologies.

Air Launch flight restriction areas in European Airspace (use case specific)



STATUS

- Continued collaborative work between DLR, Embry Riddle Aeronautical University and FAA-AST on interoperable solutions for improved integration of space flight operations into ATM. Specific focus on enhanced information process, e.g. utilizing SESAR SWIM ↔ FAA SWIM solutions.
- Impact analysis of flight restriction areas related to air launch operation in European airspace as part of a use case study based on historic operational data.

ECONOMIC IMPACT

- Provision of concepts and technical solutions enabling interoperable space flight operations in Europe & US.

FUTURE WORK

- Enhanced modelling of space vehicles for future traffic impact analysis of relevant space vehicle trajectories
- Applying advanced ATM concepts such as Flexible Use of Airspace, Flight Centric ATC and Dynamic Sectorization
- Enhanced functions for space flight SWIM services including all ATM planning and execution levels.

Task 380. Spaceport Operations Online Reference Guide

PROJECT AT-A-GLANCE

- UNIVERSITY: New Mexico State University
- PRINCIPAL INVESTIGATOR(S): Patricia C. Hynes, Ph.D.
- STUDENT(S): Isaac Garza

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Provide a starting point and ready references to industry and government groups interested in conducting Spaceport Operations.

STATEMENT OF WORK

- Complete an end-to-end review of the Spaceport Operation Body of Knowledge to identify missing or broken links
- Establish a workflow to allow for regular and efficient updates to the Body of Knowledge
- Preliminary identification of gaps and weaknesses in the Body of Knowledge resulting from industry advancements since inception of the BoK

STATUS

- Completed the end-to-end review of the BoK, identifying all "broken" or missing reference links
- Established the workflow for BoK updates through this minor update and for future updates
- Graduate student staff to perform bulk of the work

Body of Knowledge for Spaceport Operations



About this collection

Today's space access systems do not employ standard systems allowing spaceports, ranges, and launch providers to interoperate in the seamless manner needed to stimulate a vibrant commercial space industry. This poses a challenge for the long term development of a commercial space transportation system. The development of a Framework for Spaceport Operations has shown that space launch sites, i.e. spaceports, consider that some of their operational activities, but not all, are similar to those of other spaceports.

Funded by the FAA Center of Excellence for Commercial Space Transportation, the Body of Knowledge for Spaceport Operations is an evolving collection of documents and information that fall within the Framework and support the development of space launch site interoperability. The information has been selected by members of the Body of Knowledge for Spaceport Operations research team, and the database is constructed and maintained by the New Mexico State University Library.

Framework for Spaceport Operations

The information in this database is organized according to the Framework for Spaceport Operations. The Framework is composed of 12 top-level categories, each with multiple subcategories. The top-level categories are:

ECONOMIC IMPACT

- Minimize the cost of research by any group or entity researching spaceport operations. This database is especially effective for new spaceports, as well as spaceports looking towards upgraded operations.

FUTURE WORK

- Revision of the BoK, including new references and best practices
- Integration of the BoK and Framework with other groups, such as ASTM F47 and FAAAST field work
- Develop and publish, with FAAAST concurrence, a Spaceport "pre-audit" preparation guide
- Develop a project plan for a Spaceport Startup "Roadmap"

Task 241. High Temperature, Optical Sapphire Pressure Sensors

PROJECT AT-A-GLANCE

- UNIVERSITY: Florida State University
- PRINCIPAL INVESTIGATOR(S): William S. Oates, Rajan Kumar
- STUDENT: Jakob Consoliver-Zack

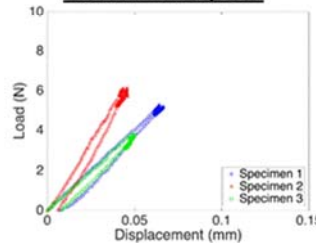
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Structural health monitoring and control of space vehicles.

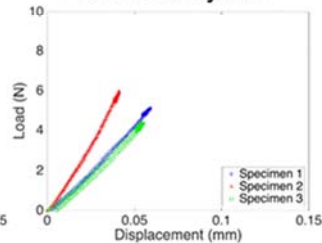
STATEMENT OF WORK

- Research is focused on advancing high temperature pressure sensor technology for sensors that can sustain elevated temperatures ($T > 1300^{\circ}\text{C}$) and high pressures.
- Research developed fundamental understanding of laser machined sapphire mechanics
 - Facilitated technology transition to sensor structures
 - Fracture and fatigue resistance studied through high temperature material characterization
 - Advantage: Laser machining produces desirable fracture toughness enhancements
 - Disadvantage: Expensive machining process requiring picosecond pulsed, high energy laser
- Solution: Introduced metallo-ceramic MAX-phase material
 - This material (e.g. Maxthal Ti_2AlC) is machinable with conventional cutting tools
 - Can operate up to $\sim 1300^{\circ}\text{C}$
 - Material will oxidize alumina (polycrystalline sapphire) at elevated temperatures—ideal for corrosion resistance and structural support at high temperature
 - Self-healing properties and structure-property relations post machining not well understood
- Research focused on understanding these materials to replace sapphire as the next generation sensor structural support for high temperature pressure sensors

Post-Anneal Cycle 1



Post-Anneal Cycle 2



STATUS

- Material response of annealed Maxthal 211 circular wafer specimens has been investigated using axially symmetric bending experiments.

ECONOMIC IMPACT

- Better reliability of re-launch space vehicles
- Enhanced rocket engine control enabling better fuel efficiency
- Better understanding of turbulence and aeropropulsion at hypersonic speeds.

FUTURE WORK

- Characterize material behavior at high temperatures under high speed fluid flow.
- Experimental characterization of alumina surface growth; its affect on strength and correlation with structure and interface properties
- Such research will facilitate machinable high temperature ($>1000^{\circ}\text{C}$) sensors that can be mass produced

Task 253. Ultra-high Temperature Composites Thermal Protection Systems

PROJECT AT-A-GLANCE

- UNIVERSITY: University of Central Florida
- PRINCIPAL INVESTIGATOR(S): Drs. Jan Gou & Jay Kapat
- STUDENT(S): Marcus Francis, Shengheng Gu

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Ultra-high temperature, light-weight, and cost-effective composites thermal protection systems (TPS) are enabling technologies for viable commercial spacecraft and launch vehicles.

STATEMENT OF WORK

- Develop oxide-oxide ceramic matrix composites (CMCs) based on polymer derived ceramics for ultra-high temperature thermal protection systems made by vacuum infusion and additive manufacturing
- Develop top hard ceramic coatings for ultra-high temperature thermal protection systems.
- Ground testing of polymer derived ceramics composites (PDCC) thermal protection systems using Oxyacetylene exposure test, shock tube test, and hot jet facilities.
- Flight testing of PDCC-based solid rocket nozzles and in-situ sensing for structural health monitoring
- Thermo-mechanical modeling of polymer derived ceramics composites (PDCC) thermal protection systems

Additive Manufacturing of Ceramic Rocket Nozzle



STATUS

- Synthesis, 3D printing and sintering of SiOC polymer-derived ceramics
- Develop 3D oxide-oxide CMCs based on Nextel™ 720 fibers/SiOC ceramic matrix composites.

FUTURE WORK

- Initial flight testing of PDC thermal protection systems using solid rocket motor
- Develop high performance front surface ceramic coatings for thermal protection systems
- Ground-based testing of PDCC thermal protection systems made by vacuum infusion and additive manufacturing

Task 299: Nitrous Oxide Composite Case Testing

PROJECT AT-A-GLANCE

- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR(S): Seokbin (Bin) Lim, Andrei Zagrai
- STUDENT(S): Luis Ortega, Chris Rood
- TECHNICAL MONITORS: Ken Davidian

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

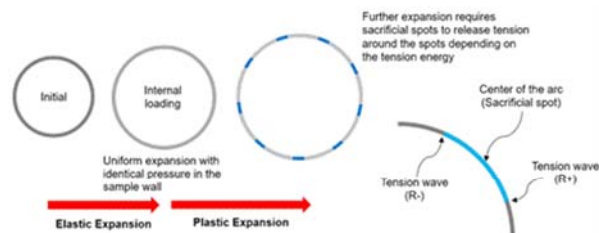
- Develop an understanding of fragmentation hazards from composite tanks used for fuel/oxidizer storage
- Develop a testbed for evaluating different storage tank materials or configurations at small and large scales

STATEMENT OF WORK

- Construction of hypothesis and experimental validation of how cracks form in test samples
- Develop methods/hypothesis to predict crack opening behavior
- Construction of analytical approach to predict such behaviors (1D extreme tension theory)

APPROACH

- 1D beads model with conservation equations deliver a clue to understand the material behavior under the extreme dynamic tension
- Understanding of the speed of tension wave and other EoS during the extreme dynamic tension



HYPOTHESIS

1. The sample expands driven by the sudden internal pressure loading
2. The sample expands uniformly until the elastic limit
3. Once it reaches to the elastic limit, the plastic deformation starts
4. The sample forms sacrificial spots to release the tension energy
 - The # of sacrificial spots will be varied depending on the energy
 - The release of the tension energy will be only on the sacrificial spots causing other areas stay in elastic
 - It propagates the tension wave along the sample circumference causing some sacrificial spots disappear
5. The sacrificial spots crack

STATUS

- Construction of the extreme tension theory: completed
- Numerical simulations to evaluate the theory: completed

FUTURE WORK

- A series of field tests is required to evaluate the theory and applications

Task 307. Commercial Satellite Communications



Solstar Space Co.

Solstar team, post launch, July 18, 2018, at Blue Origin's West Texas launch facility.



PROJECT AT-A-GLANCE

- UNIVERSITY MEMBER: New Mexico State University
- AFFILIATE MEMBER: Solstar
- PRINCIPAL INVESTIGATOR: Mr. Brian Barnett
- CO-INVESTIGATORS: Dr. Pat Hynes

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Provision of economical commercial 2-way data, voice, and internet services to connect commercial space vehicles, people in space, smallsats, machines in space, and people/machines on the ground.
- Space traffic control

STATEMENT OF WORK

- Test Solstar commercial satellite communications networks and equipment to provide data and voice communications for research payloads, passengers, and spacecraft during suborbital flights.

STATUS

- Two successful demonstrations of Solstar's technology in 2018 on-board Blue Origin's New Shepard Crew Capsule. Flights provided by NASA's Flight Opportunities Program
- April 29, 2018– First Commercial WiFi in Space; posted first commercial Tweet from Space
- July 18, 2018 – successful technology demonstration; maintained data connection during entirety of flight during crew escape test.

FUTURE WORK

- Moving toward development of commercial space communicator hardware and service for suborbital flights, smallsats, LEO
- Future flights through FOP, Tipping Point
- Technology demonstration on ISS or other LEO platform
- Seeking science payloads to test Solstar 2-way data service

Task 311. Advancement of LED-Based Hazardous Gas Sensors for Space Applications



PROJECT AT-A-GLANCE

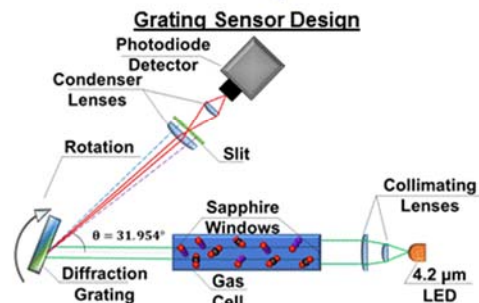
- UNIVERSITY: University of Central Florida
- PRINCIPAL INVESTIGATOR(S): Dr. Subith Vasu
- POST DOC(S): Anthony C. Terracciano, Ph.D.
- STUDENT(S): Akshita Parupalli, Zachary Loparo, Justin Urso

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- CO₂ and N₂O measurements are relevant to the health and safety of the crew.
- Time-resolved measurements of these gases could help quickly detect electrical shorts or fuel leaks

STATEMENT OF WORK

- A sensor is used for the detection of CO₂ and N₂O.
- Balloon tests were conducted to validate sensor responsiveness at micro-gravity conditions across a range of temperatures and pressures.
- The results from the balloon tests are used to improve the optical and electrical design.
- A rotating diffraction grating is used in conjunction with a single LED to scan from 4.1 to 4.6 μm.
- Laboratory tests were performed in a fume hood for different mixtures of CO₂ and N₂O balanced in Argon.
- The results show the capabilities for detecting multiple gases with the use of a single LED.



STATUS

- The system was tested to increase the wavelength range and sensitivity.

ECONOMIC IMPACT

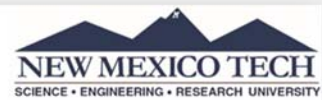
- This project shows the potential for replacing expensive lasers with cheaper and more robust LEDs in space vehicles
- The overall cost for safety devices can decrease as a result

FUTURE WORK

- Increase precision
- Increase range of applicable gases
- Test in more hazardous environments and conduct suborbital flight



Task 323. Structural Health Monitoring Framework for Commercial Space Transportation



PROJECT AT-A-GLANCE

- UNIVERSITY: New Mexico Institute of Mining and Technology
- PRINCIPAL INVESTIGATOR(S): Andrei Zagrai
- STUDENT(S): Mary Anderson, David Hunter, Dyllian Powell

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

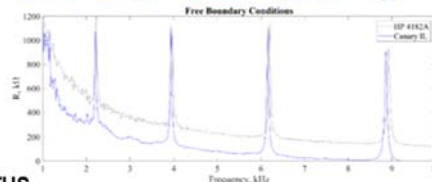
- Information provided by a vehicle's SHM system may be used to predict a component's remaining life and hence enable prognosis and mission scheduling in accordance with current and projected structural performance. SHM data may also assist in accident investigation if needed.

STATEMENT OF WORK

- Sensor and structural deterioration due to space environment
- We further develop approaches to better understand other aspects of environmental influences on space systems and manifestation of these aspects in SHM data.
- Prepare hardware for evaluation of space effects on structural condition and sensor system.
- In preparation for evaluation of space effects on structural condition we have developed portable hardware capable of performing electro-mechanical impedance SHM. At this point, a single channel unit has been developed.

ECONOMIC IMPACT

- The economic benefit includes avoiding very costly catastrophic events and reducing maintenance cost by replacing parts on "as needed" versus "lifespan" basis.



STATUS

- A pathway to improve sensor models under radiation has been proposed.
- Portable hardware for acquisition of electro-mechanical impedance of sensors has been developed
- Software to run electro-mechanical impedance experiments on portable hardware has been developed.
- Performance of hardware and software for portable electro-mechanical impedance acquisition unit has been validated through experimental testing.

FUTURE WORK

- Explore possibility of multi-channel portable impedance measurement unit.
- Improve frequency control of the portable impedance measurement device.

Task 325. Optical Measurements of Rocket Nozzle Thrust and Noise



Optical Measurements of Thrust and Noise

PROJECT AT-A-GLANCE

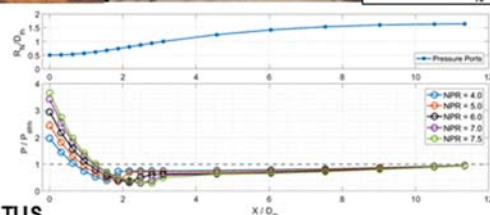
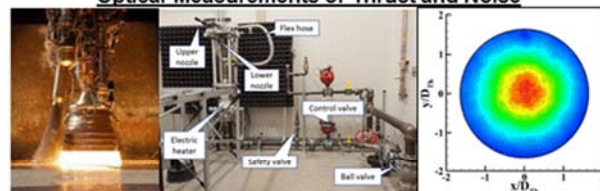
- UNIVERSITY: Florida State University
- PRINCIPAL INVESTIGATOR(S): Rajan Kumar & Farrukh Alvi, Jonas Gustavsson
- STUDENT(S): Rohit Vemula & Nikhil Khobragade

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Measurement of nozzle thrust and noise is necessary for the design of future launch and reentry space systems and hypersonic vehicles. The improved aerodynamic performance and propulsion system will help increase payload capacity and safety for many government and commercial space transportation programs.

STATEMENT OF WORK

- Development of a research plan based on state-of-art thrust and noise measurement techniques and discussion with NASA /commercial launch engineers to ensure the transition of technology from laboratory to full-scale implementation.
- Design of a scaled rocket nozzle to simulate realistic temperature and pressure conditions of the jet exhaust and carry out thrust and noise measurements in the FSU free jet lab.
- Design and develop advanced optical techniques for thrust measurements and characterize its performance at controlled conditions.
- Refine and test the measurement techniques over a wide range of test conditions.



STATUS

- Thrust measurements using optical methods
- Extensive testing (velocity, pressure and acoustic surveys as well as load cell measurements) completed
- Implementation of microjet based flow control to delay flow separation

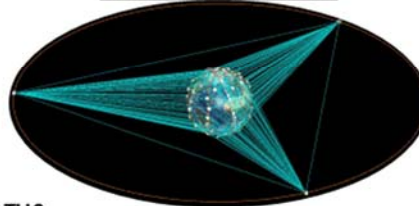
FUTURE WORK

- Pressure and load cell measurements with control
- Thrust enhancement with optimized microjet control
- Noise reduction technique during launch operations

Task 359. Relaying Communications from LEO to Earth Using GEO CommSats



GEOs relaying for LEOs



PROJECT AT-A-GLANCE

- UNIVERSITY: NMSU Affiliate, University of North Florida
- PRINCIPAL INVESTIGATOR: Brian Kopp, Ph.D.
- STUDENT: Caio Lauand

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Potential to provide a high availability, lower-cost, as-needed earth communications link for LEOs
- Earth station construction becomes optional with only a few needed to have global coverage

STATEMENT OF WORK

- Investigate the necessary technical parameters
 - Frequency bands, transponder bandwidths, coverage, polarization, doppler, etc.
 - User spacecraft orbits and constellations
 - Link budget analysis to establish design constraints
 - Interference and mitigation
 - Establish minimum antenna requirements
- Establish performance capabilities for typical configurations
- Identify regulatory issues needing resolution
- Perform cost benefit analysis.

STATUS

- The technical parameters have been investigated.
- The regulatory issues have been identified.
- Draft performance capabilities for typical configurations have been identified and are being finalized.
- Cost benefit analysis in underway.

ECONOMIC IMPACT

- Lower cost to operate large commercial satellite networks in LEO orbit.

FUTURE WORK

- Complete cost benefit analysis
- Finalize performance capabilities for typical configurations
- Develop proposal and investigate funding opportunities for a proof of concept test on the International Space Station

Task 368. Research Area 2 Workshop



PROJECT AT-A-GLANCE

- UNIVERSITY: University of Central Florida
- PRINCIPAL INVESTIGATOR: Dr. Subith Vasu

RESULTS

- Majority of the discussions were focused on how to engage more industry in COE-CST activities.
- There is an inherent risk when a company undertakes a "low TRL project". Large corporations (Lockheed, Boeing, General Dynamics, etc.) have dedicated R&D programs funded by other operations. Small corporations (<\$5M/year revenue) are often mandated by razor thin operating margins and are rarely able to undertake NEW low TRL projects which stem from university research. Thus COE CST investment in technology projects are highly valuable.
- Safety is a key concern for a corporation's public image. Thus, many corporations are spending countless dollars validating safety components. Simultaneously there is an incredible amount of government air traffic regulation which needs to occur for any space related launch. There needs to be a non-governmental organization which assists corporations in validating safety. Similar to how the IHS has a standardized crash test in the automotive industry.
- Corporations are profit driven, thus they are reluctant to share information which could enable competitors. This creates a financial waste in which many corporations are devoting resources to solve the same problem. More government insight is needed on how to enhance corporate divulgence of intellectual property. This is industry specific.
- Many corporations suffer from stovepipe culture in which there is little information sharing between the corporate offices as per HR & executive level mandates. This leads employees which are not in a decision making position to be reluctant to search/communicate for opportunity. Programs need to be made available to many levels of corporate offices to enable greater space-based participation.



RESULTS (continued)

- At public, and some private, higher learning institutions, there is a predominate focus on the number of research publications which are made. While many universities have an intellectual property office, there is a general reluctance of this office to file new IP. Additionally, tenure often is not validated by new IP. The FAA and other federal government programs need to encourage Universities to "see the merit" in filing for IP.
- Events which bring together government grant administrators with corporations looking to solve space related challenges is a necessary involvement in furthering Commercial Space. Fostering breakout meetings with "teams of corporate talent" and grant administrators to solve space flight challenges can enable highly focused and directed research needs in a dynamic manner to optimize the cost/risk/profit expectations.
- Investors have capital that they don't know what to do with. These people are looking for means of a return on investment that suits the individual's, group's, or firm's style/risk/reward characteristics. However, these people often only want a return on money and are not interested in managing the day to day operations. A bridge needs to be made between non-government entities with funding, Federal/State/Local grant underwriters, and scientific innovators in which an "operating board" and sales team can be integrated directly with engineers'/scientists' space related visions.
- Contact non-profit organizations: CASIS, Union of Concerned Scientists, etc. for their insight on grant topics related to commercial space.

Task 308. Assessment of Screening and Training Requirements for SFPs Regarding Anxiety During Repeated Exposures to Sustained High Acceleration



PROJECT AT-A-GLANCE

- University: The University of Texas Medical Branch
- Principal Investigator: James Vanderploeg, MD, MPH
- Co-Investigators: Rebecca Blue, MD, MPH; Tarah Castleberry, DO, MPH; Charles Mathers, MD, MPH, Johnene Vardiman, MS
- Residents: Rahul Suresh, MD

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- The viability of the commercial spaceflight industry will be dependent upon layperson participation, which requires a perception that flights are safe and enjoyable.
- Spaceflight participants are likely to have expectations regarding training and risk mitigation; efforts towards meeting expectations or educating the public may have beneficial effects for the industry.
- Spaceflight participants may have difficulty performing tasks in stressful scenarios, but may not fully understand how their own actions affect the risk profile of spaceflight activities

STATEMENT OF WORK

- Understand how minimally trained laypersons perform during simulated emergency in centrifuge-simulated suborbital spaceflight
- Identify preconceptions of risk, training requirements, and commercial spaceflight safety



STATUS

- Project data collection completed
- 157 subjects recruited, centrifuge trials completed June 2016
- Data analysis completed 2017

FUTURE WORK

- Presentation and publication of significant findings – publication anticipated 2018, presentation expected at Aerospace Medical Association Annual Scientific Meeting 2018
- Publication anticipated 2018, *Aerospace Medicine and Human Performance*

Task 309: Assessment of Physiological Screening Requirements & Training Modalities for Repeated Exposures to Sustained High G Acceleration



PROJECT AT-A-GLANCE

- University: The University of Texas Medical Branch
- Principal Investigator: Tarah Castleberry, DO, MPH
- Co-Investigator: James Vanderploeg, MD, MPH
- Residents: James Pavel, MD; Wilfredo Rodriguez-Jimenez, MD

RELEVANCE TO COMMERCIAL SPACEFLIGHT INDUSTRY

- Repeated exposure of the crew to sustained high +Gx and +Gz acceleration in highly demanding spaceflight profiles is a new and untested paradigm. Identifying the unique physiological challenges, screening and training techniques will enable spaceflight operators to ensure safe operations.

STATEMENT OF WORK

- Compare pilot performance and physiological response in aerobic flights, centrifuge acceleration profiles, and actual spaceflight.
- Develop recommendations for pilot training and medical screening.



STATUS

- Collected data on pilots in centrifuge-simulated suborbital flight, aerobic flight, and space flight through 2018

FUTURE WORK

- Obtain and analyse physiological data during centrifuge runs, aerobic flights and spaceflights in 2019

Task 310. Assessment of Methods, Procedures, and Technologies Available for the Protection of SFPs in Commercial Spaceflight Vehicles



PROJECT AT-A-GLANCE

- University: The University of Texas Medical Branch
- Principal Investigator: Charles H. Mathers, MD, MPH
- Co-Investigators: James M. Vanderploeg, MD, MPH; Tarah Castleberry, DO, MPH; Rebecca Blue, MD, MPH, Leigh Speicher, MD, MPH
- Residents: Alejandro Garbino, MD, PhD

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Dedicated efforts towards the enhanced safety in spaceflight vehicles will improve the success of commercial space endeavors
- Direct applicability to design phase of commercial spaceflight vehicles, integration of medical efforts with cabin engineering

STATEMENT OF WORK

- Identify injury patterns associated with various restraint designs
- Identify injury patterns and relative risks of anthropometrically and demographically varied populations, including factors such as sex, obesity, advanced age
- Identify any best practices for restraint design in commercial spaceflight vehicles



STATUS

- Literature review and analysis completed 2017
- Abstract accepted for Aerospace Medical Association Annual Scientific Meeting presentation, 2018
- Manuscript accepted for publication in *New Space*

FUTURE WORK

- Publication in *New Space* in 2019

Task 353. Design and Operational Considerations for Occupant Safety



PROJECT AT-A-GLANCE

- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: David Klaus
- STUDENT: Mitchell Woolever

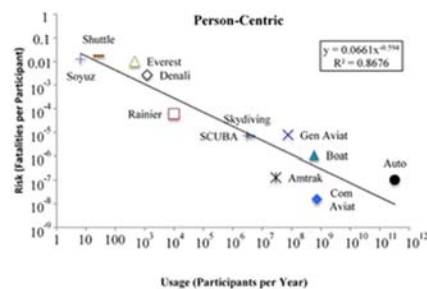
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- The FAA Recommended Practices document provides a framework of subject areas that the FAA Office of Commercial Space Transportation (AST) believes are important aspects for improving the safety of launch and entry vehicles designed to carry humans. The document also offers a platform that may be used to help identify and establish industry consensus standards and provide supporting information for potential future regulatory decision making, should that need arise.

STATEMENT OF WORK

- **AIM 1:** Review the Recommended Practices document and provide suggested edits and/or recommended additional subject areas to be included in any future versions released;
- **AIM 2:** Provide design and operational considerations for each topic area including additional details, quantified where possible, and/or candidate design and operational solutions that meet the intent of the qualitative guidelines provided in the Recommended Practices document. To be clear, this information is not meant to be included in future revisions of this document, rather it will reference the Recommended Practices framework in supplemental, standalone publications describing any proposed quantitative details along with design and operational considerations.

Risk vs. Usage Regression Analysis



STATUS

- Related risk analysis from previous task 320 now published
- Task 353 start was initially delayed due to funding issues
- Anticipated collaboration efforts did not fully materialize due to funding issues
- Analysis is now complete and results are being formatted for final report submission, publication effort is in progress
- Two COE CST Affiliates participated in this task – Sovaris Aerospace, LLC and Carminati Law, PLLC

FUTURE WORK

- This current project will conclude with submission of the final report and ensuing publication outcome
- Follow on research task is aimed at mapping life support system functions and technologies to CST applications (proposal pending)



Task 353. Design & Operational Considerations for Occupant Safety

PROJECT AT-A-GLANCE

- UNIVERSITY: Florida Institute of Technology
- PRINCIPAL INVESTIGATOR(S): Ondrej Doule, Ph.D. (initiated by Dr. Guy Boy)
- STUDENT(S): De Vere Kiss, Yash Mehta, Keith Crisman

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Occupant safety is critical for operational and economical success of the commercial space transportation industry. Review and recommendations based on existing practices and lessons learnt is the most effective way to quickly progress in normative research and development of official, government guides and regulations that will support CST development.

STATEMENT OF WORK

- Review the Recommended Practices document and provide suggested edits and/or recommended additional subject areas to be included in any future versions in area of Human-System Integration for commercial space vehicles
- Identify design and operational considerations for each topic area including additional details, quantified where possible
- Provide candidate design and operational solutions that meet the intent of the qualitative guidelines provided in the Best Practices document
- Generate database of relevant existing resources / references for CST industry
- Summarize findings in research publication (New Space Journal)

Research Analytics Sources



STATUS

- Collaborative task 353, part FIT has been completed. Spin off research topics are ongoing.

ECONOMIC IMPACT

- Research supported enhancement of FIT's HSF CST collaborative network and establishment number of projects one of which acquired seed funding. Standardization committee on HSF CST has been established at AIAA SATC

FUTURE WORK

- Human-System Input for CST focuses on HSF CST human-machine interaction complementing NASA, FAA, ISO STDs
- Streamlining Export Control develops roadmap to avoid administrative burden between academia and CST industry
- Omnidirectional Radiation Detector and Situational Awareness System is a new type of radiation detector for suborbital vehicles for more precise real-time radiation data

Task 373. Research Area 3 Workshop



PROJECT AT-A-GLANCE

- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: David Klaus
- STUDENT(S): N/A

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- This workshop was conducted to identify, evaluate and prioritize current research needs in the area of commercial human space flight, including topics of aerospace physiology and medicine, personnel training, environmental control and life support systems, habitability and human factors, and human-rating.

STATEMENT OF WORK

- To ensure a comprehensive review of this research area is accomplished, representation will be solicited from various academic, industry and government partners working across the different topics noted above.
- The workshop will be held at the University of Colorado Boulder with local and virtual attendance options, including an opportunity for post-workshop final feedback.

FUTURE WORK

- The results of this workshop will be used by the FAA to inform future research needs and strategic directions

Workshop hosted at the University of Colorado Boulder
RESEARCH THEME 3
Human Spaceflight Research



STATUS

- The workshop, held May 21-22, 2018, was hosted by Prof. Klaus and co-organized with COE CST colleagues Jim Vanderploeg (UTMB/Baylor) and Ondrej Doule (FIT)
- A total of 64 individuals from academia, government and industry responded to the invitation with interest in the event. Of the total, 27 attended in person, 25 called in remotely and 12 others were tentative, but requested to be kept abreast of the activities and outcomes
- Within the 3 categories of Vehicle Design (Klaus), Human Factors (Doule) and Occupant Health (Vanderploeg), a total of 48 research topics (16, 12 and 20, respectively) were identified, summarized and prioritized



Task 304. Legal Issues of Cross-Border Sub-Orbital Flights

PROJECT AT-A-GLANCE

- UNIVERSITY: McGill University, Institute of Air and Space Law
- PRINCIPAL INVESTIGATOR(S): Dr. Ram S. Jakhu
- STUDENT: Aram Daniel Kerkonian

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- The viability of commercial sub-orbital flights depends on establishing a robust regulatory framework.
- There is currently no regulatory framework for cross-border sub-orbital flights, whether public or private.
- The regulatory framework that will most likely emerge will depend on State agreements, regardless of whether sub-orbital flights are deemed to take place in airspace or outer space.
- Incongruent national regulatory frameworks may cause safety issues, thus international harmonization is important.
- Does an international organization (ICAO, UNOOSA, etc.) have a role to play?
- If cross-border sub-orbital flights move cargo, are there other considerations that ought to be identified?

STATEMENT OF WORK

- Phase I: Define the scope, terms and participants
- Phase II: Identify historical models related to cross-border air/space flight (specific to the craft and the personnel)
- Phase III: Determine limitations of current international regulatory framework (specific to potential cross-border partners)
- Phase IV: Analyze findings and make recommendations for improvement of regulatory framework between likely partners
- Phase V: Disseminate results via publication in legal journal

Air Law or Space Law: Does it Matter?



STATUS

- Phase I: Complete
- Phases II-III: On Going
- Phases IV-V: To Be Completed

FUTURE WORK

- Complete outstanding phases and present findings at various presentation to spread understanding of the importance of a regulatory framework.
- After having established the regulatory framework that ought to apply, the project will further impress upon the proper participants of the importance for developing such a framework.

Task 378. Commercial Space Research Center Initiative



PROJECT AT-A-GLANCE

- UNIVERSITY: University of Southern California, Affiliate to Florida Institute of Technology
- PRINCIPAL INVESTIGATOR(S): Dr. Greg Autry (USC), Dr. Andy Aldrin (FIT)

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Southern California has long and deep roots in the space industry and has become the center of the emerging entrepreneurial New Space sector. This vibrant commercial space ecosystem calls for dedicated management research and support from the academic community. Funds from industry donations and in-kind contributions from the University will match the amount received by the Center. The activities supported will include business focused research published in management, entrepreneurship, aerospace and policy journals along with the launch of an annual commercial space conference event.

CURRENT ACTIVITIES

- Initiated a business research experiment to investigate the value add of "flown in space" items. These items should be flown this year. As the flight provider does not wish to be identified, it would be awesome if FAA AST could work with me to certify these items were part of a licensed commercial payload.
- Working with students to form a new organization to connect Latino students with the space industry (along the lines of Brook Owens Fellowship).
- Presented first annual Commercial Space Research Award to Pat Hynes of NMSU for her many years of service hosting ISPCS.

Special Guest Speaker at First SCCSI Workshop: Charlie Bolden



STATUS

- Established Southern California Commercial Spaceflight Initiative and leveraged FAAAST funding into broad support from industry partners.
- First annual SCCSI workshop held on Nov. 4. Attendees included Ken Davidian (FAA), Scott Pace (National Space Council) and many current and former NASA leaders: Dan Rasky, Charlie Bolden, George Whitesides.

FUTURE WORK

- Plan to host Space Foundation & Dept. of Commerce "Space Commerce Workshop" for Minority Business Development Agency on January 26, 2019, to connect local minority owned firms and underrepresented students to the commercial space sector.
- Work just started on first annual (2019) report on the economic contribution of commercial spaceflight industry in California.

COE CST STUDENTS, PARTNERS, PUBLICATIONS, AND PRESENTATIONS

COE CST YEAR 8 STUDENTS

The following list gives the names, tasks, schools, and demographic information of the 38 COE CST students (both funded and unfunded), working on COE CST research tasks during 2018. The table is sorted alphabetically by the student's last name, first by columns, then by rows.



*Anderson, Mary
(323-NMT)*



*Garbino, Alejandro
(310-UTMB)*



*Gustavsson, Jonas
(325-FSU)*



*Kiss, De Vere
(353-FIT)*



*Consoliver-Zack,
Jakob (241-FSU)*



*Garza, Isaac
(380-NMSU)*



*Iyer, Shiva
(371-NMSU/UTA)*



*Klay, Niklas
(375-DLR)*



*Crisman, Keith
(353-FIT)*



*Goebler, John
(367-CU)*



*Kerkonian, Aram
(304-MU/FIT)*



*Lauand, Caio
(359-NMSU/UNF)*



*Francis, Marcus
(253-UCF)*



*Gu, Shengheng
(253-UCF)*



*Khobragade, Nikhil
(325-FSU)*



*Limonta, Lorenzo
(186-SU)*



Loparo, Zachary
(311-UCF)



Pellegrino, Marielle
(372-CU)



Urso, Justin
(311-UCF)



Mehta, Yash
(353-FIT)



Rodriguez-Jimenez,
Wilfredo (309-UTMB)



Vemula, Rohit
(325-FSU)



Parupalli, Akshita
(311-UCF)



Strassman, Joseph
(371-NMSU/UTA)



Venigalla, CK
(372-CU)



Pavela, James
(309-UTMB)



Sugar, Glenn
(186-SU)



Wolfgang, Jennie
(371-NMSU/UTA)



Slovenski, Michael
(371-NMSU/UTA)



Tompa, Rachael
(311-SU)



Woolever, Mitch
(353-CU)

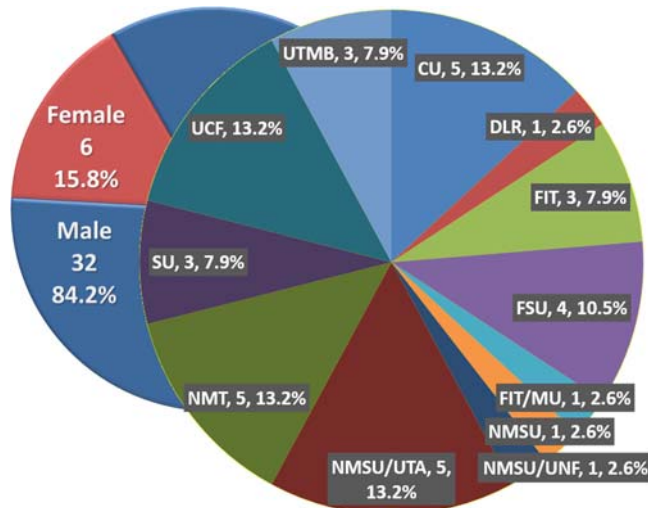
Students not shown:
Greaves, Jesse (372-CU),
Hunter, David (323-NMT),
Kryusher, Kathleen (371-
NMSU/UTA), McNeely,
Drew (371-NMSU/UTA),
Ortega, Luis (299-NMT),
Powell, Dyllian (323-
NMT), Rood, Christopher
(299-NMT)..

Abbreviations:
CU-University of Colorado
Boulder, DLR-Deutschen
Zentrums für Luft- und
Raumfahrt, FIT-Florida
Tech, FSU-Florida State
University, MU-McGill
University, NMSU-New
Mexico State University,
NMT-New Mexico Tech,
SU-Stanford University,
UCF-University of Central
Florida, UF-University of
Florida, UNF-University
of Northern Florida, UTA-
University of Texas Austin,
UTMB-University of Texas
Medical Branch at
Galveston



COE CST YEAR 8 STUDENT DEMOGRAPHICS

Each year, certain demographic data is collected on all COE CST students (by law). A summary of these data for gender and university, is shown in the following pie charts.



Abbreviations:

CU-University of Colorado Boulder
 DLR-Deutschen Zentrums für Luft- und Raumfahrt
 FIT-Florida Tech
 FSU-Florida State University
 MU-McGill University
 NMSU-New Mexico State University
 NMT-New Mexico Tech
 SU-Stanford University
 UCF-University of Central Florida
 UF-University of Florida
 UNF-University of Northern Florida
 UTA-University of Texas Austin
 UTMB-University of Texas Medical Branch at Galveston

COE CST YEAR 8 PUBLICATIONS

The following is a list of the 34 publications and patents completed during COE CST Year 8, or not reported in previous COE CST Annual Report Executive Summaries.

186-SU

Limonta, L., Close, S., and Marshall, R.A. (2018). A technique for inferring lower thermospheric neutral density from meteoroid ablation, *Planetary and Space science*, in review.

Limonta, L., Sugar, G., Close, S., and Marshall, R.A. (2018), Cross calibration of meteoroid's mass parameters from optical and radar measurements, *Journal of Geophysical Research: Space Physics*, in review.

Sugar, G., Oppenheim, M., Dimant, Y., & Close, S. (2018). Formation of Plasma Around a Small Meteoroid: Simulation and Theory.

220-NMSU

Bachner, H., & Hynes, P. (2018). The Development of a Framework to Capture a Body of Knowledge for Commercial Spaceport Operations. *New Space*, 6(1), 20–27.
<http://doi.org/10.1089/space.2017.0012>

253-UCF

Cai, Y. Z., Chen, L. Q., Yang, H. Y., Gou, J., Detroids, M., Tin, S., ... Wang, X. W. (2016). Mechanical and electrical properties of carbon nanotube buckypaper reinforced silicon carbide nanocomposites. *Lasers in Manufacturing and Materials Processing*, 42, 4984–4992.

Jian, X., Jiang, M., Zhou, Z., Zeng, Q., Lu, J., Wang, D., ... Gou, J. (2012). Gas-Induced Formation of Cu Nanoparticle as Catalyst for High-Purity Straight and Helical Carbon Nano fibers.

American Chemical Society Nano Letters, 6(10), 8611–8619.

Kapat, J. S., Jihua, G. O. U., Nagaiah, N., & Schmitt, J. (2016). Power generation system using closed or semi-closed brayton cycle recuperator. U.S.: World Intellectual Property Organization.

Liu, Z., Gao, Y.B., Liang, F., Wu, B.X., Gou, J., Detroids, M., Tin, S., Yin, M., Nash, P., Tang, X.D., and Wang, X.W. (2016). "Fabrication of Carbon Nanotube - Chromium Carbide Composite through Laser Sintering," *Lasers in Manufacturing and Materials Processing*, Vol. 3, pp. 1-8.

Skovron, J., Zhuge, J., Gordon, A. P., Kapat, J., & Gou, J. (2012). Effect of Nano-Paper Coating on Flexural Properties of a Fire-Treated Glass Fiber-Reinforced Polyester Composite. In *Supplemental Proceedings: Volume 1: Materials Processing and Interfaces* (Vol. 1, pp. 313–320). John Wiley & Sons.

Skovron, J., Zhuge, J., Gou, J., and Gordon, A. (2016). "Effect of Nanopaper Coating on Flexural Properties of a Fire-Treated Glass Fiber-Reinforced Polyester Composite," *Journal of Composite Materials*, doi: 10.1177/0021998316630584.

Wu, B., & Gou, J. (2016). Fabrication of carbon nanotube-nonoxide structural ceramic nanocomposites through laser sintering. U.S.Liu, Z., Gao, Y. B., Liang, F., Wu, B. X., Gou, J., Detroids, M., ... Wang, X. W. (2016). Fabrication of carbon nanotube - chromium carbide composite through laser sintering. *Lasers in Manufacturing and Materials Processing*, 3, 1–8.

**305-FIT**

Benjamin, S. (2018). Exploration to Exploitation: An Industry Analysis of Suborbital Space Tourism. *New Space*, 6(1), 87–98. <http://doi.org/10.1089/space.2017.0041>

308-UTMB & 309-UTMB

Blue, R. S., Bonato, F., Seaton, K., Bubka, A., Vardiman, J. L., & Mathers, C. H. (2017). The Effects of Training on Anxiety and Task Performance in Simulated Suborbital Spaceflight. *Aerospace Medical Human Performance*, 88(7), 641–650.

Suresh, R., Blue, R. S., Mathers, C. H., Castleberry, T. L., & Vanderploeg, J. M. (2017). Dysrhythmias in Laypersons During Centrifuge-Simulated Suborbital Spaceflight. *Aerospace Medicine and Human Performance*, 88(11), 1008–1015.

Suresh, R., Blue, R. S., Mathers, C., Castleberry, T. L., & Vanderploeg, J. M. (2017). Sustained Accelerated Idiopathic Rhythm in a Centrifuge-Simulated Suborbital Spaceflight. *Aerospace Medicine and Human Performance*, 88(8), 789–793.

311-UCF

Terracciano, A. C., Thurmond, K., Villar, M., Urso, J., Ninnemann, E., Parupalli, A., ... Vasu, S. S. (2018). Hazardous Gas Detection Sensor Using Broadband Light-Emitting Diode-Based Absorption Spectroscopy for Space Applications. *New Space*, 6(1), 12–15. <http://doi.org/10.1089/space.2017.0044>

323-NMT

Hunter, D., & Zagrai, A. (2017). Electro-Mechanical Impedance Assessment of a Bolted Circular Plate Element of a Space Structure. In *ASME 2017 International Mechanical Engineering Congress and Exposition* (p. V009T17A004-V009T17A004). American Society of Mechanical Engineers.

Hunter, D., Zagrai, A. N., & Demidovich, N. (2018). Miniaturized Electro-mechanical Impedance Hardware for Structural Health Monitoring of Space Systems. In *Commercial and Government Responsive Access to Space Technology Exchange*.

325-FSU

Vemula, R. C., Gustavsson, J., & Kumar, R. (2018). Rocket Nozzle Thrust and Flow Field Measurements Using Particle Image Velocimetry. *New Space*, 6(1), 37–47. <http://doi.org/10.1089/space.2017.0045>

330-FIT

Fiedler, T. J. (2018). Partnership with the Center of Excellence for Commercial Space Transportation. *New Space*, 6(1), 18–19. <http://doi.org/10.1089/space.2017.0049>

333-FIT

Boy, G. A., Doule, O., Kiss, D. V. M., & Mehta, Y. (2018). Human-Systems Integration Verification Principles for Commercial Space Transportation. *New Space*, 6(1), 53–64. <http://doi.org/10.1089/space.2017.0040>

353-CU

Klaus, D. (2018). The Pursuit of Occupant Safety in Commercial Human Spaceflight. *New Space*, 6(1), 48–52. <http://doi.org/10.1089/space.2017.0048>

Ocampo, R. P., & Klaus, D. M. (2018). Applying regression analysis to model the risk of space flight and terrestrial activities. *Journal of Space Safety Engineering*, 5(3–4), 135–139.

367-CU

Boylston, A., Gaebler, J. A., & Axelrad, P. (2019). Extracting cubesat relative motion using in situ deployment imagery. In *Proceedings of AAS/AIAA Space Flight Mechanics Meeting* (pp. 1–10).

Gaebler, J., & Axelrad, P. (2017). CubeSat Cluster Deployment Tracking with a CPHD Filter. In *9th International Workshop on Satellite Constellations and Formation Flying*. Boulder, CO.

Gaebler, J. A., & Axelrad, P. (2019). Improving orbit determination of clustered cubesat deployments using camera-derived observations. In *Proceedings of AAS/AIAA Space Flight Mechanics Meeting* (pp. 1–10).

Gaebler, J. A., & Axelrad, P. (2019). Label assignments in cubesat cluster deployment tracking. In *Proceedings of AAS/AIAA Space Flight Mechanics Meeting* (pp. 1–15). Schumacher, P. W.,

Gaebler, J. A., Roscoe, C. W. T., Wilkins, M. P., & Axelrad, P. (2018). Parallel initial orbit determination using angles-only observation pairs. *Celestial Mechanics and Dynamical Astronomy*, 130(9), 60.

375-DLR

Luchkova, T., Kaltenhäuser, S., Klay, N., Ang, R. B. R., & Schultz, M. (2018). Integration and Evaluation of the Impact of Space Vehicle Operations in the European ATM. In *International Conference on High-Speed Vehicle Science Technology*.

Morlang, F. (2018). Swim in space with comrades in the air. In *69th International Astronautical Congress*.

Schmitt, D.-R., Werner, K., Morlang, F., Hampe, J., & Kaltenhäuser, S. (2018). Satellite based ADS-B for Commercial Space Flight Operations. In *69th International Astronautical Congress*.

Schmitt, D.-R., Luchkova, T., Morlang, F., Hampe, J., & Kaltenhäuser, S. (2018). Spaceport operations in Europe. In *69th International Astronautical Congress*.

NO TASK

Davidian, K. J. (2018). Introduction to the Center of Excellence for Commercial Space Transportation Issue of the *New Space Journal*. *New Space*, 6(1). <http://doi.org/10.1089/space.2018.0001>

Davidian, K. J., & Watts, P. (2011). Overview of the Federal Aviation Administration Center of Excellence for Commercial Space Transportation. In *Proceedings of the 2011 IAF* (Vol. 12, pp. 9820–9827). IAC-11-E6.1.4. Presented at the 62nd International Astronautical Congress in Cape Town, South Africa.:



APPENDIX. PUBLIC LAW 101-508 TITLE IX SUBTITLE C SECTION 9209

SEC. 9209. AVIATION RESEARCH AND CENTERS OF EXCELLENCE.

(a) *IN GENERAL*- Section 312 of the Federal Aviation Act of 1958 (49 App. U.S.C. 1353) is amended by adding at the end the following new subsection:

(i) AVIATION RESEARCH AND CENTERS OF EXCELLENCE-

(1) GENERAL AUTHORITY- The Administrator may make grants to one or more colleges or universities to establish and operate several regional centers of air transportation excellence, whose locations shall be geographically equitable.

(2) RESPONSIBILITIES- The responsibilities of each regional center of air transportation excellence established under this subsection shall include, but not be limited to, the conduct of research concerning airspace and airport planning and design, airport capacity enhancement techniques, human performance in the air transportation environment, aviation safety and security, the supply of trained air transportation personnel including pilots and mechanics, and other aviation issues pertinent to developing and maintaining a safe and efficient air transportation system, and the interpretation, publication, and dissemination of the results of such research. In conducting such research, each center may contract with nonprofit research organizations and other appropriate persons.

(3) APPLICATION- Any college or university interested in receiving a grant under this subsection shall submit to the Administrator an application in such form and containing such information as the Administrator may require by regulation.

(4) SELECTION CRITERIA- The Administrator shall select recipients of grants under this subsection on the basis of the following criteria:

(A) The extent to which the needs of the State in which the applicant is located are representative of the needs of the region for improved air transportation services and facilities.

(B) The demonstrated research and extension resources available to the applicant for carrying out this subsection.

(C) The capability of the applicant to provide leadership in making national and regional contributions to the solution of both long-range and immediate air transportation problems.

(D) The extent to which the applicant has an established air transportation program.

(E) The demonstrated ability of the applicant to disseminate results of air transportation research and educational programs through a statewide or regionwide continuing education program.

(F) The projects which the applicant proposes to carry out under the grant.

(5) MAINTENANCE OF EFFORT- No grant may be made under this subsection in any fiscal year unless the recipient of such grant enters into such agreements with the Administrator as the Administrator may require to ensure that such recipient will maintain its aggregate expenditures from all other sources for establishing and operating a regional center of air transportation excellence and related research activities at or above the average level of such expenditures in its 2 fiscal years preceding the date of enactment of this subsection.

(6) FEDERAL SHARE- The Federal share of a grant under this subsection shall be 50 percent of the costs of establishing and operating the regional center of air transportation excellence and related research activities carried out by the grant recipient.

(7) ALLOCATION OF FUNDS- Funds made available to carry out this subsection shall be allocated by the Administrator in a geographically equitable manner.'

(b) RESEARCH ADVISORY COMMITTEE-

(1) Section 312(f)(2) of the Federal Aviation Act of 1958 (49 App. U.S.C. 1353(f)(2)) is amended by adding at the end the following new sentence: 'In addition, the committee shall review the research and training to be carried out by the regional centers of air transportation excellence established under subsection (h).'

(2) Section 312(f)(3) of the Federal Aviation Act of 1958 (49 App. U.S.C. 1353(f)(3)) is amended--

(A) by striking '20' and inserting '30'; and

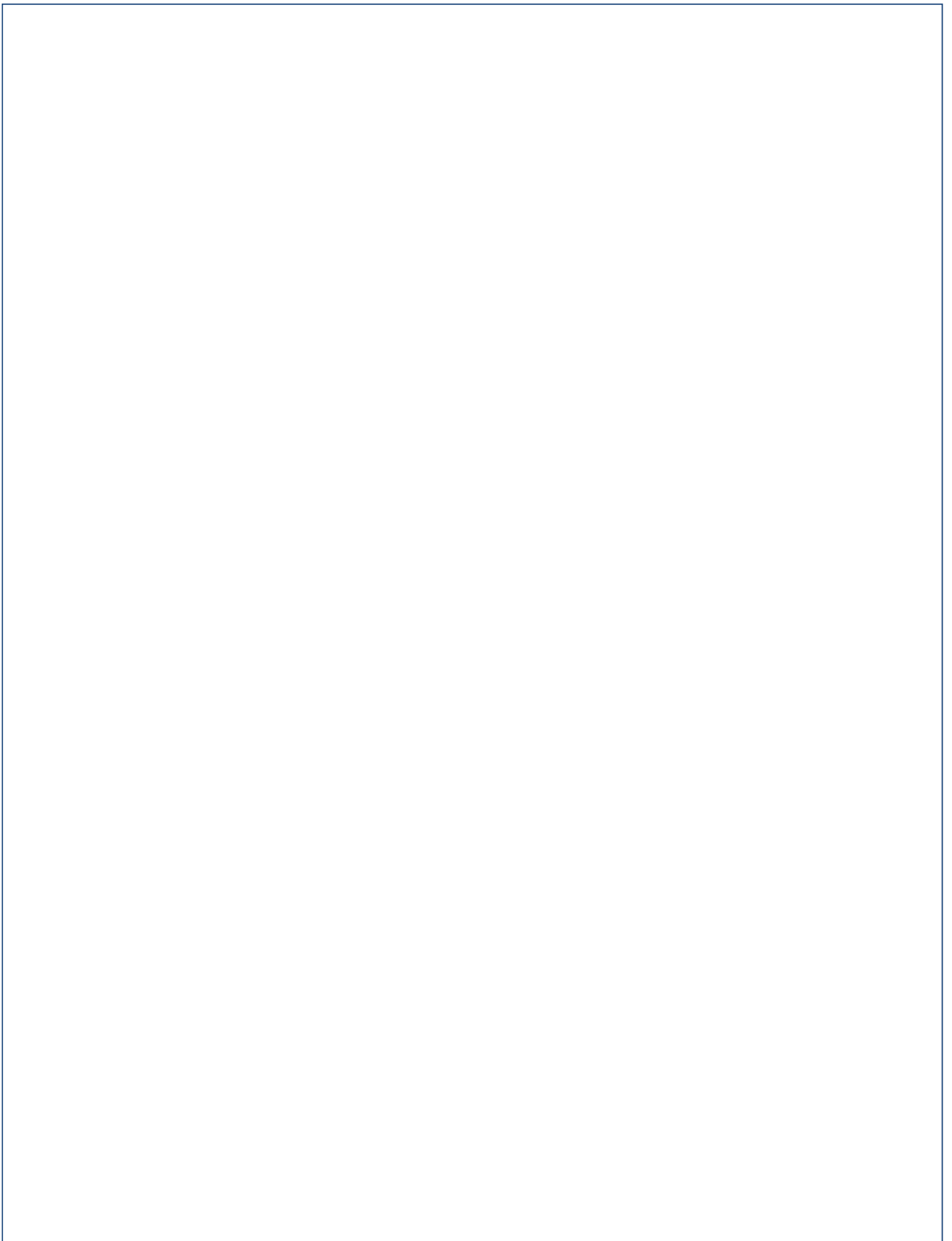
(B) by striking the last sentence and inserting the following: 'The Administrator in appointing the members of the committee shall ensure that the research centers of air transportation excellence, universities, corporations, associations, consumers, and other Government agencies are represented.'

(c) RESEARCH AUTHORITY OF ADMINISTRATOR- Section 312(c) of the Federal Aviation Act of 1958 (49 App. U.S.C. 1353(c)) is amended by inserting after the third sentence the following: 'The Administrator shall undertake or supervise research programs concerning airspace and airport planning and design, airport capacity enhancement techniques, human performance in the air transportation environment, aviation safety and security, the supply of trained air transportation personnel including pilots and mechanics, and other aviation issues pertinent to developing and maintaining a safe and efficient air transportation system.'

(d) CONFORMING AMENDMENT- That portion of the table of contents contained in the first section of the Federal Aviation Act of 1958 relating to section 312 of that Act is amended by adding at the end the following:

(i) Aviation research and centers of excellence.'







Center of Excellence for
Commercial Space Transportation