Florida Institute of Technology

Florida State University

NM State University

New Mexico Tech

Leland Stanford Junior University

University of Colorado

University of Central Florida

UF University of Florida

utmb Health

www.coe-cst.org

COE CST Center of Excellence for Commercial Space Transportation

Federal Aviation Administration Center of Excellence for Commercial Space Transportation

Year 6 Annual Report

Executive Summary

December 31, 2016

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LETTER FROM THE EXECUTIVE DIRECTOR

Center of Excellence for Commercial Space Transportation

This sixth Executive Summary of the work undertaken and the products produced by the Center of Excellence for Commercial Space Transportation highlights the breadth and depth of the work being accomplished at nine core universities, other agencies, many affiliate members, and an expanding group of spaceflight companies across the country. The work summarized here demonstrates the research, education, and training necessary to support, safeguard, and promote the growing commercial space flight industry. It takes a team effort, visionary leadership, and an attitude of not accepting "no" as an answer when facing the challenges of ensuring safe access to space. Our goal is to make saying "yes" the correct and safest answer we can.

Through the guidance of the FAA Office of Commercial Space Transportation we have assembled a robust and expanding team of academia, industry, and government participants – all working together to push the edges of knowledge, science, and engineering to make the future brighter and safer for commercial space flight.

An exciting component of the information presented within is the growing number of students who are directly participating in the work of the COE. It is these individuals who will become the life-blood of workers, scientists, and engineers in the future. By engaging students at each of our universities in the research supporting commercial spaceflight, the Center of Excellence for Commercial Space Transportation will meet its mission of enabling safe access to space.

THANK YOU to the FAA Office of Commercial Space Transportation for your vision, direction, and support over the past six years to enable these advances in commercial spaceflight.

James M. Vanderploeg, MD

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 6 Annual Report Executive Summary. This year is a tipping point in the history and evolution of the COE CST.

The COE CST is a collection of nine incredible universities (as will be described in more detail later in this document) 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 five years of operation were focused on building the various types of relationships (e.g., research, administrative, financial, personal, etc.) among the many individuals at each of the 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 more challenging than what may be encountered at other COEs with more universities and larger budgets. Despite this complexity, the COE CST has successfully emerged from the initial “getting to know you” period as a fully functional, cohesive unit.

Year 6, however, begins the second half of the ten-year program. During this phase of the organization, emphasis is being placed on raising the COE CST profile with industry to better understand the needs of the evolving commercial space marketplace, and to be better understood by the major marketplace actors.

Dr. George Nield, Associate Administrator of FAA AST, and Dr. Patricia Watts, National Program Director of the FAA COEs, are two individuals without whose support the COE CST could not function today. They are recognized as driving forces for the past successes of the COE CST and will be the source of any future accomplishments as well. The COE CST is very grateful for their support.

Each of these 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. Thank you ALL.

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 COE CST Program Manager, Mr. Ken Davidian, 202-267-7214, ken.davidian@faa.gov.

- December 31, 2016

INTRODUCTION

This executive summary accompanies a more detailed, three-volume annual report of the FAA COE CST. The annual report volumes will be available on the COE CST web site:

- Volume 1 provides a full description of the FAA COE CST including its research, structure, member universities, funding, and research tasks.
- Volume 2 is a comprehensive set of presentation charts of each research task as presented at the Sixth Annual Technical Meeting in October 2016.
- Volume 3 is 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 and has subsequently added Affiliate and Associate organizations including both universities and industry members.

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.

The overall scope of COE CST research themes is given and each of the research tasks initiated, conducted and concluded by the COE CST during the sixth year of operation are listed. Summary information of each task is then provided 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.

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 and education, technology transfer and 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 $300M in matching contributions to offset the research costs incurred by the government organizations.

Other COEs have been established by the FAA that pre-date the COE CST, including:

- 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 Joint Center for Advanced Materials (JAMS), in operation from 2003 to 2016.
- The Airliner Cabin Environment and Intermodal Research (ACERite) Center, in operation from 2004 to 2014.

Since the creation of the COE CST in August 2010 and as of December 2016, four new COEs have been created. They are:

- The Center of Excellence for General Aviation Safety Research (named PEGASAS, Partnership to Enhance General Aviation Safety, Accessibility and Sustainability), established in 2012.
- The Center of Excellence for Alternative Jet Fuels and Environment (ASCENT), established in 2014.
- The Center of Excellence for Unmanned Aircraft Systems (UAS), established in 2015.
- The Center of Excellence for Technical Training and Human Performance, established in 2016.

FAA CENTER OF EXCELLENCE FOR COMMERCIAL SPACE TRANSPORTATION

Below is a quick look at COE CST year 6 highlights and technical publications.

COE CST YEAR 6 HIGHLIGHTS

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

- Sixth Annual Administrative Meeting held on the campus of the University of Texas Medical Branch in Galveston, Texas on March 29-30, 2016.
- Sixth Annual Technical Meeting held in Las Cruces, New Mexico, in conjunction with the International Symposium for Personal & Commercial Spaceflight, on November 11, 2016.
- The New Space Journal completed its fourth year featuring topics of lunar markets, the risk and safety of human spaceflight, the booming commercial small satellite market, and international, non-governmental space activities.
- There were 22 research activities conducted during the sixth year of COE CST operation, resulting in 29 technical publications. All tasks are listed later in the Executive Summary.

COE CST STUDENTS, PARTNERS AND PUBLICATIONS

Table of COE CST metrics for operational years 1 through 6.

COE CST Year-by-Year Metrics	Year 1 (FY10)	Year 2 (FY11-12)	Year 3 (FY13)	Year 4 (FY14)	Year 5 (FY15)	Year 6 (FY16)
Active Tasks	34	24	28	28	36	22
Unfunded Tasks	34	22	22	11	6	5
Principal Investigators	27	28	29	25	31	22
Students	31	37	55	47	61	28
Publications	0	38	28	22	29	19
Research Partners	-	17	20	27	27	11
Industry Partners	-	29	44	55	57	11
Affiliate Members	0	1	6	6	6	6
Associate Members	-	-	-	3	6	3
Funding Profile	$2M	$2.4M	$1.1M	$1.1M	$1M	$1M
Administrative Overhead	13.6%	20.0%	9.9%	27.0%	19.7%	16.4%

In the sixth year of operation, the COE CST benefited from the research of 28 students, 11 research partners and 11 industry partners. The combined effort resulted in 19 technical/programmatic papers published in journals or presented at conferences. A complete list of students, industry, research organizations, and publications is given after the research task summary charts in this report.

A new row has been added to the metrics this year to show the percentage of total FAA funding that has been dedicated to the administrative costs of operating the COE CST. Accounting for funding provided over all seven fiscal years, the average annual administrative cost is just less than 15%. On the basis of six operating years, the average is under 18%. The variation seen from one fiscal year to the next results from paying for administrative costs of more than one operating year from the allocation of a single fiscal year (e.g., paying for three bi-annual meetings from a single fiscal year's budget, instead of two).

FAA AST TECHNICAL MONITORS

Technical monitors are the links between FAA's research requirements and the work being performed by COE CST member universities. Below is a brief listing of the FAA COE CST Technical Monitors who contributed to the research efforts of the principal investigators and students:

- Mr. Ken Davidian, COE CST Program Manager, Office of the Chief Engineer
- Mr. Nickolas Demidovich, Office of the Chief Engineer
- Mr. Steph Earle, Office of Special Projects
- Mr. Henry Lampazzi, Licensing & Evaluation Division
- Ms. Karen Shelton-Mur, Space Transportation Development Division

- Mr. John Sloan, Office of Strategic Planning
- Mr. Gunther Smiley, Space Transportation Development Division
- Ms. Yvonne Tran, Regulations & Analysis Division
- Dr. Paul Wilde, Deputy Chief Engineer

The specific tasks for which each Technical Monitor is responsible is given in the research task table in the "COE CST RESEARCH TASKS" section and on each of the research task summary (quad) charts. The universities appreciate the time, dedication, and intellectual expertise provided by the technical monitors. The researcher/technical monitor relationship is important to all partners, equally beneficial.

COE CST MEMBER UNIVERSITIES

The COE CST member universities are: 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 University of Texas Medical Branch at Galveston (UTMB).

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. Combined, the universities bring over 50 other government, industry and academic organizations as research partners.

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.

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, 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. SpaceX and UP 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)

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. This is complemented by more recent involvement in the commercial orbital and suborbital spaceflight industry supporting space flight participant visits to the ISS and preparation of passengers and crew for suborbital space flights.

COE CST AFFILIATE MEMBERS

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY (ERAU)

Embry-Riddle Aeronautical University (ERAU) team focuses on the demonstration, verification, and validation of the AST funded, and ERAU developed ADS-B prototype (UAT Beacon Radio – ERAU model) for the reusable sub-orbital space vehicles for the first year.

MCGILL UNIVERSITY (MU)

McGill University's Institute of Air and Space Law (IASL) offers the most comprehensive and advanced graduate level space law program in the world covering General Principles of Space Law, Law of Space Applications and Government Regulation of Space Activities.

NATIONAL AEROSPACE TRAINING AND RESEARCH (NASTAR) CENTER

The National AeroSpace Training and Research (NASTAR) Center is partnering with UTMB and the FAA COE CST to participate as an industrial affiliate in an advisory board capacity and also as a research partner providing cost sharing support. It offers a strong foundation in flight training and research to

improve the health and safety of passengers in the extreme aviation and space environments. Most recently, NASTAR donated time and use of its centrifuge for a COE CST sponsored novel study on G-tolerance of subjects with chronic diseases.

SOLSTAR SPACE CORPORATION (SOLSTAR)

Solstar Communications focuses on test of satellite communications systems on-board suborbital platforms to provide low-cost data communications for research payloads, payload operators, and space vehicle operators, and government agencies such as the FAA and NASA. The satellite systems to be tested include, but are not limited to, Iridium, Globalstar, and Inmost.

SIMPSON COLLEGE (SIM)

Simpson College had a strong background in interdisciplinary modeling, with the college routinely producing nearly one-third of the world's top MCM/ICM teams every year. This strong modeling heritage has been recently combined with significant FAA AST regularity expertise, meaning Simpson College is now able to create, test, and support unique policy or regulatory solutions through the COE CST. These solutions - like the Draper-Santos airspace projection, the Class X airspace concept, and the risk-based population database being built and supported at Simpson College - enable the creation of performance-based regulations that facilitate industry growth while protecting public property and safety.

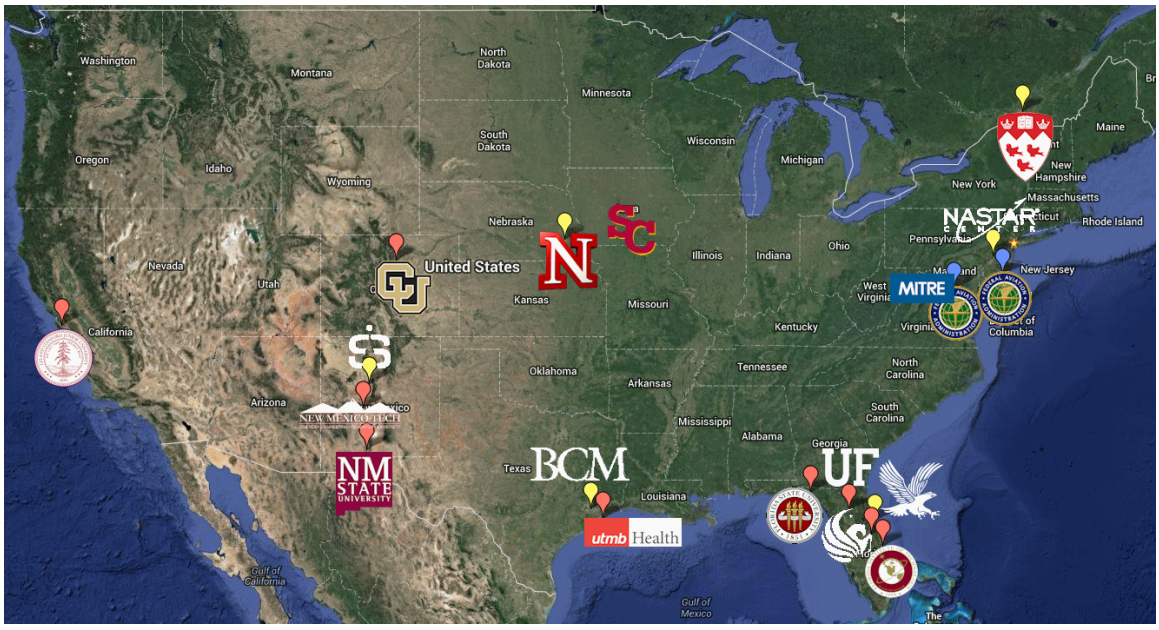
UNIVERSITY OF NEBRASKA LINCOLN (UNL)

The University of Nebraska, emphasizing collaboration between space law and policy, focuses on how the liability regime will achieve the appropriate balance between the risks and benefits of allowing lay persons to travel to space, and what elements of the liability regime are best addressed at both the national and international levels. In addition the research will look at how to avoid over/under-regulating so as to retain profitability and viability, and how regulation should evolve as the industry matures.

COE CST ASSOCIATE MEMBERS

Associate Members are much more loosely associated with the COE CST, but their contributions can be very significant. During the sixth year of operation, the COE CST was proud to have the following institutions as Affiliate Members: NASA Ames Research Center, the MITRE Corporation, and the German Space Agency, DLR.

Map of COE CST Member and Affiliate University Geographic Distribution

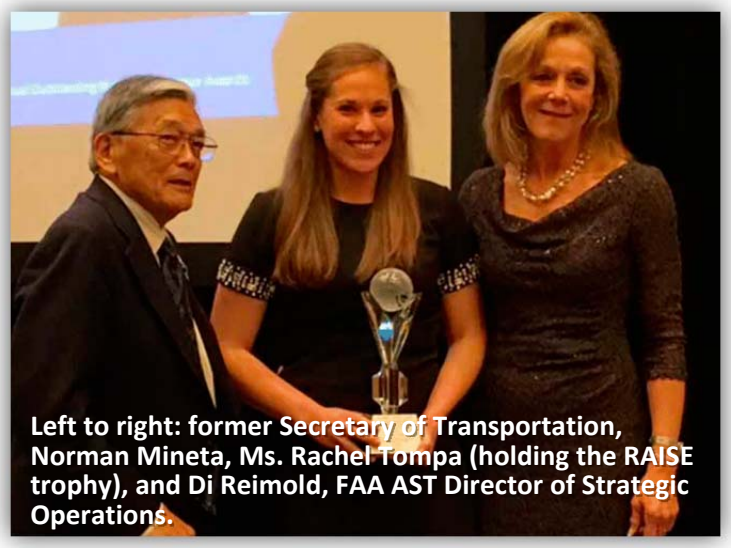


AWARDS AND RECOGNITION

During the past five years, many of the principal investigators and students from COE CST member universities have received promotions, awards, and recognition for the work they do. The FAA would like to recognize and congratulate all the recognized recipients for their great achievements in the sixth year of operation.

RACHEL TOMPA RECEIVES DOT RAISE AWARD[1]

Secretary of Transportation Anthony R. Foxx honored Rachael Tompa, a Ph.D. student at Stanford University, with the Recognizing Aviation and Aerospace Innovation in Science and Engineering (RAISE) award at the 26th Annual Outstanding Student of the Year ceremony in Washington, D.C. on January 7 hosted by the Council of University Transportation Centers (CUTC) at TRB. The annual award encourages college students to think creatively and develop innovative solutions to aviation challenges.



Left to right: former Secretary of Transportation, Norman Mineta, Ms. Rachel Tompa (holding the RAISE trophy), and Di Reimold, FAA AST Director of Strategic Operations.

Tompa's work with the FAA Center of Excellence for Commercial Space Transportation focuses on safely integrating commercial space vehicles into the National Airspace System. She has explored a method to minimize airspace closures and civilian aircraft rerouting that are typically implemented to maintain safety during commercial space launch operations.

186-SU SPACE ENVIRONMENT MODELING AND PREDICTION

- S. Close promoted to Associate Professor with tenure.
- A. Li - Outstanding Paper Award for Young Scientists from the Committee on Space Research

304-MU LEGAL ISSUES OF CROSS-BORDER SUB-ORBITAL FLIGHTS

- Dr. Nicholas M. Matte Prize
- Joseph A. Bombardier Scholarship
- The Eilene M. Galloway Award
- The Milton "Skip" Smith Award
- The Robert E. Morrow, QC Fellowship Award

311- ROBUST AND LOW-COST LED ABSORPTION SENSOR

- Subith Vasu received 2016 Reach for the Stars award.

MITRE SAFETY OF LAUNCH AND REENTRY OPERATIONS IN THE NATIONAL AIR SPACE

- Best paper of track: Dr. Wang, G., Tao, Z., Masek, T., and Schwartz, J. L., "A Monte Carlo Simulation Tool for Evaluating Space Launch and Re-entry Operations," Integrated Communications Navigation and Surveillance (ICNS) Conference. Herndon, VA, 2016.

COE CST RESEARCH RESULTS – "SUCCESS STORIES"

The following are examples of research results that were presented at the Sixth Annual Technical Meeting (ATM6) held in Las Cruces, NM on October 11, 2016.

[1] Verbatim text taken from the "MyFAA FocusFAA" news feed on January 10, 2017.

TASK 193-CU: YOUNG PROFESSIONAL INDUSTRY VIABILITY WORKSHOPS

In fulfillment of all three of the FAA Center of Excellence for Commercial Space Transportation (COE CST) goals, research, training, and outreach, PhD student Brad Cheetham has conducted nine Emerging Space Industry Leader's (ESIL) workshops since 2011. With a primary research focus of industry viability, ESIL workshops use a game-theory based framework to investigate key commercial space industry segments, encourage and enhance participation by young professionals and students, and disseminate the information at conferences and in publications.

The workshops are typically conducted over 1-2 days, including 6-8 hours of learning, and conducting research based on the game theory PARTS analysis with the help of subject matter experts. The final products typically include presentations and papers. Past workshops have focused on relevant topics, such as microgravity research, commercial remote sensing, small satellite launchers, and spaceflight training. The workshops include extensive industry involvement in presentations and sponsorship. To date, over 100 participants have attended ESIL workshops. In 2016, two ESIL workshops were conducted, in the topic areas of cis-lunar resource utilization and space traffic management.

Participants of the ESIL-09 workshop on space traffic management.

The ESIL workshop format is continually being refined and improved. ESIL-10 is currently in the conceptual planning stages and seeking industry partners and sponsors. For more information about past ESIL workshops, with links to workshop presentations and reports, visit www.ESIL.space on the web.

TASK 308-UTMB: SCREENING SPACEFLIGHT PARTICIPANTS FOR SUBORBITAL SCIENCE

As part of the FAA Center of Excellence for Commercial Space Transportation (COE CST), researchers at the University of Texas Medical Branch (UTMB) have been studying whether people with common physical ailments and diseases (including back and neck injuries, heart problems, diabetes, asthma, implanted devices such as pace makers, etc.) can fly into space.

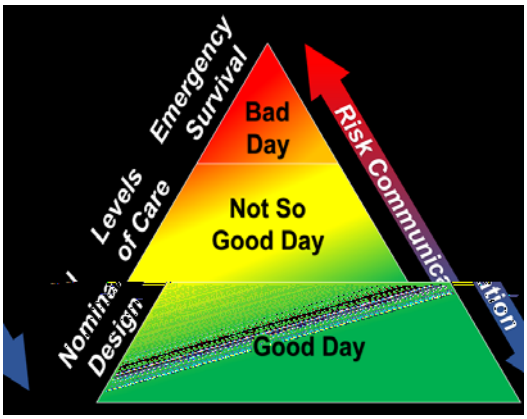
Space doctors are finding that the most significant barrier to flying ordinary people may not be their physical ailments but something that is much less understood: anxiety. After "spinning" more than 150 average individuals in a centrifuge that simulates suborbital space travel, UTMB researchers found that anxiousness could have the biggest impact on their ability to fly, resulting in a negative experience, or endangering the flight itself.

Ideally, space flight candidates who may experience a panic attack would be identified before they invest a lot of time and money on tickets and training. At present, there are currently no known effective methods to predict who will react negatively to the space flight experience.

The most recent set of studies addressed this issue, comparing different training techniques and trying to identify different predictive indicators of an individual's likelihood of experiencing high anxiety during space flight. A new set of centrifuge trials were conducted between November 2015 and June 2016, "spinning" another set of subjects through simulated suborbital space flight experiences, bringing the total to over 300. Preliminary results of this research indicate that of the 157 subjects recruited, ten opted out of one or more centrifuge runs due to "poor tolerance" generally related to anxiety, motion sickness, or both. The most successful training techniques that improved the subject's comfort included high-fidelity simulations and repetitive exposure. Regarding the prediction of an individual's anxiety, few reliable factors were identified.

TASK 320-CU: SIMPLY PRESENTING SPACEFLIGHT SAFETY

As part of the FAA Center of Excellence for Commercial Space Transportation (COE CST), researchers from the University of Colorado Boulder (CU) have been developing a framework for assessing and communicating the risk associated with spaceflight to possible spaceflight participants.



Commercial space travel, as with any mode of transportation, inherently introduces some degree of risk to the onboard occupants and the uninvolved public. Risks arise from the potential for vehicle failures, environmental hazard interactions, or human errors. Outcomes range from discomfort or incomplete objectives, up to health impacts and loss of life. The potential for onboard illness or injury unrelated to vehicle failure can also be considered as a risk. Risks that cannot be mitigated must be characterized and effectively communicated to crewmembers and spaceflight participants. The process of identifying, quantifying and mitigating risk is typically accomplished using various techniques in systems engineering design, through operational protocols, and is generally vehicle-specific. CU researchers have proposed a more general framework with three categories: “Good Day, Not so Good Day, and Bad Day.” Ways of comparing risks of spaceflight have been developed with the finding that spaceflight is approximately as dangerous as climbing Mt. Everest! Ultimately, the output of this research is to facilitate the ability of commercial launch operators and the FAA to fulfill their responsibilities related to informed consent.

TASK 329-NMT: FAST TRACKING TELESCOPE PHOTO TESTS

Researchers at New Mexico Institute of Mining and Technology (NMT) are developing ways to use a very powerful telescope that can move very fast to take pictures of commercial rocket as they take off and return. These photos can be used to assist investigators if there is an accident or incident with the rocket.

As part of the FAA Center of Excellence for Commercial Space Transportation (COE CST), astronomers from the NMT, using the Magdalena Ridge Observatory (a fast-tracking telescope with a 2.4-meter mirror produced as a backup for the Hubble Telescope) are developing methods to help monitor the launch and reentry operations of spacecraft. In the case of an "off-nominal event" (more commonly referred to as an "accident"), this activity could provide useful information.

The goals of this task were to develop software to perform fully autonomous, closed-loop tracking using observational data collected via both the acquisition telescope and the 2.4-meter telescope imaging camera. As a pilot program, this task took eight half-nights of observational tracking data of weather balloons (or similar) as targets.

An undergraduate student in mechanical engineering at NMT spent the summer of 2016 developing a Python program to grab target positional information and then interface with and point the telescope to acquire the target. The software was successfully tested in September 2016. Additional software was developed to open-loop track the target and was tested successfully on two additional targets.

Most recently, a high-altitude balloon was imaged at a distance of 400 km and 3º above horizon. Future work includes testing and perfecting the closed-loop auto-tracking using night-time, lighted targets, and an attempt will be made to increase the resolution of the imagery with a fast-framing CCD camera and selected image reconstruction post-processing.

COE CST RESEARCH TASKS

The research conducted within FAA AST is broken into four major research themes:

- Space Traffic Management & Spaceport Operations
- Space Transportation Vehicles
- Human Spaceflight
- Space Transportation Industry Viability

The goals associated with each of the four areas of CST research include:

- Safe Integration of Air & Space Traffic Management, to effectively answer those topics related to the development and optimization of technical and regulatory provisions and processes used to oversee, coordinate, regulate, and promote safe and responsible space all activities between space and Earth (including access to, operations in and return from space to Earth) to avoid physical and/or electromagnetic interference.
- Improved vehicle safety and risk management, including knowledge of all safety-critical components and systems of the space vehicles and their operations, so as to better identify potential hazards and to better identify, apply and verify hazard controls.
- Ensure human safety of those onboard during space vehicle operation and those involved with spaceport operations.
- Increase industry viability, including economic, legal, legislative, regulatory, and market analysis & modeling.

Each of these major research themes is divided into programs and these are further divided into projects and tasks. Further subdivisions of these research areas are provided in the Commercial Space Transportation Research Road Map document, available on the web at www.coe-cst.org.

The following pages include a list of the individual COE CST research tasks conducted during the sixth year of operation followed by summary (quad) charts for each task.

The presentation order of the summary charts follows the list of tasks given in the table below.

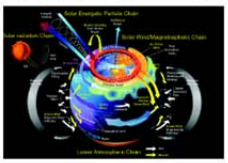
All FAA FY16 COE CST R&D Tasks (as of 31 Dec 2016)				
Task #	**Task Title**	**Principal Investigator(s)**	**Technical Monitor**	**Status**
SPACE TRAFFIC MANAGEMENT AND SPACEPORT OPERATIONS RESEARCH TASKS				
186-CU	Space Environment Modeling and Prediction	Fuller-Rowell	Shelton-Mur	IP-F
186-SU	Space Environment Modeling and Prediction	Close	Shelton-Mur	IP-UF
187-CU	Space Situational Awareness	Scheeres	Earle	IP-F
329-NMT	Tracking and Monitoring Suborbital Space Vehicles	Ryan / Shirer	Demidovich	IP-F
331-SU	Advanced 4D Special Use Airspace Research	Alonso	Smiley	IP-F
332-SIM	Defining Class X Air Space	Draper	Wilde	AFF
MITRE	Safety of Launch and Reentry Operations in the NAS	Tao	Wilde	ASSOC
SPACE TRANSPORTATION VEHICLE RESEARCH TASKS				
241-FSU	High Temperature, Optical Sapphire Pressure Sensors	Oates	Demidovich	NCE
253-UCF	Ultra High Temperature Composites	Kapat, Gou	Demidovich	NCE
299-NMT	Nitrous Oxide Composite Tank Testing	Lim / Zagrai	Tran	IP-F
306-ERAU	ADS-B Research and Demonstration	Stansbury	Demidovich	AFF
307-SOL	Commercial Satellite Communications for Spacecraft	Barnett	Demidovich	AFF
311-UCF	Robust and Low-Cost LED Absorption Sensor	Vasu / Kapat	Demidovich	IP-F
323-NMT	Structural Health Monitoring Framework	Zagrai	Demidovich	IP-F
325-FSU	Optical Measurements of Rocket Nozzle Thrust and Noise	Kumar	Demidovich	IP-F
HUMAN SPACEFLIGHT RESEARCH TASKS				
308-UTMB	Suborbital SFP Anxiety Assessment	Vanderploeg	Lampazzi	IP-F
309-UTMB	Suborbital Pilot Training Assessment	Vanderploeg	Lampazzi	IP-F
310-UTMB	Increasing Cabin Survivability in Commercial Spacecraft	Vanderploeg	Lampazzi	IP-F
320-CU	Comm'l Spaceflight Risk Assessment and Communication	Klaus	Lampazzi	IP-F
333-FIT	Onboard Context-Sensitive Info System	Boy	Lampazzi	IP-UF
SPACE TRANSPORTATION INDUSTRY VIABILITY RESEARCH TASKS				
193-CU	Emerging Space Industry Leader Workshops	Scheeres	Davidian	IP-F
304-MU	Legal Issues of Cross-Border Sub-Orbital Flights	Jakhu	Sloan	AFF

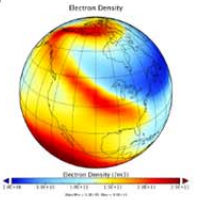
Note: Among the 22 COE CST tasks active in Year 6, 13 are in process and funded (IP-F), 2 are in process with a no cost extension (NCE), and 2 are in process but unfunded (IP-UF). 5 tasks are being performed by an Associate (ASSOC) or Affiliate Member (AFF).

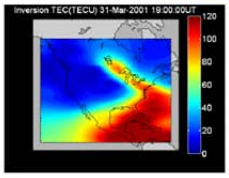
Abbreviations:
CU–University of Colorado Boulder, ERAU–Embry-Riddle Aeronautical University, FIT–Florida Tech, FSU–Florida State University, MU–McGill University, NMSU–New Mexico State University, NMT–New Mexico Tech, SIM–Simpson College, SOL-Solstar Space, SU–Stanford University, UCF–University of Central Florida, UF–University of Florida, UTMB–University of Texas Medical Branch.

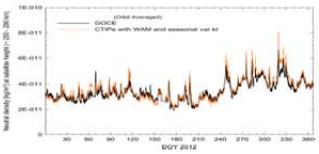
TASK 186-CU. MITIGATING THREATS THROUGH SPACE ENVIRONMENT MODELING & PREDICTION

The Physical System (image courtesy of Joe Grebowsky)









PROJECT AT-A-GLANCE

- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. Tim Fuller-Rowell
- STUDENT: Catalin Negrea

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

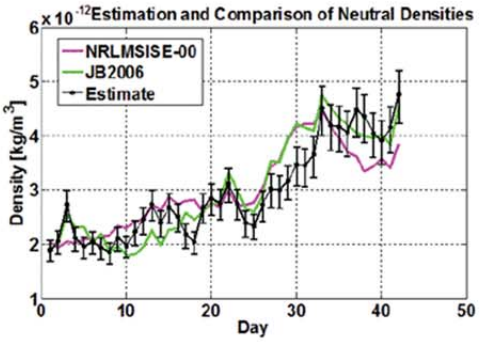
- Real-time NEMS-WAM with lower atmosphere data assimilation has been running in development mode for one year
- WAM has been coupled 1-way to a plasma model IPE

FUTURE WORK

- Compare WAM tidal and wind fields in the 100 to 150 km suborbital and re-entry region with satellite wind and temperature observations from SABER and WINDII.
- Compare WAM temperature structure with available ground-based LIDAR observations.
- Examine impact of WAM dynamic variability on the ionosphere.
- Begin to investigate how WAM/IPE fields can support CST.

TASK 186-SU. SPACE ENVIRONMENT METEOROID AND ORBITAL DEBRIS MODELING & PREDICTION

Comparison of Neutral Densities Estimated by New Method with Existing Models



PROJECT AT-A-GLANCE

- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR: Sigrid Close
- STUDENT: Diana Hernandez Juarez Madera

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 characterization of 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 identify the mechanisms for the effects of charging on electrical failures. 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.

STATUS

- Developed new order estimate models using multiple equivalent platforms to determine neutral densities
  - Improvement of 7-10% using CubeSats
  - Improvement of 2-5% using meteoroids
- Developed models to assess meteoroid threat to spacecraft (mass flux and speed as a function of orbit)

FUTURE WORK

- Meteoroid fragmentation using combined radar and optical data with particle-in-cell (PIC) models
- CFD models for meteor formation

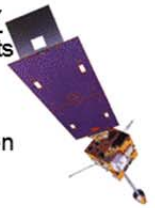
TASK 187-CU. SPACE SITUATIONAL AWARENESS

PROJECT AT-A-GLANCE

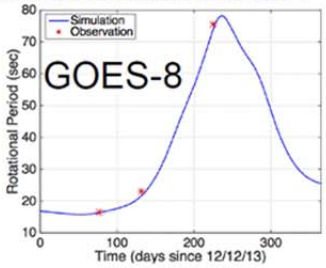
- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. Dan Scheeres

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.



Large Fluctuations of Spin Period in Defunct GOES-8 Satellite can be accurately fit by modeling Solar Radiation Pressure Effects



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.

STATUS

- Graduated two FAA-funded PhD students: Kohei Fujimoto, May 2013 & In-Kwan Park Fall 2015
- 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 12 papers published with more in peer review

FUTURE WORK

- Next proposed stage of direct FAA funded research will focus on developing a rapid asset/debris conjunction analysis tool
- Non-directly funded research will focus on:
  - Long-term space debris dynamics (orbit and attitude)
  - Modeling and estimation of debris non-gravitational forces

TASK 329-NMT. TRACKING AND MONITORING SUBORBITAL COMMERCIAL SPACE VEHICLES

PROJECT AT-A-GLANCE

- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR(S): William H. Ryan, Eileen V. Ryan
- STUDENT: Jacob Schirer

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Develop an asset ~100 km Northwest of Spaceport America in New Mexico that can be utilized to assess spacecraft health and assist in launch/re-entry anomaly resolution.
- Develop data products useful for mishap investigation for Commercial Space Vehicle launches.

STATEMENT OF WORK

- Develop software to perform fully autonomous, closed-loop tracking using observational data collected via both the acquisition telescope and the 2.4-meter imaging camera.
- Take 8 half-nights of observational tracking data using weather balloons (or similar) as targets.
- Analyze test tracking data, identify limitations, then improve algorithms for target tracking.

The MRO 2.4-meter telescope is a fast-tracking instrument located within line-of-sight to NM Spaceport. Stratospheric balloons serve as good test targets for pointing and tracking-software development in preparation for commercial space vehicle launch monitoring.

BALLOON TRACKING USING 2.4-M TELESCOPE

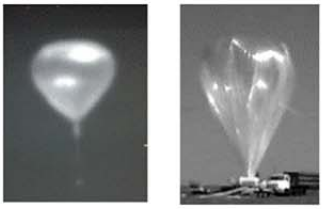


Image (left) taken with the MRO 2.4-meter telescope of "Test Flight" on 09/29/16. Telescope was pointed at an elevation of 3.1° and slant range to balloon was 400 km. Actual balloon (right).

STATUS

- An undergraduate student in mechanical engineering developed a Python program to grab positional information on balloon targets from the data posted by Ft. Sumner in order to point the telescope. The pointing software was tested successfully on the HASP balloon on 09/02/16.
- Additional software was developed to open-loop track the target and was tested successfully on two additional targets.

FUTURE WORK

- Test and perfect closed-loop auto-tracking using night-time, lighted targets.
- Potentially improve resolution with a fast-framing CCD camera and selected image reconstruction post-processing.

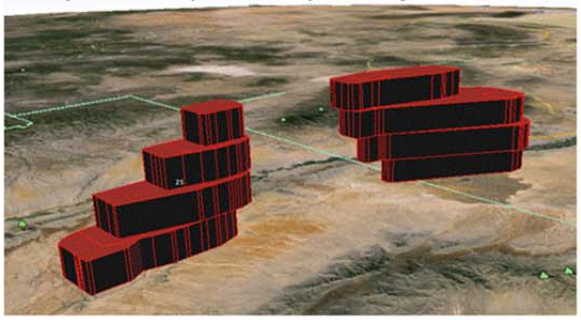
TASK 331-SU. ADVANCED 4D SPECIAL USE AIRSPACE RESEARCH

PROJECT AT-A-GLANCE
- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR: Prof. Juan J. Alonso
- STUDENT: Thomas Colvin (graduated Sept. 2016)

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- We are developing and analyzing new methods for safely integrating space vehicle into the National Airspace System. This work will reduce the disruption to air traffic associated with launch and reentry events to ensure fair and safe access to the national airspace.

STATEMENT OF WORK
- Developed initial Compact Envelope techniques
- Modifications of NASA FACET tool to enable Compact Envelope analysis
- Basic Kernel Density Estimation techniques are used to generate probabilistic compact envelopes
- Implemented Aircraft Vulnerability Models for improved risk calculation
- FACET modified to incorporate Terminal Area Forecast data for simulations of future air traffic
- Run multiple future NAS-wide simulations to quantify the impact of Compact Envelopes on the national airspace
- Quantified near-elimination of air/space conflicts with the use of compact envelopes, even in very congested airspace.
- Multiple paper published. Final journal paper manuscript undergoing final revisions.

Example of a Compact Envelope for a Lynx-like vehicle



STATUS
- Completed NAS-wide simulations jointly with FAA Office of NextGen to demonstrate the superiority of compact envelopes over traditional methods for air/space integration.
- Details presented in multiple publications and in PhD dissertation.

FUTURE WORK
- Publication of journal version of results
- Final version of open-source environment to be completed
- Project will conclude in the coming months

TASK 332-SIM. ASSESSING RURAL AIRPORTS FOR MANNED AND UNMANNED RLV

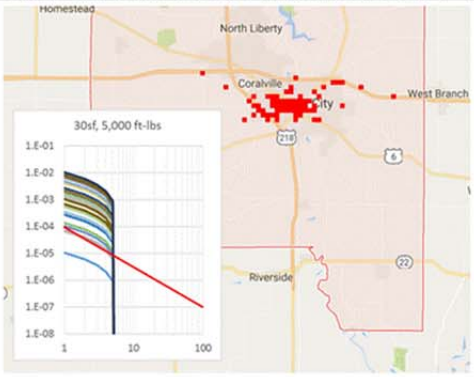
PROJECT AT-A-GLANCE
- COE CST UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR: Chris Draper (Meidh)
- STUDENTS: Kristina Smith, Nick Joslyn, Mackenzie Finnegan

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- Expanding manned and unmanned RLV operations requires streamlined strategies for enabling more flights from more locations while continuing to protect the public.

STATEMENT OF WORK
- This work will define airspace volumes of the NAS as a function of vehicle kinetic energy within which vehicles may operate in an unrestricted manner without violating an appropriate risk level.

STATUS
- Analysis run for daytime flights in the areas of Johnson County surrounding Iowa City over a rage of debris field sizes and impact energies
- Refining data ingestion and manipulation procedures for nationwide population database that accounts for sheltered populations based upon county tax assessor level structure data, which will output RRAT and RSAT compatible population input files.

Regions that Violate Risk Profile Assuming Pf = 1



FUTURE WORK
- Population Modelling
  - Refine structure-to-structure precision
  - Improve cluster modelling
  - Improve roof and wall classification system
- Airspace Boundary Modelling
  - Optimize Draper-Santos boundaries using RSAT

TASK MITRE. EVALUATING THE SAFETY OF LAUNCH AND REENTRY OPERATIONS IN THE NATIONAL AIR SPACE

MITRE

PROJECT AT-A-GLANCE

- The MITRE Corporation
- PRINCIPAL INVESTIGATOR: Zheng Tao
- Team: Dr. Ganghuai Wang, Ashley G. Williams, Tudor Masek, Tom St. Clair, Jon L. Semanek, Jonathan L. Schwartz

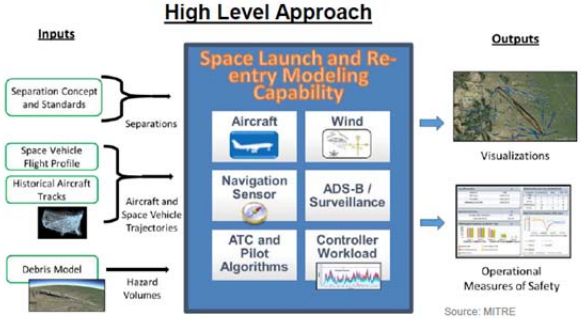
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

The FAA segregates large amounts of airspace to ensure safety during launch and reentry operations. This requires other National Airspace System (NAS) users to reroute around them, and may limit launch and reentry opportunities in the future. The FAA is implementing more efficient separation concepts such as contingent (dynamic) aircraft hazard areas (AHAs) to minimize their impact on NAS users, and allow for more routine launch and reentry operations. However, the FAA does not have a capability to statistically examine how long it would take aircraft to evacuate the AHAs while considering a variety of different factors. Understanding these interactions is critical to implementing more efficient separation concepts and standards.

STATEMENT OF WORK

- The MITRE Corporation's Center for Advanced Aviation System Development (MITRE CAASD) is developing a flexible, fast-time modeling and simulation capability that examines the time to evacuate these AHAs and quantifies how different factors (e.g., air traffic control notification delay, traffic orientation, and traffic density) affect those times
- The capability can help determine the safety of current and future dynamic AHAs
- Use of more dynamic AHAs will allow for more routine launch and reentry operations that have less impact on other NAS users

High Level Approach



STATUS

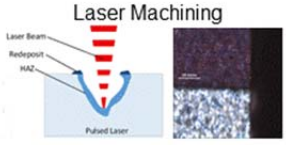
- This research is finishing up its second year, and to date the team has developed a prototype that has been used to evaluate the required response times in a variety of launch and reentry scenarios based on past missions

FUTURE WORK

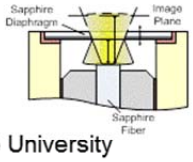
- Improve performance and functionality of model
- Assess additional launch and reentry scenarios
- Continue outreach and transition efforts to FAA and community

TASK 241-FSU. HIGH TEMPERATURE, OPTICAL SAPPHIRE PRESSURE SENSORS FOR HYPERSONIC VEHICLES

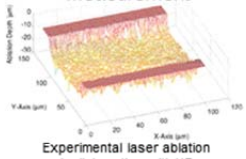
Laser Machining



Sensor Characterization

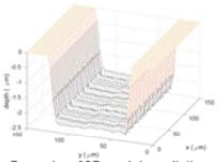


High Temp. Strength Measurement



Experimental laser ablation (collaboration with UF.

Laser Ablation Material Physics



Example of 3D model prediction of laser ablation of sapphire.

PROJECT AT-A-GLANCE

- UNIVERSITY: Florida State University
- PRINCIPAL INVESTIGATOR: William S. Oates
- STUDENT: Peter Woerner

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Development of high temperature sapphire based pressure transducers for structural health monitoring

STATEMENT OF WORK

- Implement sapphire based pressure transducer that can operate in high temperature environments (~1000 C to 1200 C)
- Sapphire transducers will be manufactured using silicon based chemical etching
- Sapphire based transducer requires a strong understanding of mechanical property changes due to laser micromachining
- Combined studies of single crystal dislocation mechanics and experimental testing focused on improved sensor reliability and manufacturing methods

STATUS

- Material physics of laser ablation expa dimensions to support micromachining manufacturing of sensors
- Uncertainty in light-matter physics and temperature mechanics analyzed usi Bayesian statistics algorithms and ne techniques
- Developed new fractal theories and f derivative methods that apply to com mechanisms governing fr ceramics

FUTURE WORK

- X-ray analysis of laser sub-surface material behavior governing dislocations, residual st their uncertainty
- High temperature pressure sensor calibratio hot jet implementation

TASK 253-UCF. ULTRA-HIGH TEMPERATURE COMPOSITES THERMAL PROTECTION SYSTEMS (TPS)

University of Central Florida

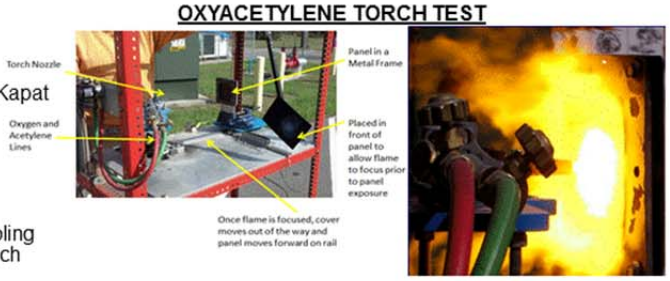
PROJECT AT-A-GLANCE

- UNIVERSITY: University of Central Florida
- PRINCIPAL INVESTIGATOR(S): Drs. Jan Gou & Jay Kapat
- STUDENTS: Chris Harris & Hongjiang Yang

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.

OXYACETYLENE TORCH TEST



STATEMENT OF WORK

- Develop structural ceramic matrix composites (CMCs) based on polymer derived ceramics for ultra-high temperature thermal protection systems.
- Develop top hard ceramic coatings for ultra-high temperature thermal protection systems.
- Ground testing of polymer derived ceramics composites (PDCC) thermal protection systems using Oxyacetytlene exposure test, shock tube test, and hot jet facilities.
- Arc Jet testing of polymer derived ceramics composites (PDCC) thermal protection systems
- 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

STATUS

- Develop 3D CMCs based on ceramic fibers/polymer derived ceramics composites.
- Oxyacetylene exposure testing of PDCC thermal protection systems.

FUTURE WORK

- Process optimization of ultra-high temperature ceramic fiber/PDC composites.
- Develop high performance front surface ceramic coatings for thermal protection systems
- Thermal-mechanical characterization of PDCC thermal protection systems using ground testing and flight testing

TASK 299-NMT. NITROUS OXIDE COMPOSITE CASE TESTING

NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH • UNIVERSITY

PROJECT AT-A-GLANCE

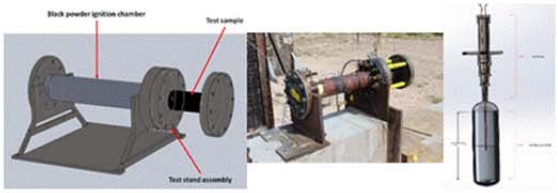
- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATORS: Seokbin (Bin) Lim, Andrei Zagrai
- STUDENTS: Antonio Garcia, Steven Sweeney, Josh Carroll

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

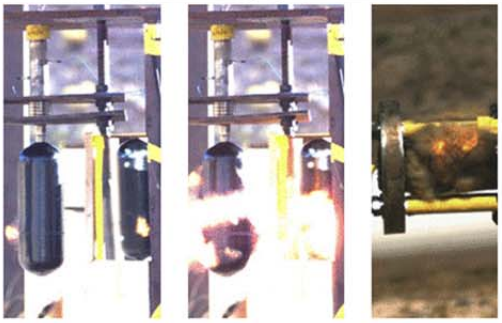
- Develop an understanding of fragmentation hazards from composite tanks used for fuel/oxidizer storage
- Develop a testbed for evaluating different storage tank materials or configurations at small and large scales

STATEMENT OF WORK

- Test metallic and composite tubes to failure to understand fragmentation hazards
- Develop standard test procedures for composite materials under shock and high-rate loading
- Develop analytical and computational models to compare to experiments
- Provide data to help set guidelines for safe distances during launch of commercial vehicles



Test fixture for pressurizing cylindrical tubes to failure



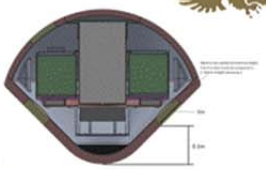
STATUS

- A system was developed for pressurizing cylindrical tubes & tanks to failure
- Nine tests have been completed with Composite tubes, and Tanks
- The fracture patterns are related with the type of materials under the extreme loading (Brittle & Non-brittle)
- Numerical simulations to predict the fragmentation are in progress

FUTURE WORK

- Finalize quantification of the crack opening characteristics
- Test composite tanks crack opening behavior
- Understand the kinetics of the fragments

TASK 306-ERAU. ADVANCED ADS-B PROTOTYPE FOR SUPPORT OF REUSABLE LAUNCH VEHICLES AND OTHER SPACECRAFT

- **PROJECTAT-A-GLANCE**
- UNIVERSITY: Embry-Riddle Aeronautical University
- PRINCIPAL INVESTIGATOR: Dr. Richard S. Stansbury
- STUDENTS: Brandon Neugebauer, Richard P. Day, Alonso Yosvany, and Dominic Tournour, Kelsey Klein, Andrew "Jack" Strange

RELEVANCE TO COMMERCIAL SPACE INDUSTR,Y

- ADS-B technology provides a low cost means of tracking suborbital reusable launch vehicles both during the ascent and descent providing details including: position, and velocity. It could reduce the footprint of airspace segregation required for commercial space operations as vehicle location would be known to both FAA and aircrews using their existing equipment

GOALS

- Demonstrate UBR-ERAU Advanced ADS-B on Up Aerospace SpaceLoft 8 rocket launch (complete)
- Analysis of data from SL-8 data to determine advanced ADS-B performance (complete)
- Demonstrate UBR-ERAU Advanced ADS-B on Up Aerospace SpaceLoft 11 rocket launch with upgraded GPS antenna
- Develop Advanced ADS-B for reentry spacecraft (complete)
- Continued integration on diverse set of platforms (in progress)
- Propose follow-on research for LEO operation (in progress)
- Propose concepts new ADS-B message format (in progress)

STATUS

- Flight demonstration on high-altitude balloon, sounding rocket, and re-entry vehicle prototype
- Maturation plan through flights via NASA Flight Opportunities Program and other commercial space stakeholders

FUTURE WORK

- Future flight tests: SL-11, NSC HASS, VirginGalactic's SS2, and others
- Evaluation of DO-282B specifications to design new message format for space vehicles
- Proposed research to upgrade further for LEO spacecraft

TASK 307-SOL. COMMERCIAL SATELLITE COMMUNICATIONS

Solstar

PROJECT AT-A-GLANCE

- UNIVERSITY MEMBER: New Mexico State University
- AFFILIATE MEMBER: Solstar
- PRINCIPAL INVESTIGATOR: M. Brian Barnett
- CO-INVESTIGATORS: Dr. Pat Hynes, Michael Potter, Mark Matossian

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Provision of economical commercial 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 and spacecraft tracking during suborbital flights.

STATUS

- Successfully tested Solstar's technology in space, November 12, 2013. Sent first text message to space using entirely commercial hardware, networks, and spacecraft.
- Search for "Texts To Space" documentary on YouTube
- Testing delayed by Virgin Galactic accident
- Solstar is developing proprietary payload and space communicators and services for LEO and suborbital

Solstar payload communicator receiving text message at 67.4 miles

FUTURE WORK

- Continue to test and mature Solstar's payload communicators and internet services in sub-orbit/LEO through NASA's Flight Opportunities Program and others.
- NASA FOP has scheduled Solstar to test its payload on Virgin Galactic's 2nd research flight. Other flights in works.

TASK 311-UCF. ROBUST AND LOW-COST LED ABSORPTION SENSOR FOR SIMULTANEOUS, TIME-RESOLVED MEASUREMENTS OF CO AND CO2

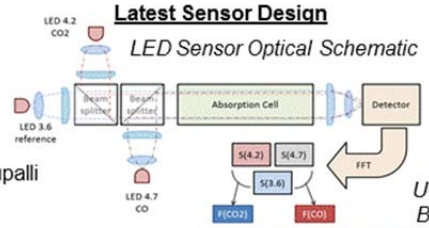
University of Central Florida

PROJECT AT-A-GLANCE
- UNIVERSITY: University of Central Florida
- PRINCIPAL INVESTIGATOR: Dr. Subith Vasu
- STUDENTS: Michael Villar, Justin Urso, Akshita Parupalli

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- CO/CO2 measurements are relevant to the health and safety of the crew.
- Time-resolved measurements of CO could be used to detect fuming which may lead to fire or explosion.

STATEMENT OF WORK
- The sensors electronics and optics were further optimized to maximize sensitivity and reduce noise.
- A model of the absorption of the broad-spectrum source characteristic of LEDs were explored for increasing the flexibility and understanding of the sensors.
- Sensor design and housing must be adapted for spacecraft environment. This would include optimizing weigh, size, and power demand as well as fortifying it.
- Bench testing of the ruggedized sensor/housing system was carried out in an environmental chamber to simulate relevant conditions.
- Balloon tests were conducted to validate design at high-altitudes and micro-gravity conditions.

Latest Sensor Design



LED Sensor Optical Schematic

UCF Payload on HASP Balloon Flight Chassis

STATUS
- Sensor electronics and optics are being reevaluated so as to optimize detectability limit and noise reduction.
- Broad-spectrum absorption models are being explored to promote optimization efforts and increase sensor robustness.

FUTURE WORK
- Reducing the size of the system
- Increasing precision and expanding the applicable gases
- Optimizing for space applications

TASK 323-NMT. STRUCTURAL HEALTH MONITORING FRAMEWORK

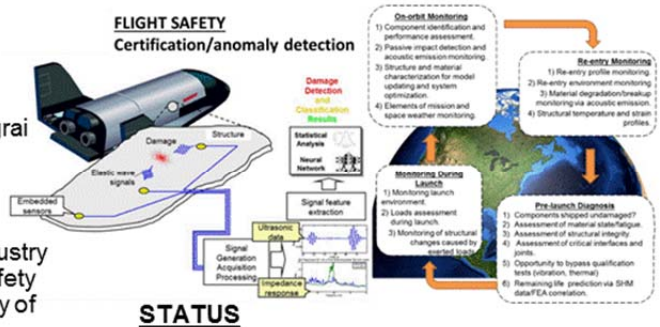
NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH UNIVERSITY

PROJECT AT-A-GLANCE
- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR: Dr. Andrei Zagrai
- STUDENTS: Blaine Trujillo, Mary Anderson

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

The benefits of SHM for commercial space industry include opportunities to improve spaceflight safety and affordability. It may also increase efficiency of operations through integration of structural condition data in flight management process.

STATEMENT OF WORK
- Review current approaches on sensor information integration in space vehicle.
- Investigate thermal and radiation fatigue of smart structures for assessment of RVL's condition during flight.
- Prepare hardware for evaluation of space effects on structural condition and sensor system.



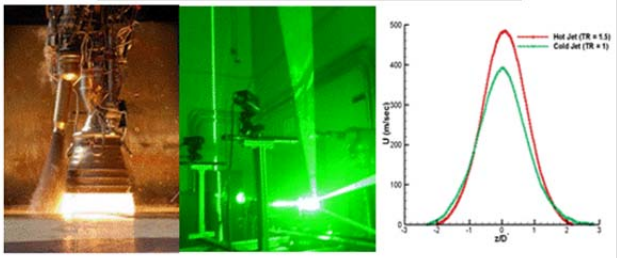
STATUS
- 4 sets of experiments investigating thermal, vacuum, and radiation environments were conducted.
- Data analysis and model development is in progress.

FUTURE WORK
- Develop descriptive models for effects of radiation, vacuum and thermal environment.
- Preliminary payload design for spaceflight experiments.

TASK 325-FSU. OPTICAL MEASUREMENTS OF ROCKET NOZZLE THRUST AND NOISE

PROJECT AT-A-GLANCE
- UNIVERSITY: Florida State University
- PRINCIPAL INVESTIGATORS: Rajan Kumar & Farrukh Alvi
- STUDENT: Rohit Vemula

Optical Measurements of Thrust and Noise



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 optimized parabolic rocket nozzle design and fabrication completed
- Velocity measurements over a range of nozzle pressure ratio using particle image velocimetry is in progress

FUTURE WORK
- Velocity measurements in the streamwise direction
- Noise measurements in the anechoic jet facility
- Pressure measurements in the exit plane using total pressure rake
- Design and development of active flow control methods
- Thrust optimization at low nozzle pressure ratios.
- Noise reduction technique during launch operations.

TASK 308-UTMB. 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: Rebecca Blue, MD, MPH
- Co-Investigators: James Vanderploeg, MD, MPH; Tarah Castleberry, DO, MPH; Charles Mathers, MD, MPH
- Residents: Rahul Suresh, MD

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- Psychological stressors can be significant challenges in the operational environment, and laypersons with minimal training are at risk for high anxiety and potentially mission-impacting psychological sequelae during commercial flight.
- This study aims to evaluate the risk of anxiety during commercial spaceflight activities and to develop effective mitigation techniques and identify and best assist those at greatest risk.

STATEMENT OF WORK
- Identify individuals with high anxiety levels through screening questionnaires and psychological testing
- Develop risk mitigation strategies and training techniques for individuals with higher levels of anxiety
- Develop recommendations for optimum training protocols to reduce anxiety prior to and during suborbital flight

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

FUTURE WORK
- Presentation and publication of significant findings – publication anticipated 2017, presentation expected at Aerospace Medical Association Annual Scientific Meeting 2017, Denver, CO

TASK 309-UTMB. ASSESSMENT OF PHYSIOLOGICAL SCREENING REQUIREMENTS & TRAINING MODALITIES FOR REPEATED EXPOSURES TO SUSTAINED HIGH G ACCELERATION

utmb Health Aerospace Medicine

PROJECT AT-A-GLANCE
- University: The University of Texas Medical Branch
- Principal Investigator: James Vanderploeg, MD
- Co-Investigator: Tarah Castleberry, DO
- Residents: James Pavela, MD; Wilfredo Rodriguez-Jimenez

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 aerobatic flights, centrifuge acceleration profiles, and actual spaceflight.
- Develop recommendations for pilot training and medical screening.

STATUS
- Collect data on pilots in centrifuge-simulated suborbital flight and aerobatic flight Fall 2016/Spring 2017

FUTURE WORK
- Recruit pilots for research study
- Conduct physiological monitoring during spaceflights in 2017/2018

TASK 310-UTMB. ASSESSMENT OF METHODS, PROCEDURES, AND TECHNOLOGIES AVAILABLE FOR PROTECTION OF SFPS IN COMMERCIAL SPACEFLIGHT VEHICLES

utmb Health Aerospace Medicine

PROJECT AT-A-GLANCE
- UNIVERSITY: University of Texas Medical Branch
- PRINCIPAL INVESTIGATOR: Charles Mathers, MD, MPH
- STUDENT: Alejandro Garbino, M.D., Ph.D.

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- Dedicated efforts towards the enhanced safety of crew extraction in spaceflight vehicles will improve the success of commercial space endeavors.
- Direct applicability demonstrated by NTSB safety recommendations from Scaled Composites crash investigation

STATEMENT OF WORK
- This project will evaluate methods to enhance the safety of the cabin environment
- Focusing on crew extraction

STATUS
- Complete literature review and analysis in 2016 – *in progress*
- Submit abstract for Aerospace Medical Association 2017 Annual Scientific Meeting in Denver, CO
- Build a model of "best practices" for commercial space operations support

FUTURE WORK
- Extraction Workshop – *tentative Spring 2017*
  - IndyCar
  - USAF 17th Test Squadron
  - NASA
  - Commercial Space Operators
- Reference NTSB recommendations from Scaled Composites crash investigation report

TASK 320-CU. COMMERCIAL SPACEFLIGHT RISK ASSESSMENT AND COMMUNICATION

PROJECT AT-A-GLANCE
- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: David Klaus
- STUDENT: Robert Ocampo (graduated May 2016)

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- The risks and hazards of space flight must be presented to space flight participants "in a manner that can be readily understood by a space flight participant with no specialized education or training." - 14 CFR 460.45, Operator Informing Space Flight Participant of Risk, 2013

STATEMENT OF WORK
- **Year 1 of Task 320 (June 1, 2015 through May 31, 2016)**
  - Define relative degrees of 'safe' and means of quantifying 'acceptable' levels of risk for commercial spaceflight
  - Develop framework to deal with inflight medical issues
  - Comparative perspective for understandable ways of communicating risks of spaceflight to the general public
- **Year 2 of Task 320 (June 1, 2016 through May 31, 2017)**
  - Establish metrics for characterizing the notional 'Good Day, Not so Good Day, Bad Day' scenarios with a focus on recommended medical equipment provisioning and associated personnel training needs
  - Characterize verification processes aimed at ensuring stated level of reliability (risk mitigation) is achieved for a given vehicle.

Scenario-Dependent Risk Framework

STATUS
- Delineated criteria defining 'safe enough'
- Unique perspective on risk provided by contrasting to more typical terrestrial transportation and adventure sport activities
- Framework offered for scenario-dependent risk categorization and management strategies
- 2 journal articles published in 2016, 3 more in review / prep

FUTURE WORK
- Assess and summarize recommended means of crew survivability to keep a 'bad day' from getting worse
- Build on medical 'levels of care' to provide vehicle provisioning recommendations in conjunction with UTMB

TASK 333-FIT. HUMAN-SYSTEMS INTEGRATION CERTIFICATION RULES FOR COMMERCIAL SPACE TRANSPORTATION

PROJECT AT-A-GLANCE
- UNIVERSITY: Florida Institute of Technology
- PRINCIPAL INVESTIGATOR: Dr. Guy A. Boy
- TEAM MEMBERS: Dr. Ondrej Doule, Captain De Vere Kiss and Yash Mehta

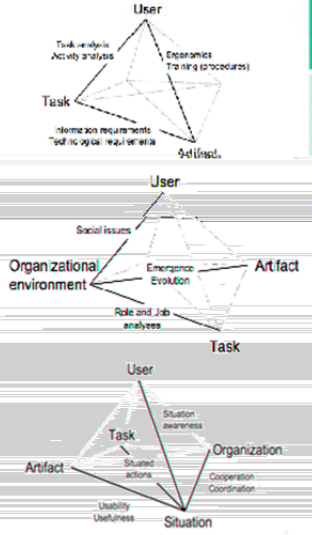
RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- To identify the relevant HSI methods for CST certification taking into account safety, efficiency and comfort requirements

STATEMENT OF WORK

Study certification specifications in 4 critical areas:
- HCI: Design and layout of displays and controls
- Mission planning, which includes analyzing tasks and allocating functions between humans and equipment
- Restraint or stowage of all individuals and objects in a vehicle
- Vehicle operation, so that the vehicle can be operated with standardized flight crew qualification and training (e.g., physical and mental stress factors)

- **STATUS**
- First year – analysis of key topics human space flight certification (State-of-the-art review on certification rules and standards; lessons learned on certification from commercial aviation and specific topics in CST)
- **FUTURE WORK**
- Refinement of current CST certification concepts
- Propose recommendations on CST certification rules.

Use of the AUTOS Pyramid to study FAA-AST Licensing Specifications



HCDi Human-Centered Design institute

Action items

Combine experience in commercial aviation certification and human space flight HSI
Synthesis of certification specifications and standardization in commercial aviation (FAR & CS 25, IATA, ICAO)
Projection to certification specifications and standardization in human space flights (NASA, KSC, MIL, ISO draft)
Accident analyses, spacecraft structures and functions analyses, and human-centered design case studies
FIT-HCDi proposal for FAA-AST certification rules and methods

TASK 193-CU. ROLE OF COE CST IN ENCOURAGE, FACILITATE, AND PROMOTE

PROJECT AT-A-GLANCE
- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. Daniel Scheeres
- STUDENT RESEARCHER: Mr. Bradley Cheetham (PhD)

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- **Research** – workshops focus on industry viability research
- **Training** – emerging leaders are prepared to evaluate important industry dynamics and trends
- **Outreach** - networking opportunities are provided to participants to build networks that strengthen industry growth

STATEMENT OF WORK
- Identify key industry characteristics to facilitate EFP efforts
- Host targeted workshops to engage students and young professionals
- Support conferences to educate students and young professionals
- Incorporate young professional perspectives in ongoing industry planning efforts
- Disseminate information about commercial space industry to relevant audiences

ESIL Workshop Participants and Sponsors

STATUS
- 8th & 9th Emerging Space Industry Leaders (ESIL) Workshops Held in 2016
- 100+ total participants and 3 publications presented

FUTURE WORK
- 2017: Ongoing support of relevant EFP activities
- 2017: Host ESIL-10 and continue to distribute model and information
- www.ESIL.space

TASK 304-MU. LEGAL ISSUES OF CROSS-BORDER SUBORBITAL FLIGHTS

PROJECT AT-A-GLANCE
- UNIVERSITY: McGill University, Institute of Air and Space Law
- PRINCIPAL INVESTIGATOR: 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

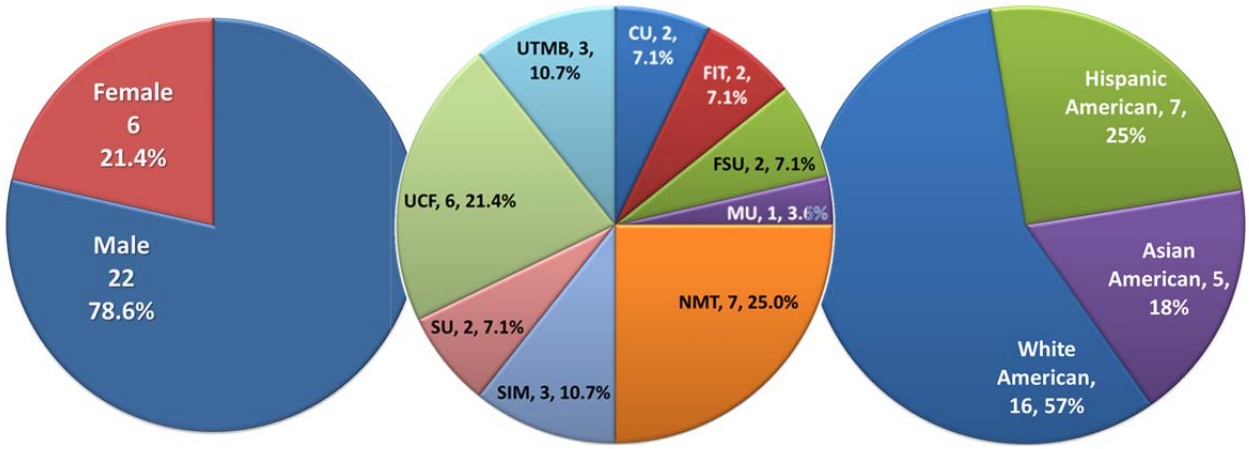
Air Law or Space Law: Does it Matter?

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.

COE CST STUDENTS, PARTNERS, PUBLICATIONS, AND PRESENTATIONS

COE CST YEAR 6 STUDENT DEMOGRAPHIC CHARTS



COE CST YEAR 6 STUDENTS

The following is a list and demographic information of the 28 COE CST students working on research tasks during the year of operation.

- Anderson, Mary (323-NMT)
- Carroll, Josh (299-NMT)
- Colvin, Thomas (331-SU)
- Finnegan, Mackenzie (322-SIM)
- Flores, Meliton (299-NMT)
- Garcia, Antonio (299-NMT)
- Harris, Chris (253-UCF)
- Hernandez-Juarez-Madera, Diana (186-SU)
- Joslyn, Nick (322-SIM)
- Kerkonian, Aram (304-MU)
- Kiss, De Vere (333-FIT)
- Mehta, Yash (333-FIT)
- Negrea, Catalin (186-CU)
- Ocampo, Robert, (320-CU)
- Parupalli, Akshita (311-UCF)
- Pavela, James (308, 310-UTMB)
- Rodriguez-Jimenez, Wilfredo (308, 310-UTMB)
- Shirer, Jacob (329-NMT)
- Smith, Kristina (322-SIM)
- Suresh, Rahul (308, 309-UTMB)
- Sweeney, Steven (299-NMT)
- Thurmond, Kyle (311-UCF)
- Trujillo, Blaine (323-NMT)
- Urso, Justin (311-UCF)
- Vemula, Rohit (325-FSU)
- Villar, Michael (311-UCF)
- Woerner, Peter (241-FSU)
- Yang, Hongjiang (253-UCF)

Abbreviations: CU-University of Colorado Boulder, ERAU-Embry Riddle Aeronautical University, 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, UTMB-University of Texas Medical Branch at Galveston

COE CST YEAR 6 RESEARCH AND INDUSTRY PARTNERS

The following is a list of the 11 COE CST research and industry organization partners that have contributed to the year 6 COE CST research tasks.

- Aerospace Engineering Sciences, UC Boulder
- Center for Advanced Turbomachinery and Energy Research (CATER), UCF
- Environmental Modeling Center, Camp Springs, MD
- FAA Technical Center
- Florida Center for Advanced Aero-Propulsion
- Oak Ridge National Laboratory
- Montclair State University
- NASA Marshall Space Flight Center
- NOAA Space Weather Prediction Center
- St. Peter's University
- University of Western Ontario

COE CST YEAR 6 INDUSTRY PARTNERS

The following is a list of the 11 COE CST industry partners that have contributed to the year 6 COE CST research tasks.

- Advanced Space
- Blue Origin
- Lockheed-Martin
- National AeroSpace Training and Research Center (NASTAR)
- Secure World Foundation
- Sierra Nevada Corporation Space Systems
- Solstar Communications
- Space Florida
- SpaceX
- United Launch Alliance
- Virgin Galactic

COE CST YEAR 6 PUBLICATIONS

The following is a list of the 19 publications and presentations completed during COE CST Year 6.

186-SU Space Environment Modeling and Prediction

Li, A., & Close, S. (2016). Neutral density estimation derived from meteoroid measurements using high-power, large-aperture radar. Journal of Geophysical Research: Atmospheres, 121(13), 8023–8037.

241-FSU High Temperature, Optical Sapphire Pressure Sensors

Singh, H. B., Oates, W. S., Kumar, R., Mills, D. A., & Sheplak, M. (2016). Experimental investigation of laser machining of sapphire for high temperature pressure transducers.

Woerner, P., Blood, D., Mills, D. A., Sheplak, M., & Oates, W. S. (2016). Modeling development and Bayesian uncertainty analysis of laser ablation in sapphire.

Woerner, P. (2016). Ultrafast laser machining of dielectrics: A sharp interface model.

Woerner, P., Oates, W. S., Sheplak, M., Blood, D., & Mills, D. A. (2016). Laser ablation of dielectrics for development of high temperature sapphire Based pressure transducers.

253-UCF Ultra High Temperature Composites

Cai, Y. Z., Chen, L. Q., Yang, H. Y., Gou, J., Cheng, L. F., Yin, X. W., & Yin, H. F. (2016). Mechanical and electrical properties of carbon nanotube buckypaper reinforced silicon carbide nanocomposites. Ceramics International, 42, 4984–4992.

Liu, Z., Gao, Y. B., Liang, F., Wu, B. X., Gou, J., Detrois, M., … Wang, X. W. (2016). Fabrication of carbon nanotube - chromium carbide composite through laser sintering. Lasers in Manufacturing and Materials Processing, 3.

Skovron, J., Zhuge, J., Gou, J., & Gordon, A. (2016). Effect of nanopaper coating on flexural properties of a fire-treated glass fiber-reinforced polyester composite. Journal of Composite Materials. http://doi.org/10.1177/002199831663

308-UTMB Suborbital Space Flight Participant Anxiety Assessment

Mulcahy, R. A., Blue, R. S., Vardiman, J. L., Castleberry, T. L., & Vanderploeg, J. M. (2016). Screening and mitigation of layperson anxiety in aerospace environments. Aerospace Medical Human Performance, 87(10), 1–8.

310-UTMB Increasing Cabin Survivability in Commercial Spacecraft

Garbino, A., Nusbaum, D. M., Buckland, D. M., Menon, A. S., Clark, J. B., & Antonsen, E. L. (2016). Emergency medical considerations in a space-suited patient. Aerospace Medical Human Performance.

Menon, A. S., Jourdan, D., Nusbaum, D. M., Garbino, A., Buckland, D. M., Norton, S., … Antonsen, E. L. (2016). Crew recovery and contingency planning for a manned stratospheric balloon flight - the StratEx program, 1–8.

311-UCF Robust and Low-Cost LED Absorption Sensor

Thurmond, K., Loparo, Z., Partridge, W. P. J., & Vasu, S. S. (2016). A light-emitting-diode (LED) based absorption sensor for simultaneous detection of carbon monoxide and carbon dioxide. Applied Spectroscopy, 70(6), 962–971.

320-CU Commercial Spaceflight Risk Assessment and Communication

Ocampo, R. P. (2016). Defining, characterizing, and establishing “safe enough” risk thresholds for human space flight. PhD Dissertation, University of Colorado, Boulder.

Ocampo, R. P., & Klaus, D. M. (2016). A quantitative framework for defining “how safe is safe enough?” in crewed spacecraft. New Space, 4(2), 75–82. http://doi.org/10.1089/space.2015.0040

Ocampo, R. P., & Klaus, D. M. (2016). Comparing the Relative Risk of Spaceflight to Terrestrial Modes of Transportation and Adventure Sport Activities. New Space, 4(3), 190–197. JOUR. http://doi.org/10.1089/space.2016.0012

323-NMT Structural Health Monitoring Framework

Anderson, M., Daniel J. D, Zagrai, A. N., & Westphal, J. D. (2016). Electro-mechanical impedance measurements in an imitated low Earth orbit radiation environment. In Proceedings of the ASME 2016 International Mechanical Engineering Congress and Exposition. Phoenix, AZ.

325-FSU Optical Measurements of Rocket Nozzle Thrust and Noise

Kumar, R. (2016). Measurement of rocket nozzle thrust and noise using optical methods.

MITRE Safety of Launch and Reentry Ops in the NAS

Tao, Z., Wang, G., Williams, A. G., Semanek, J. L., & Schwartz, J. L. (2016). Assessing factors that affect the safety of space launch and re-entry operations in the national airspace system.

Tao, Z., Wilde, P. D., Schwartz, J. L., Semanek, J. L., Wang, G., & Williams, A. G. (2016). Exploring necessary altitude awareness and response times for air traffic control during space launch and re-entry operations.

Wang, G., Tao, Z., Masek, T., & Schwartz, J. L. (2016). A Monte Carlo simulation tool for evaluating space launch and re-entry operations.

COE CST YEAR 6 PRESENTATIONS

The following is a list of the 14 presentations completed during COE CST Year 6.

186-SU Space Environment Modeling and Prediction

A. Li and S. Close, "Mean density estimation derived from satellite constellations", American Geophysical Union conference, December 2015.

253-UCF Ultra High Temperature Composites

M. Mohagheghi, H. Zawati, T. Pinol. J. Gou, C. Yu, J. Kapat, "Use of 1-D Finite Enthalpy Method for a High-Temperature Recuperator Made of Polymer Derived Ceramic Composite for a Supercritical Carbon Dioxide Power System," Proceedings of 5th International.

C. Harris, J. Kapat, J. Gou, "Ultra-High Temperature Thermal Protection Systems," 5th Annual Technical Meeting of FAA COE CST, Arlington, VA, October 26-28, 2015.

304-MU Legal Issues of Cross-Border Sub-Orbital Flights

Manfred Lachs Moot Court Competition (North American Regional Round , World Finals).

307-SSC Commercial Satellite Communications for Spacecraft

"Texts to Space" documentary Published on Aug 31, 2016 on YouTube, https://www.youtube.com/watch?v=RwQsYKPfYo8.

308-UTMB Suborbital Space Flight Participant Anxiety Assessment

Mulcahy RA, Blue RS, Vardiman J, Castleberry T, Vanderploeg J. Screening and Mitigation of Anxiety in Unique Environments. Presented at the Aerospace Medical Association Annual Scientific Meeting, Atlantic City, NJ, May 2016.

311-UCF Robust and Low-Cost LED Absorption Sensor

K. Thurmond, J. Urso, M. Villar, W.P. Partridge Jr., S.S. Vasu, "A Light-Emitting-Diode (LED) Non-Dispersive Absorption Sensor for Early Fire and Hazardous Gases Detection", presented at the ESS/CI Spring Technical Meeting, Princeton, NJ, 3/2016, paper #1.

M. Villar, J. Urso, W.P. Partridge Jr., J. Kapat, S. S. Vasu, "Progress in Development and Testing of a LED-Based Fire and Hazard Detection Sensor for Space Vehicles", National Space & Missile Materials Symposium (NSMMS) Commercial and Government Responsive Access to Space Technology Exchange (CRASTE).

J. Urso, M. Villar, K. Thurmond, Z. Loparo, W.P. Partridge Jr., J. Kapat, S. S. Vasu, "Robust Sensors for Spacecraft Fire Detection", Center of Excellence for Commercial Space Transportation Annual Technical Meeting (ATM 5), Washington, D.C., 10/2015.

320-CU Commercial Spaceflight Risk Assessment and Communication

NSBRI Workshop on Piloting Spacecraft: Guidance and Control of Human Vehicles, 'Functional Integration of humans in piloted spacecraft', Houston, TX, Sept 2016.

Rocky Mountain Chapter of the American Vacuum Society (RMCAVS) Annual Symposium - Space: The Final Vacuum Frontier (invited) 'Protecting Human Life in the Vacuum of Space: Challenges and Solutions', Westminster, CO, Sept. 2016.

323-NMT Structural Health Monitoring Framework

Zagrai, A., Anderson, M., Daniel, J.D., Henneke, D., and Westpfahl, D.J. (2016) "Investigation of radiation effects on smart structures for commercial space vehicles," invited presentation at Institute of Nuclear Materials Management (INMM) student meeting, University of New Mexico, October 21, 2016.

Zagrai, A., and Demidovich, N. (2016) "Structural health monitoring potential of commercial space vehicles," invited talk at Commercial and Government Responsive Access to Space Technology Exchange (CRASTE), June 20-23, 2016, Westminster, Colorado.

Zagrai, A., Trujillo, B. and Demidovich, N. (2016) "Acoustic emission during thermal fatigue of aluminum alloy," presentation at Commercial and Government Responsive Access to Space Technology Exchange (CRASTE), June 20-23, 2016, Westminster, Colorado.

Anderson, M., Zagrai, A., Daniel, J.D. (2016) "Potential use of piezoelectric sensors for structural health monitoring in radioactive environments", presentation for the workshop organized by Institute of Nuclear Materials Management Technical Exchange, Taos, New Mexico, May 19, 2016.

MITRE Safety of Launch and Reentry Operations in the National Air Space

Air Traffic Controllers Association Annual Conference and Exposition, Nov 2015.

Commercial and Government Responsive Access to Space Technology Exchange, Jun 2016

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Center of Excellence for
Commercial Space Transportation