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 5 Annual Report

## Executive Summary

**December 31, 2015**

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## LETTER FROM THE EXECUTIVE DIRECTOR

Center of Excellence for Commercial Space Transportation

As we welcome the new challenges beginning our sixth year (Phase II) of commercial space transportation research, it is appropriate that we recognize the huge debt of gratitude owed to our FAA COE National Program Director, Dr. Patricia Watts, and to our FAA Program Manager, Mr. Ken Davidian. Without their vision, leadership, tenacious attention to detail, and "get it done" attitude, the COE for Commercial Space Transportation would not have happened. Their selflessness, passion, and integrity were the lamplight in the dark days of all COE start-ups. As Pat Watts is fond of saying "They don't know what they don't know". Well, Pat, today - we know!

This fifth Executive Summary of the work undertaken and the products produced by the Center of Excellence for Commercial Space Transportation provides insight into the breadth and depth of the work being accomplished at nine core universities across the nation, supported by a growing cadre of affiliate members and direct participation by vital companies and agencies in the space industry. 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 not accepting "no" as an answer when facing bureaucratic roadblocks whether from academia, industry, or government.

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.

THANK YOU, Pat and Ken, for your vision, direction, support, and overcoming "no" over the past five years.

James M. Vanderploeg, MD

James M. Vanderploeg M.D.

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 5 Annual Report Executive Summary.

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, 2015

## ACKNOWLEDGEMENTS

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. Stepping back from his COE CST duties this year, and moving toward a well-deserved (partial) retirement is Professor Scott Hubbard from Stanford University. Since the inception of the COE CST, Prof. Hubbard led the team of Stanford principal investigators. Scott is transitioning out of his former duties related to the COE CST, but is retaining his role of New Space Journal Editor, the COE CST's official peer-reviewed quarterly.

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 make the research possible, provide matching cash and in-kind contributions, post the extensive technical and financial data for government-required reports, and fundamentally make the overall system function efficiently through their individual actions.

These important 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.

**PICTURED:** The nine COE CST member universities posed for a picture at the Fifth Annual Administrative Meeting on April 27, 2015. From left to right: Dr. Jay Kapat (UCF), Dr. Juan Alonso (SU), Professor Scott Hubbard (SU), Dr. Tristan Fiedler (FIT), Carol Gregorek (OAT), Dr. Jim Vanderploeg (UTMB), Ken Davidian (FAA), Dr. Norm Fitz-Coy (UF), Dr. Andrei Zagrai (NMT), Dr. Dave Klaus (CU), Evelina Bern (FAA), Brad Cheetham (CU), Dr. Warren Ostergren (NMT). Circled: Dr. Pat Watts (FAA), Dr. Pat Hynes (NMSU), Dr. Farrukh Alvi (FSU), Fred Bowen (OAT).

# INTRODUCTION

This executive summary accompanies a more detailed, three volume annual report of the FAA COE CST. A fourth volume is being published commemorating the fifth anniversary of the COE CST, a significant milestone. This special volume will not be produced again until the tenth anniversary. 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 Fifth Annual Technical Meeting in October 2015.
- Volume 3 is a comprehensive set of notes and links to recordings from all FAA COE CST teleconferences and face-to-face meetings.
- Volume 4 is a comprehensive overview of each task executed under the COE CST during the first five years.

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 are given and each of the research tasks initiated, conducted and concluded by the COE CST during the fifth 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

As of December 2015, the FAA Office of Commercial Space Transportation (AST) is comprised of approximately 81 full time equivalent (FTE) civil servants and operates with a budget of $17.6 million that includes $1.0 million for the COE CST. (By contrast, the FAA has approximately 48,000 FTEs and a total budget of $15.7 billion.) Despite its relatively small size (0.11 percent of the total FAA budget), 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 taxpayer a hard 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 2015, three 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.

## FAA CENTER OF EXCELLENCE FOR COMMERCIAL SPACE TRANSPORTATION

Below is a quick look at COE CST year 5 highlights and technical publications.

### *COE CST YEAR 5 HIGHLIGHTS*

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

- Fifth Annual Administrative Meeting held at Dallas, Texas on April 27 – April 28, 2015.
- Fifth Annual Technical Meeting held in Arlington, VA. October 27-28, 2015.
- The New Space Journal completed its third year featuring topics of spaceports, Mars, human spaceflight research, and the “space generation” of upcoming professionals.
- NOVA science series featured research accomplished by New Mexico Tech and Stanford University.
- Faculty and student national and international awards, cited in summary further in this report.

**COE CST Year 5 Status**

| At–A–Glance Metrics | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 |
|---|---|---|---|---|---|
| # Active Tasks | 34 | 24 | 28 | 28 | 36 |
| # Unfunded Tasks | 34 | 22 | 22 | 11 | 6 |
| # Principal Investigators | 27 | 28 | 29 | 25 | 31 |
| # Students | 31 | 37 | 55 | 47 | 61 |
| # Reports | 0 | 38 | 28 | 22 | 29 |
| # Research Partners | - | 17 | 20 | 27 | 27 |
| # Industry Partners | - | 29 | 44 | 55 | 57 |
| # Affiliate Members | 0 | 1 | 6 | 6 | 6 |
| # Associate Members | - | - | - | 3 | 6 |
| Funding Profile | $2M (FY10) | $2.4M (FY11/12) | $1.1M (FY13) | $1.1M (FY14) | $1M (FY15) |

In the fifth year of COE CST operation, there were 8 new tasks started, 19 on-going from the previous year and 9 tasks completed. The complete list of all tasks is given in the second half of this Executive Summary.

*COE CST STUDENTS, PARTNERS AND PUBLICATIONS*

In the fifth year of operation, the COE CST benefited from the research of 61 students, 27 research partners and 57 industry partners. The combined effort resulted in 29 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.

## 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. Nickolas Demidovich, Office of the Chief Engineer, AST
- Mr. Steph Earle, Space Transportation Development Division, AST
- Mr. Kevin Hatton, Space Vehicles Office, NextGen Office
- Mr. Henry Lampazzi, Licensing & Evaluation Division, AST
- Ms. Karen Shelton-Mur, Space Transportation Development Division, AST
- Mr. John Sloan, Office of Strategic Planning, AST
- Ms. Yvonne Tran, Regulations & Analysis Division, AST
- Dr. Paul Wilde, Chief Engineer, AST

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 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 AT GALVESTON (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 upon 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.

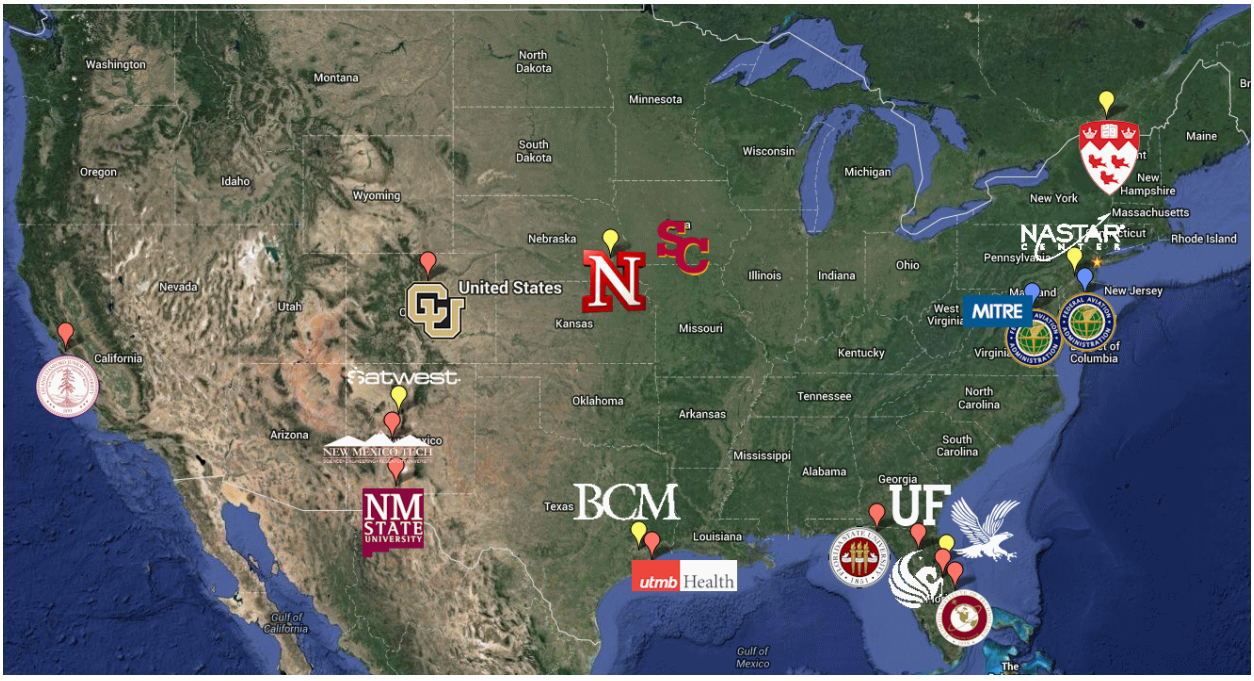
## MCGILL UNIVERSITY (MU)

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.

## SATELLITE COMMUNICATIONS SYSTEMS (SOLSTAR)

Satellite Communications Systems 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.

**Map of COE CST Member and Affiliate University Geographic Distribution**



## COE CST ASSOCIATE MEMBERS AND PRIMARY PARTNERS

### 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.

### UNIVERSITY OF NEBRASKA LINCOLN

The University of Nebraska, a collaboration on 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.

### SIMPSON COLLEGE

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.

## 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, sometimes related to their COE CST tasks (and sometimes not). Regardless, the FAA would like to congratulate all the recognized recipients for their great achievements!

- **Dr. David Klaus (CU)** - Promoted to full Professor; Associate Department Chair for Undergraduate Program.
- **Dr. Emmanuel Collins (FSU)** - Black Engineer of the Year Award for College-Level Promotion of Education, February 2015.
- **Dr. William S. Oates (FSU)** - Best paper award at the ASME Smart Materials, Adaptive Structures, and Intelligent Systems (SMASIS) Conference: P. Miles, A. Guettler, M. Y. Hussaini, W. Oates, "Uncertainty Analysis of Dielectric Elastomer Membranes under Multi-axial Loading", ASME SMASIS SMASIS Colorado Springs, CO, 2015; and a Service Award for Adaptive Structures and Materials System Branch award for service as Chair of the Branch.
- **Dr. Patricia Hynes (NMSU)** - AIAA Associate Fellow designation; Millionaires Award for Research NMSU
- **Dr. Sigrid Close (Stanford)** - Elected Chair USNC-URSI (International Union of Radio Science) Commission G, 2015-2018; Outstanding Professor in Aeronautics and Astronautics, Stanford University; DoE Early Career Research Award, 2013-2018; Presidential Early Career Awards for Scientists and Engineers, 2012 (Awarded in 2015); NSF CAREER Award, 2011-2016; Steering Committee, ESA QB50 (2011-present).
- **Dr. Penny Axelrad (UC)** - 2015 Women in Aerospace Educator Award.
- **Dr. Subith Vasu Sumathi (UCF)** - 2015 American Chemical Society (ACS) PRF Doctoral New Investigator Award (equivalent of young investigator); Selected as a member of two technical

committees under ASME IGTI; Graduate student (Bader Almansour) won the best student paper award at the Optical Society of America's 3rd Laser Ignition Conference held at Argonne, IL 2015.

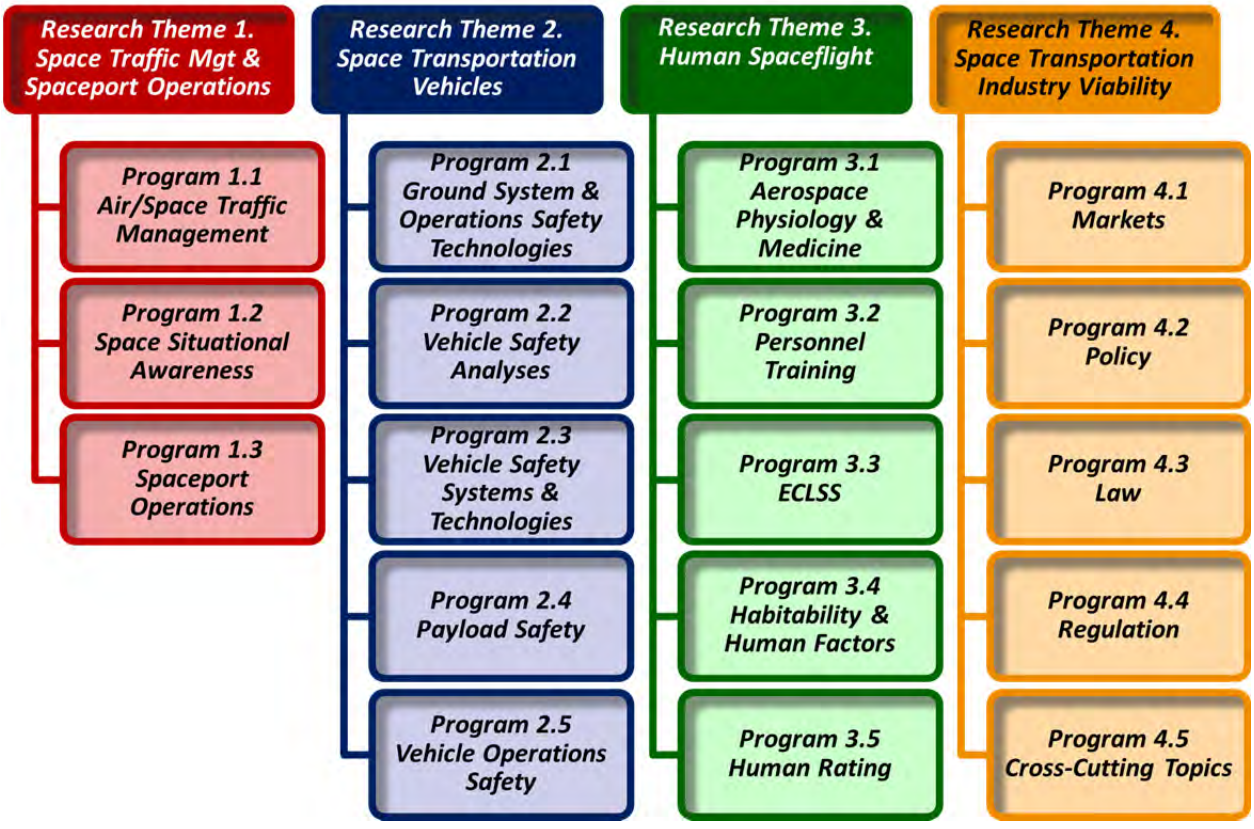
- **Rebecca S. Blue, MD, MPH (UTMB)** - Arnold D. Tuttle Award-
- **Tarah L. Castleberry, DO, MPH (UTMB)** - Outstanding Mentor
- **R. Yvette Schulz, MBA (UTMB)** - Society of NASA Flight Surgeons Honorary Member
- **James Pattarini, MD, MPH (UTMB)** - Space Medicine Association Journal Publication ; Society of NASA Flight Surgeons Outstanding Student; UTMB Outstanding Overall Resident
- **James Pavela, MD (UTMB)** - UTMB Outstanding PGY-1 Resident

## COE CST RESEARCH TASKS

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

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

Each of these major research themes are divided into programs and these are further divided into projects and tasks.




The following pages include a list of the individual COE CST research tasks conducted during the fifth 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 AST R&D Tasks (as of 31 Dec 2015)

| Task # Name / PI Name (Univ) – AST TM | | Task # Name / PI Name (Univ) – AST TM | |
|---|---|---|---|
| **185 Unified 4-Dimensional Trajectory Analysis** Alonso (SU) – Wilde | END | **228 Magneto-Elastic Sensing for SHM** Zagrai, Ostergren (NMT) – Demidovich | IP-F |
| **186* Space Environment MMOD Modeling** Fuller-Rowell(CU) – Shelton-Mur | END | **241* High Temperature Pressure Transducers** Sheplak (UF) – Demidovich | IP-F |
| **186 Space Environment MMOD Modeling** Close(SU) – Shelton-Mur | IP-F | **241 High Temperature Pressure Transducers** Oats (FSU) – Demidovich | NCE |
| **187* Space Situational Awareness** Scheeres (CU) – Earle | END | **244 Autonomous Rendezvous and Docking** Fitz-Coy (UF) – Earle | IP-F |
| **220 Space Operational Framework** Hynes (NMSU) – Rey | IP-F | **244 Autonomous Rendezvous and Docking** Collins (FSU) – Earle | END |
| **257* Master's Launch and On-Orbit Operations Laboratory** Born (CU) – Davidian | END | **244* Autonomous Rendezvous and Docking** Rock (SU) – Earle | END |
| **329 Tracking and Monitoring Suborbital Vehicles** Ryan (NMT) – Demidovich | NEW | **244* Autonomous Rendezvous and Docking** Axelrad (CU) – Earle | NCE |
| **331* Advanced 4D Special Use Airspace Research** Alonso (SU) – Wilde | NEW | **253 Ultra High Temperature Composites** Gou & Kapat (UCF) – Demidovich | IP-F |
| **332* Defining Class X Air Space** Draper (SIM) – Wilde | AFF NEW | **258* Multi-Disciplinary Analysis of Safety Metrics** Alonso (SU) – Wilde | END |
| **MITRE Defining Class X Air Space** Draper (SIM) – Wilde | ASSOC NEW | **293 Reduced Order Non-Linear Structural Modeling** Miller (NMT) – Demidovich | NCE |
| **308 Suborbital Cabin Lethality** Vanderploeg (UTMB) – Lampazzi | IP-F | **299 Nitrous Oxide Composite Tank Testing** Ostergren (NMT) – Tran | IP-F |
| **309 Suborbital Pilot Assessment** Vanderploeg (UTMB) – Lampazzi | IP-F | **306 Advanced ADS-B Prototype for RLVs** Stansbury (ERAU) – Demidovich | AFF IP-UF |
| **310 Increasing Cabin Survivability in Commercial Spacecraft** Vanderploeg (UTMB) – Lampazzi | IP-F | **307* COTS Satellite Communications Systems** Barnett (SolStar) – Demidovich | AFF IP-UF |
| **320 Commercial Spaceflight Risk Assessment and Communication** Klaus (CU) – Lampazzi | NEW | **311 LED–Based Low Cost Gas Sensor for Crew and Vehicle Safety** Vasu (UCF) – Demidovich | IP-F |
| **333 Onboard Context-Sensitive Informational System** Boy (FIT) – Lampazzi | NEW | **323 Structural Health Monitoring Framework** Zagrai (NMT) – Demidovich | NEW |
| **Note:** Among the 36 COE CST tasks active in Year 5, 8 are new (NEW), 13 are in process and funded (IP-F), 3 are in process with a no cost extension (NCE), 3 are in process but unfunded (IP-UF), and 9 have ended (END). 5 tasks are being performed by an Associate (ASSOC) or Affiliate Member (AFF). | | **325 Optical Measurements of Rocket Nozzle Thrust and Noise** Kumar (FSU) – Demidovich | NEW |
| | | **193 Role of COE CST in EFP** Alonso/Hubbard (SU) – Davidian | END |
| | | **193* Role of COE CST in EFP** Born (CU) – Davidian | IP-F |
| **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, SU–Stanford University, UCF–University of Central Florida, UF–University of Florida, UTMB–University of Texas Medical Branch. | | **302* International Commercial Space Regulations** Jakhu (MU) – Sloan | AFF END |
| | | **304 Insurers as Regulators of Space Safety and Sustainability** Harrington (MU) – Sloan | AFF IP-UF |
| | | **305 Suborbital Industry Analysis** Benjamin (FIT) – Davidian | IP-F |
| | | **324 Space Commercialization Strategies from the Internet Experience** Hanson (SU) – Davidian | NEW |

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

**PROJECT AT-A-GLANCE**

- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR: Dr. Juan J. Alonso
- STUDENTS: Thomas Colvin

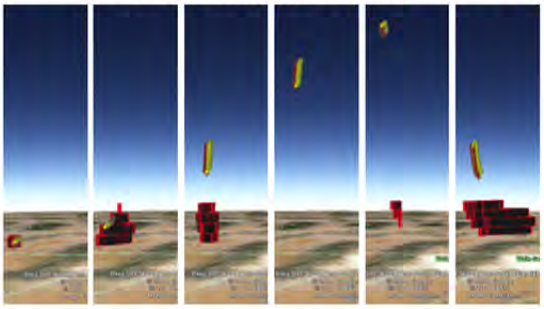
**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**

- We are developing and analyzing new methods for safely integrating space vehicles into the National Airspace System. This work will reduce the disruption to air traffic that is associated with launch and reentry events so that all transportation providers will have fair and safe access to the NAS.

**STATEMENT OF WORK**

- 2012 - Developed initial Compact Envelope techniques and modified FACET to input Compact Envelopes.
- 2013 - Basic aircraft re-routing capabilities in FACET. Worked with FAA Offices of NextGen and Commercial Space to develop realistic future launch/reentry scenarios. First sub-orbital compact envelope generated. Implemented Kernel Density Estimation techniques to generate probabilistic compact envelopes.
- 2014 - Implemented Aircraft Vulnerability Models for improved risk calculations. FACET modified to incorporate Terminal Area Forecast data for simulations of future air traffic. Began NAS-wide simulations to quantify the impact of Compact Envelopes on the NAS.
- 2015 - AIAA SciTech 2015 paper and presentation of the open-source computational tool (SU-FARM) developed to calculate risk to aircraft. AIAA Space 2015 paper and presentation discussing the results of NAS-wide simulations, which indicate a 98% reduction in aircraft disruption when using compact envelopes.

**Compact Envelope for Lynx Flight**



**STATUS**

- Results being prepared for submission to New Space Journal.
- Migrating code to github.com for public dissemination.

**FUTURE WORK**

- Develop a trade study to demonstrate the sensitivity of compact envelope shapes to the input distributions and parameters.
- Validation of our analysis environment by recreating the Space Shuttle Columbia accident and comparing with published values of aircraft risk.
- Model aircraft and air traffic controllers as a Markov Decision Process and investigate future aircraft rerouting techniques for dynamic airspaces.

## TASK 186. Space Environment MMOD Modeling & Prediction

**PROJECT AT-A-GLANCE**

- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR(S): Sigrid Close
- STUDENT(S): Alan Li

**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**

The prediction and modeling of neutral atmospheric density in Low Earth Orbit (LEO) aids in accurate trajectory prediction for not only man made space objects, but also for orbital debris and meteoroids in the region. This aids in trajectory planning and calculation of collision probabilities, critical to any commercial space mission.

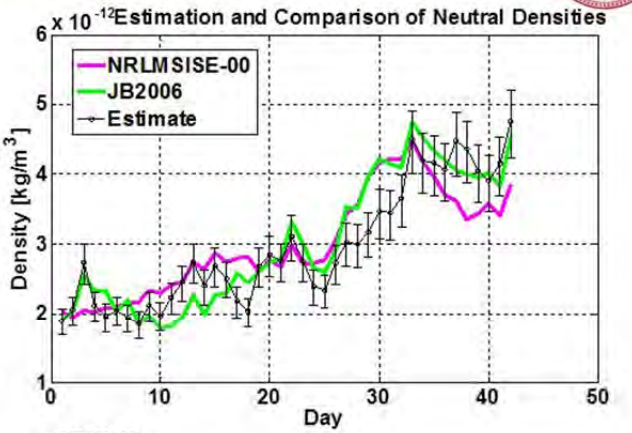
**STATEMENT OF WORK**

Thesis work:

- Developed *new* method based upon *order statistics* to determine neutral atmospheric density in near real time for different regions of the atmosphere (lower thermosphere/upper mesosphere)
- Developed statistical framework to calculate errors associated with this data driven estimation scheme
- Created *new* tomographic method to calculate altitude specific densities in the lower thermosphere
- Application to satellites and meteoroids

Previous work:

- Estimation of Fengyun debris orbits from short radar passes (EISCAT)
- Fragmentation test at NASA AMES on mock CubeSat to measure debris profiles




**STATUS**

- (PhD Thesis) Finished analysis for satellite constellations and meteoroid populations

**FUTURE WORK**

- Combine with existing filtering methods
- Satellites: increase number of constellations and apply tomographic methods on global density
- Meteoroids: gather data during meteor showers
- Orbital debris: apply method to large database of on-orbit debris

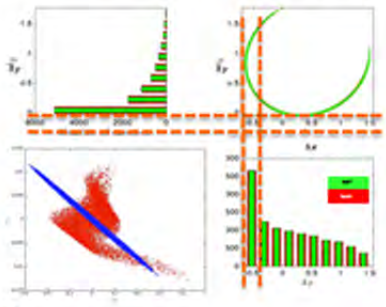
## TASK 187. SPACE SITUATIONAL AWARENESS

**PROJECT AT-A-GLANCE**
- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. Dan Scheeres
- STUDENT RESEARCHER: Mr. In-Kwan Park (PhD)

**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.

**Analytical vs Numerical Uncertainty Propagation**



**STATUS**
- Graduated one funded PhD student: Kohei Fujimoto, May 2013
- Combined student team focused on relevant SSA research topics of direct interest to the COE
- Presented over 26 distinct papers at 14 conferences
- 7 papers published, 4 more in peer review at journal

**FUTURE WORK**
- Next 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 220. Spaceport Operational Framework

- **PROJECT AT-A-GLANCE**
- AST RDAB POC: René Rey, Ken Davidian
- UNIVERSITY: New Mexico State University, Las Cruces, NM
- PRINCIPAL INVESTIGATOR: Dr. Pat Hynes

**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**
- The commercial space industry has not assembled a body of knowledge for commercial spaceports. This Task developed a framework encompassing tiered elements of the activities conducted at a commercial spaceport.
- Having a framework may allow spaceports to standardize some of their operations while increasing safety and encouraging point to point transportation.

**STATEMENT OF WORK**
- Integrate the following into a Framework for Commercial Spaceport Operations
  - Applicable Standards
  - Relevant Procedures
- Enable Documents to Be Found by Title, Subject, or Keyword
  - Assure Copyright Protections
- Implement Document Management System (DMS) including:
  - Adding documents to Knowledge DMS Database
  - Maintain Access to the Body of Knowledge DMS &
  - Continued testing

**Commercial Spaceport Framework (Top Level)**

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

**STATUS**
- Integration of new materials is ongoing
- Dissemination of digital collections at technical conferences is ongoing

**FUTURE WORK**
- Continue dissemination at technical conferences
- Continue to update Framework

# Task 329: Tracking and Monitoring Suborbital Commercial Space Vehicles

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**PROJECT AT-A-GLANCE**

- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR(S): William H. Ryan & Eileen V. Ryan
- STUDENT(S): Daniel Wimberly
- TECHNICAL MONITOR: Nick Demidovich

**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 (AT) 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

Fort Sumner is ~275 kilometers due East-Northeast of the MRO 2.4-meter facility, and the stratospheric balloons launched would provide good test targets for the tracking-software development

**Magdalena Ridge Observatory's 2.4-meter Telescope Facility**

**STATUS**

- The project was initiated and preparation included background development and assessment of current tracking capabilities of the 2.4-meter telescope
- A Mechanical Engineering student was identified and given the materials necessary to assist with the new tracking software development

**FUTURE WORK**

- Refine software algorithms for autonomous closed-loop tracking of fast-moving terrestrial targets
- Collect observations of suborbital balloon launches or other test targets over an 8-half nighttime period
- Perform observational data reduction and analysis followed by a performance assessment
- Implement new strategies for tracking if the first trial efforts need significant improvement

# Evaluating Space Launch Vehicle / Reentry Vehicle (LV/RV) Separation Concepts and Standards

MITRE

**PROJECT AT-A-GLANCE**

- The MITRE Corporation
- PRINCIPAL INVESTIGATOR(S): Zheng Tao
- Team (S): Ganghuai Wang, Tudor Masek, Tom St. Clair, Russell Wenning, Mark Banyai, Jonathan Schwartz

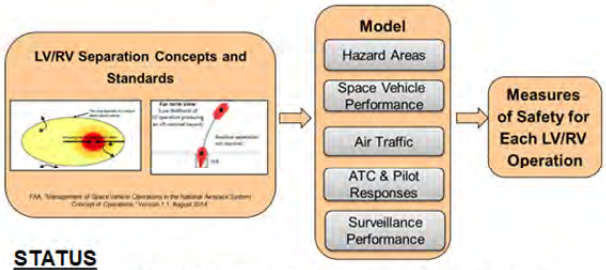
**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**

Since the 1960's, large amounts of airspace has been segregated for launch vehicle/reentry vehicle (LV/RV) operations, which increases costs for other airspace operators and may limit LV/RV opportunities in the future. The FAA is developing new and more efficient separation concepts and associated standards for a variety of LV/RV operations to minimize their impact on other NAS users. There have been limited studies on the interactions between aircraft and LV/RV, aircraft and aircraft, and impacts on controller workload for these new concepts and standards. Understanding these interactions is critical to implementing more efficient separation concepts and standards.

**STATEMENT OF WORK**

- The MITRE Corporation (MITRE) is developing a fast-time modeling and simulation capability that provides operational measures of safety of LV/RV operations with different separation concepts and standards
  - Considers the interactions between aircraft and LV/RV, aircraft to aircraft, and impacts on controller workload
  - Produces several operational metrics that the FAA can use to determine which separation concepts and associated standards meet a target level of safety for each type of LV/RV operation

**High Level Approach**




**STATUS**

- Developed an initial capability that can run and evaluate safety of LV/RV separation concepts and standards
- Collaborated with Stanford's COE CST team on developing debris models

**FUTURE WORK**

- Confirm and assessing the model's performance
- Improve trajectory models and algorithms
- Evaluate potential separation standards for large generic hazard areas, flyback ops, suborbitals, or hybrid vehicles
- International scenarios

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

utmb Health Aerospace Medicine

**PROJECT AT-A-GLANCE**
- University: The University of Texas Medical Branch
- Principal Investigator: James Vanderploeg, MD
- Co-Investigators: Rebecca Blue, MD; Tarah Castleberry, DO; Charles Mathers, MD
- Residents: Residents: **Robert Mulcahy, MD**; Ben Johansen, DO; James Pavela, MD; Rahul Suresh, MD

**RELEVANCE TO COMMERCIAL SPACEFLIGHT INDUSTRY**
- Psychological stressors can be significant challenges in the operational environment. This study will provide data regarding how individuals with different personality types can best be prepared for suborbital spaceflight through training and anxiety mitigation techniques.

**STATEMENT OF WORK**
- Identify response of personality traits in individuals to a range of training methods
- Identify triggers for anxiety and mitigation approaches
- Develop recommendations for optimum training protocols to reduce anxiety prior to and during suborbital flight

**STATUS**
- IRB approval completed
- 40 subjects recruited
- Data collection will commence next month

**FUTURE WORK**
- Conduct training and testing at NASTAR centrifuge through 12/2015
- Recruit 120 more subjects

## TASK 309. Assessment of Screening and Training Requirements for Pilots with Repeated Exposures to Sustained High Acceleration

utmb Health Aerospace Medicine


**PROJECT AT-A-GLANCE**
- University: The University of Texas Medical Branch
- Principal Investigator: James Vanderploeg, MD
- Co-Investigators: Rebecca Blue, MD; Tarah Castleberry, DO; Charles Mathers, MD
- Residents: Benjamin Johansen, DO; Robert Mulcahy, MD; James Pattarini, MD; Natacha Chough, 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 and medical clearance requirements 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**
- Collecting early data on acrobatic pilots flying sustained G exposures
- IRB research protocol being prepared

**FUTURE WORK**
- Complete IRB approval process
- Recruit pilots for research study
- Conduct aerobatic flights and NASTAR testing throughout 2016
- Conduct physiological monitoring during spaceflights in 2016/2017

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

utmb Health Aerospace Medicine

**PROJECT AT-A-GLANCE**

- University: The University of Texas Medical Branch
- Principal Investigator: James Vanderploeg, MD
- Co-Investigators: Charles Mathers, MD; Rebecca Blue, MD; Tarah Castleberry, DO
- Residents: Benjamin Johansen, DO; Robert Mulcahy, MD; James Pattarini, MD; Natacha Chough, MD

**RELEVANCE TO COMMERCIAL SPACEFLIGHT INDUSTRY**

- Optimization of crew and passenger compartments to promote the survival of occupants during human spaceflight operations is a necessary component of vehicle interior fit out. Dedicated efforts towards the de-lethalization and advanced crashworthiness of spaceflight vehicles will improve the safety of commercial space endeavors.

**STATEMENT OF WORK**

- This project will evaluate methods for the de-lethalization of the cabin environment, space vehicle crashworthiness, individual restraint systems, emergency evacuation systems, and survival equipment.

**STATUS**

- Literature search underway
- Students being trained in conducting and evaluating relevant literature review

**FUTURE WORK**

- Complete literature review and analysis.
- Compare current spaceflight operators' interior cabin designs with historical precedents for cabin safety.

## TASK 320. Commercial Spaceflight Risk Assessment and Communication

**PROJECT AT-A-GLANCE**

- UNIVERSITY: University of Colorado-Boulder
- PRINCIPAL INVESTIGATOR: Prof. David Klaus
- STUDENT: Robert Ocampo (PhD candidate)

**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**

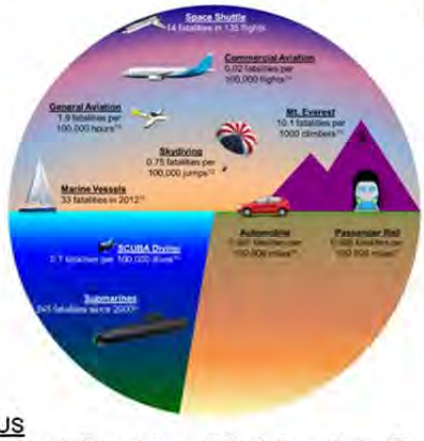
Characterizes risk factors of spaceflight and other transportation or adventure activities to allow effective, understandable ways for identifying, communicating and mitigating the risks of spaceflight to the general public, and summarizes associated design safety verification practices.

**STATEMENT OF WORK** *(6/1/15-5/31/16)*

*This task aims to provide:*

1) a systematic framework for characterizing risk as a function of phase of spaceflight and across scenarios ranging from nominal operations to catastrophic failures;
2) an assessment of risk prediction strategies along with insight from prior spaceflight and more common terrestrial activities for effectively communicating the risk of space transportation to the public in a balanced, informing manner;
3) characterization of verification processes used to ensure the defined level of reliability (risk mitigation) is achieved for a given vehicle.

**Relative Risk Summaries**




**STATUS**

1. Ocampo, R.P. and Klaus, D.M. A Quantitative Framework for Defining "How Safe is Safe Enough?" in Crewed Spacecraft [in prep for submission to New Space]

**FUTURE WORK**

1. What does it mean for a spacecraft to be "Safe Enough"?
2. How can "Safe Enough" be assessed using spacecraft risk progression statistics?
3. What type of pre-hospital medical equipment and protocols are needed to assess and treat in-flight illness or injury?
4. How can we effectively communicate the relevant risks to space flight participants?

# Task 333 – Human-Systems Integration Certification Rules for Commercial Space Transportation (CST)

HCDi Human-Centered Design Institute

**PROJECT AT-A-GLANCE**

- UNIVERSITY: Florida Institute of Technology
- PRINCIPAL INVESTIGATOR(S): Dr. Guy A. Boy
- TEAM MEMBER(S): De Vere Kiss and Ondrej Doule

**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**

- To identify the relevant human parameters, their value range, and thresholds of adequate safety, for all four critical areas (listed in the SOW).

**STATEMENT OF WORK**

Study certification specifications in 4 critical areas:

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

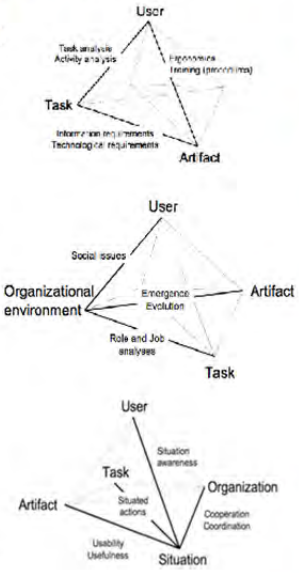
**STATUS**

- Initial stage – conceptualization of key topics in aviation enhancing human space flight areas

**FUTURE WORK**

- State-of-the-art review on certification rules and standards
- Write a work-in-progress report on lessons learned on certification from commercial aviation and specific topics in CST.

**Use of the AUTOS Pyramid to study FAA-AST Certification Specifications**




**Action items**

| |
|---|
| Study of governance in aviation and human space flights |
| 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, GOST, ECSS, 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 228. Magneto-Elastic Sensing for Structural Health Monitoring

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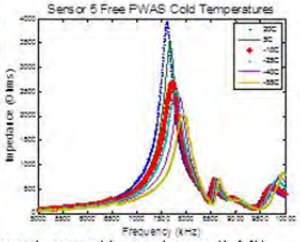
**PROJECT AT-A-GLANCE**

- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR: Dr. Andrei Zagrai and Dr. Warren Ostergren.
- STUDENTS: Blaine Trujillo (MS), Mary Anderson (MS), Matthew Campisi (MS)




**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**

The benefits of SHM for space vehicles include: pre-launch diagnostic, monitoring during launch and/or re-entry, in-orbit structural verification and structural assessment for rapid re-launch.

**STATEMENT OF WORK**

- Investigate electro-mechanical impedance manifestation of dynamic behavior of bolted joints during sub-orbital space flight.
- Modeling effect of temperature variation on electro-mechanical impedance spectrum during sub-orbital flight. Develop portable hardware for electro-mechanical impedance measurements in space environment.

**STATUS**

- Thermal Vac Electro-mechanical Impedance (EMI) tests were conducted.
- Lab bolted joints experiments were conducted.
- Acoustic emission during thermal fatigue was explored

**FUTURE WORK**

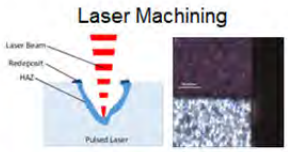
- Finalize findings pertaining bolted joints and thermal effects.
- Write a final report.

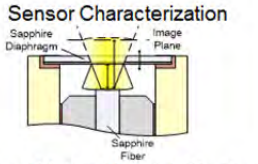
## TASK 241. High Temperature, Optical Sapphire Pressure Sensors for Hypersonic Vehicles

**PROJECT AT-A-GLANCE**
- UNIVERSITY: Florida State University
- PRINCIPAL INVESTIGATOR: William S. Oates
- STUDENT: Justin Collins

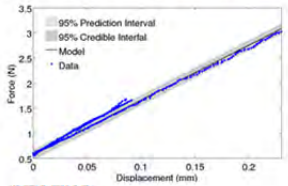
**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**
- Development of high temperature sapphire based pressure transducers for structural health monitoring.

**STATEMENT OF WORK**
- Implement sapphire based pressure transducer that can operate in high temperature environments (~1000°C to 1200°C)
- Sapphire cannot be manufactured using conventional 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

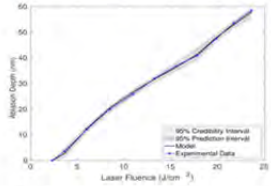



High Temp. Strength Measurement




Laser Ablation Material Physics




**STATUS**
- High temperature thermo-mechanical set-up designed and validated
- Modulus and strength of sapphire and alumina characterized from room temperature to 1300°C
- Material physics of laser ablation analyzed over broad range of laser fluence conductions
- Uncertainty in modulus and laser ablation quantified using advanced Bayesian statistics algorithms

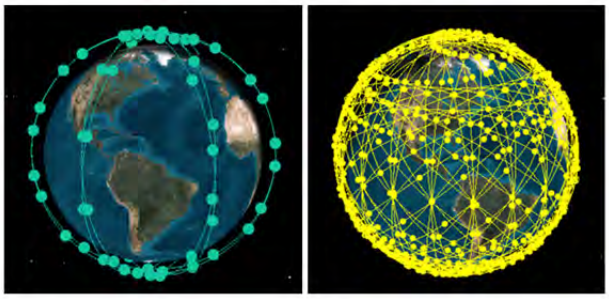
**FUTURE WORK**
- Rigorous assessment of damage evolution during loading and unloading of laser machined sapphire specimens
- Pressure transducer characterization with Univ. of Florida

## TASK #244. Autonomous Rendezvous & Docking for Space Debris Mitigation

- **PROJECT AT-A-GLANCE**
- AST RDAB POC: Stephen Earle, Ken Davidian
- UNIVERSITY: University of Florida
- PRINCIPAL INVESTIGATOR: Dr. Norman Fitz-Coy
- STUDENT(s): Bungo Shiotani (PhD)

**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**
- The proliferation of small satellites will eventually contribute to space debris and thus methodologies for the mitigation and remediation of space debris are required. The 2010 US Space Policy strongly encourages the development of commercial capabilities to enhance safe space operations.

**STATEMENT OF WORK**
- The objective of this research effort is the development of computationally efficient and robust methodologies for active space debris remediation. As this research proceeds, it is expected to make the following contributions:
- Development of artificial potential function-based guidance (APFG) algorithms for proximity operations and autonomous rendezvous/docking.
- Development of strategies to minimize the interactions between a rescue spacecraft and a non-cooperative (disabled) spacecraft. These strategies will be based on game theoretic strategies.
- Modification (Sept. 2014): Assess the impact of launch rate and satellite densities (i.e., number of satellites launched simultaneously) on LEO debris growth and identify strategies to mitigate debris growth caused by containerized satellites



Constellation of traditional and containerized satellites

**STATUS**
- Identified some potential impact factors (e.g., launch rate, satellites per launch, orbit, etc)
- Surveyed the "containerized" satellite community to assess their impact on space debris in LEO

**FUTURE WORK**
- Completing analysis of survey results
- Report findings to FAA, NASA ODPO, IADC, AIAA SmSTC

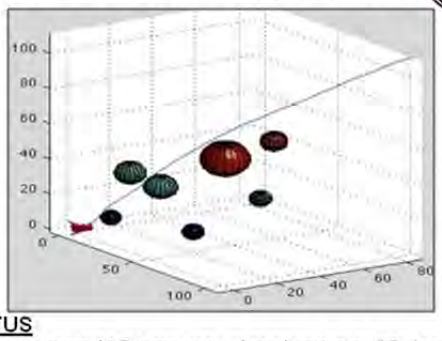
# TASK 244. Autonomous Rendezvous and Docking
## *Rapid Trajectory Generation*

**PROJECT AT-A-GLANCE**
- UNIVERSITY: Florida State University
- PRINCIPAL INVESTIGATOR(S): Dr. Emmanuel Collins
- STUDENT(S): Mr. Griffin Francis (PhD), Mr. Aneesh Sharma (PhD)

**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**
- Confirmed by recent NASA studies, there is an immediate need to develop space debris mitigation technology.
- Future space enterprise endeavors will be threatened by debris if left unchecked.
- In terms of industrial application, commercially-viable debris removal warrants the use of autonomous space vehicles equipped with on-board trajectory generation algorithms.
- Relevant to unmanned spacecraft in general, this task seeks to develop the capability to quickly generate dynamically feasible trajectories that enable an autonomous spacecraft to approach a target for docking.

**STATEMENT OF WORK**
- Develop spacecraft rendezvous dynamic models to account for actuator characteristics and vehicle momentum.
- Formulate methods to effectively plan position, orientation, and velocity with respect to rendezvous target.
- Optimize relevant trajectory metrics (e.g., distance, time, energy).
- Generate trajectories that efficiently avoid moving debris.
- Incorporate rapid replanning that uses prior trajectory data.
- Develop a graph search method called Sampling-Based Model Predictive Optimization (SBMPO).

**3D Planning in Cluttered Environment**




**STATUS**
- Demonstrated 3D trajectory planning that is 25x faster than previous methods.
- Computes time/distance optimal trajectories that end in zero relative velocity.
- Implemented methods to use previous planning data for rapid replanning in nondeterministic environments.
- Established efficient method for accommodating trajectory drift by merging from errant position onto existing solution.

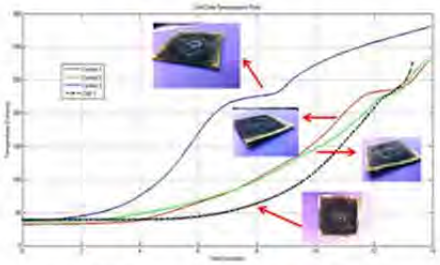
**FUTURE WORK**
- Synergize iterative and anytime planning paradigms to improve algorithm efficiency in dynamic environments.
- Implement additional planning constraints that may be encountered in a realistic app
- Survey potential hardware options for implementation.

# TASK 253. Ultrahigh Temperature Composites TPS

**PROJECT AT-A-GLANCE**
- UNIVERSITY: University of Central Florida
- PRINCIPAL INVESTIGATOR(S): Drs. Jan Gou & Jay Kapat
- STUDENT(S): Chris Harris & Hongjiang Yang

**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**
- Ultra-high temperature, lightweight, low erosion, and low cost thermal protection systems (TPS) are enabling technologies for viable commercial spacecraft and launch vehicle system.

**STATEMENT OF WORK**
- Design and fabrication of polymer derived ceramics composites (PDCC) thermal protection systems.
- Ground testing of PDCC thermal protection systems with Oxyacetylene Exposure Test, Shock Tube Test, Hot Jet and Arc Jet Facilities.
- Multi-scale modeling of PDCC thermal protection systems.
- Develop ablation sensing techniques to monitor the structural health of PDCC thermal protection systems.



***Composites Thermal Protection Systems (TPS)***

**STATUS**
- Oxyacetylene exposure testing of high temperature ceramic fiber reinforced PDC matrix composites

**FUTURE WORK**
- Resin transfer molding (RTM) process with ceramic fiber preform will used to fabricate composite panels.
- Hybrid CMC/PMC composites with PDC resin and phenolic resin will be developed for high ablative performance. PDCC composites serve as skeleton and phenolic resin serves solid coolant.
- Ground testing of PDCC composites will be conducted with Shock Tube Test, Hot Jet and Arc Jet Facilities.

**TPS for Ascent/Entry**

## TASK 293. Reduced Order Non-Linear Structural Model

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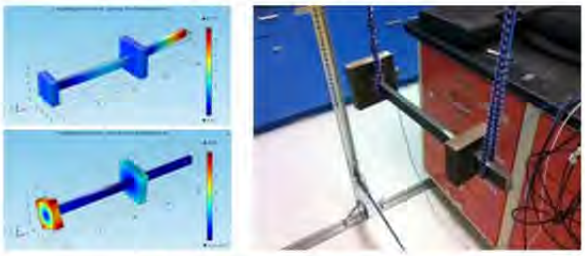
**PROJECT AT-A-GLANCE**
- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATORs: Dr. Donghyeon Ryu and Dr. Keith Miller
- STUDENT: Mr. Kevin Vedera
- FAA TECHANICAL MONITOR: Mr. Nickols Demidovich

**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**
- The structural integrity of commercial launch platforms must be assessed for each mission, i.e. safety certification or recertification. A significant amount of structural response data must be collected in order to state confidence bounds on the computed safety margins. Experimental data will very likely need to be supplemented with data generated by numerical simulations of the structural response of the launch platforms to the anticipated flight environments. Efficient, cost-effective methods for generating non-linear structural models of CST platforms will result from this effort.

**STATEMENT OF WORK**
- Solicit Industrial Working Group feedback to guide implementation of system computational assembly methods.
- Generate non-proprietary code to extract relevant structural features from experimental test data i.e. modal extraction software using rational fractional polynominals (RFP)
- Provide Matlab™ scripts for combining finite element modelled components with experimentally defined (modal) components in structural assemblies.
- Provide help to commercial companies desiring to use modal extraction an assembly codes.

**SUBSTRUCTURING**



Whole beam model = Substructure A beam model + Substructure B beam model

**STATUS**
- Experimental method was improved to yield reliable modal analysis using GMAP MATLAB code.
- Modal parameters of substructures were acquired using COMSOL beam model and experimentation.
- The developed MATLAB substructuring code was tested with COMSOL beam model substructures.

**FUTURE WORK**
- Improvement of accuracy of the MATALB substructuring code to substructure reduced-order computational model and experimentally derived model

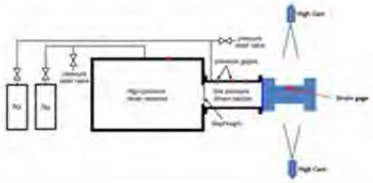
## TASK 299. Nitrous Oxide Composite Case Testing

NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH • UNIVERSITY

**PROJECT AT-A-GLANCE**
- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR(S): Warren Ostergren, Seokbin (Bin) Lim, Andrei Zagrai
- STUDENT(S): Antonio Garcia, Steven Sweeney
- TECHNICAL MONITORS: Yvonne Tran, Don Sargent

**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

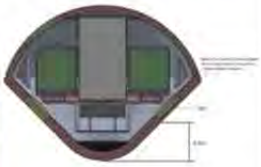


**Test fixture for pressurizing cylindrical tubes to failure**

**STATUS**
- A system was developed for pressurizing cylindrical tubes to failure
- Five tests have been completed with aluminum tubes
- The number of fracture openings in the test samples are closely related to the input pressure loading
- Numerical simulations to predict the fragmentation are in progress

**FUTURE WORK**
- Finalize quantification of the crack opening characteristics
- Test composite tube crack opening behavior
- Characterize the secondary impact and creation of pieces of shrapnel (fragments)
- Understand the kinetics of the fragments

## Task 306. Advanced ADS-B Prototype for Support of Reusable Launch Vehicles and Other Spacecraft

- **PROJECT AT-A-GLANCE**
- AST POC: Nick Demidovich
- UNIVERSITY: Embry-Riddle Aeronautical University
- PRINCIPAL INVESTIGATOR: Dr. Richard S. Stansbury
- STUDENT RESEARCHER: Brandon Neugebauer, Richard P. Day, Alonso Yosvany, and Dominic Tournour

**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**

- ADS-B technology provides a means of tracking suborbital reusable launch vehicles both during the ascent and descent providing details including: position, altitude (geodetic and pressure), and velocity. It reduces the footprint of airspace sanitization required for commercial space operations.

**STATEMENT OF WORK**

- 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)
- 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)
- Develop new ADS-B message format (in progress)

**STATUS**

- Integration of payload on terminal velocity aerospace re-entry vehicle demonstrator
- Flight test of prototype by TVA via stratospheric balloon drop

**FUTURE WORK**

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

## TASK 311. 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(S): Dr. Subith Vasu
- STUDENT(S): Kyle Thurmond & Zachary Loparo

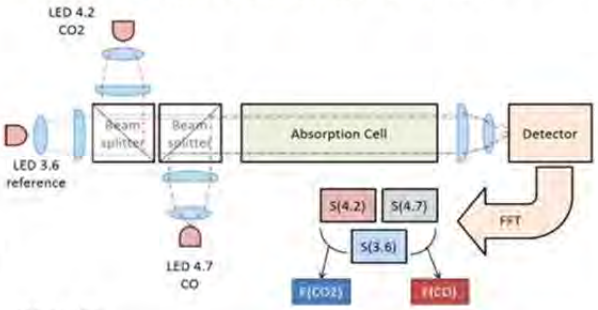
**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**

- CO/CO2 measurements are relevant to the health and safety of the crew.
- Time-resolve measurements of CO could be used to detect fuming which may lead to fire or explosion.

**STATEMENT OF WORK**

- The sensors electronics and optics must be further optimized to maximize sensitivity and reduce noise.
- A model of the absorption of the broad-spectrum source characteristic of LEDs should explored for increasing the flexibility and understanding of the sensors.
- Bench scale testing will need to be conducted to validate optimization and modeling efforts.
- 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 will be carried out in an environmental chamber to simulate relevant conditions. Following this balloon tests will used to further validate design at high-altitudes and micro-gravity conditions.

**Schematic of latest sensor design.**




**STATUS**

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

**FUTURE WORK**

- Developing current sensor design for spacecraft environment and requirements.
- Validating spacecraft ready sensor design using environmental chamber and high altitude balloon.
- Improve performance and possibly extend to measuring other species.

## TASK 323. Structural Health Monitoring Framework

NEW MEXICO TECH
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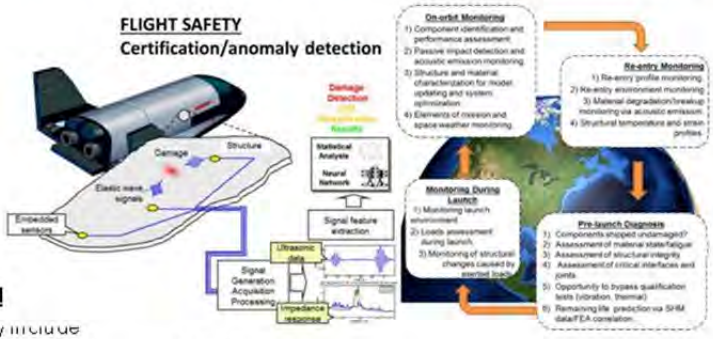
**PROJECT AT-A-GLANCE**

- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR: Dr. Andrei Zagrai
- STUDENTS: Blaine Trujillo (MS), Mary Anderson (MS)




**RELEVANCE TO COMMERCIAL SPACE INDUST**

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.

**STATUS**

- Approaches on information acquisition were discussed.
- Spaceflight providers and relative payload configurations were considered

**STATEMENT OF WORK**

- Review current approaches on sensor information integration in space vehicle.
- Prepare hardware for evaluation of space effects on structural condition and sensor system.

**FUTURE WORK**

- Investigate approaches for sensor information integration in space vehicles.
- Preliminary payload design for spaceflight experiments.

## TASK 325. Optical Measurements of Rocket Nozzle Thrust and Noise

**PROJECT AT-A-GLANCE**

- UNIVERSITY: Florida State University
- PRINCIPAL INVESTIGATOR(S): Rajan Kumar & Farrukh Alvi
- STUDENT(S): Griffin Valentich

**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.

**Optical Measurements of Thrust and Noise**

Rocket nozzle flow field

FSU hot jet facility

Optical measurements using PIV

**STATUS**

- Developing the research plan based on existing measurement techniques
- Preliminary design of thrust optimized parabolic (TOP) contour nozzle completed

**FUTURE WORK**

- Discussion with NASA / commercial launch manager (SpaceX).
- Detailed design to suit FSU jet facility and fabrication of TOP nozzle
- Instrumentation of jet facility to measure mass flow rate and exhaust velocity

## TASK 193. Role of COE CST in Encourage, Facilitate and Promote (Research Roadmap 2.0)

**PROJECT AT-A-GLANCE**
- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR: Prof. Scott Hubbard
- STUDENTS: Andrew Ow, Jonah Zimmerman

**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**
- The COE-CST Research Roadmap directs the COE's research program towards achieving its goal of identifying solutions for existing and anticipated commercial space transportation problems. These solutions will in turn inform research investment and regulations, increase safety, and facilitate the CST industry.

**STATEMENT OF WORK**
- Goals:
  - Revisit the 2011 research roadmap and update as necessary
  - Identify and differentiate near term (1-3 years), medium term (3-6 years), and far term (>6 years) research tasks
  - Define research priorities to the extent possible
- Methods:
  - 5 workshops (1-2 days) hosted by theme PIs who are domain experts
  - Distribute workshops across the country
  - Leverage virtual collaboration software to increase participation
  - Compile and distill input from the workshops into Roadmap 2.0

**Workshop Lead PIs and Locations**

| | | |
|---|---|---|
| **Theme:** 1a – Space Traffic Management<br>**Lead PI:** Juan Alonso<br>**Location:** Stanford and NASA Ames | **Theme:** 1b – Spaceports<br>**Lead PI:** Pat Hynes<br>**Location:** New Mexico State University | |
| **Theme:** 2 – Vehicle Technology<br>**Lead PI:** Farrukh Alvi<br>**Location:** Florida State University | **Theme:** 3 – Human Spaceflight<br>**Lead PI:** Jim Vanderploeg<br>**Location:** University of Texas Medical Branch at Galveston | **Theme:** 4 – Industry Viability<br>**Lead PI:** Tristan Fiedler<br>**Location:** Lockheed Martin Global Vision Center |

**STATUS**
- All workshops completed
- Research Roadmap 2.0 also completed
- Final publication arrangements being made

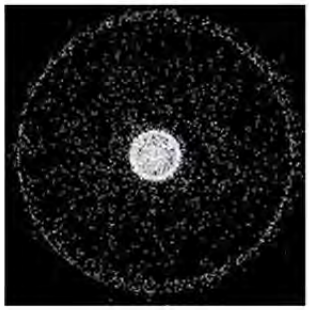
**FUTURE WORK**
- Task 193 has now officially concluded with its tasks having been met
- FAA AST in possession of Roadmap document and ready for next steps
- Roadmap 2.0 expected to be used to guide research efforts within COE CST
- Feedback from CST community currently being sought

## TASK 304. Insurers as Regulators of Space Safety and Sustainability

**PROJECT AT-A-GLANCE**
- UNIVERSITY: McGill University Institute of Air and Space Law
- PRINCIPAL INVESTIGATOR(S): Ram Jakhu
- STUDENT(S): Andrea Harrington

**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**
- Insurance is the third greatest cost when undertaking space activities
- A general need exists to balance safety and sustainability with commercial viability
- Insurers can set requirements to obtain insurance or premium levels for levels of compliance in a context where technology is changing and advancing and political will doesn't exist for new binding international requirements/ national or agency requirements are not necessarily harmonized

**STATEMENT OF WORK**
- Explore issues inherent in the offering, procurement, and handling of traditional areas of space insurance
- Provide public policy and regulatory explanations and recommendations
- Compare aviation and space insurance in the context of reusable craft
- Analyze the role of informed consent and liability waivers / insurance for spaceflight participants
- Provide options for insurers to set standards for debris mitigation
- Discuss the possibility of insurers procuring and/or providing collision avoidance-related services



**STATUS**
- Presentations with related papers have been given at a half dozen conferences on three continents
- Two publications have been produced, with two more articles pending publication

**FUTURE WORK**
- Completion of Andrea Harrington's Thesis & Thesis Defense (1st half of 2016), *Risk Management in Space: Insurance and Legal Issues in the Growth of Commercial Space Activities*
- Publication of comprehensive volume

## TASK 305. Space Transportation Industry Viability

**PROJECT AT-A-GLANCE**
- UNIVERSITY: Florida Institute of Technology
- PRINCIPAL INVESTIGATOR(S): Dr. Scott Benjamin
- STUDENT(S): Taylor Smith and Arion Gray

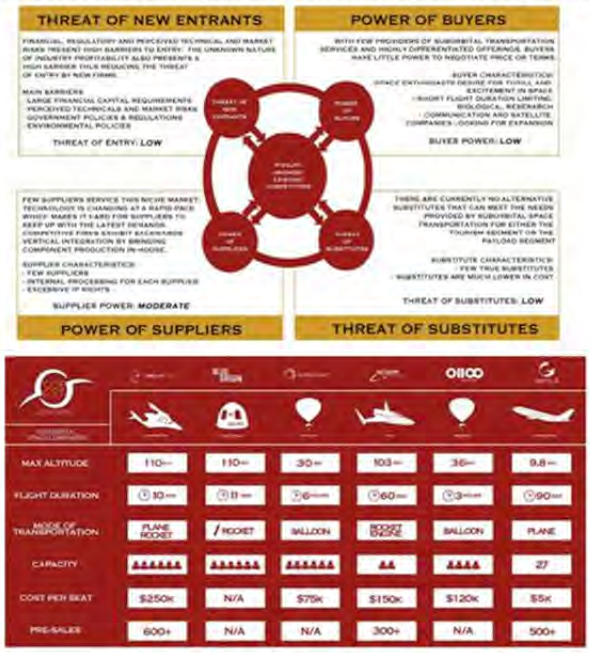
**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**
- To understand the industry structure, conduct and performance of firms in the suborbital space transportation industry by using Porter's Five Forces Model to help develop a general understanding of profitability given the interaction of stakeholders.

**STATEMENT OF WORK**
- Generated a general understanding of industry needs
- Completed a literature review and gathered data on the industry
- Conducted interviews with industry professionals
- Utilized a Porter's Five Forces analysis in order to evaluate competitive rivalry and industry profitability

**STATUS**
- Conclusions have been gathered and a paper is being finished for publication on our findings

**FUTURE WORK**
- Industry Adoption: A Comparative Analysis Between Commercial Aviation and Commercial Space Transportation

**Porter's Five Forces Analysis of Commercial Space Transportation**




## TASK 324. Space Commercialization Strategies From the Internet Experience

**PROJECT AT-A-GLANCE**
- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR: WARD HANSON
- CO-INVESTIGATOR: GREG ROSSTON

**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**
- During the 1990s, the Internet transformed from a government sponsored closed network to a global private commercial force. At the same time, the U.S. government auctioned off substantial amounts of radio spectrum for advanced private uses.
- Government space activities are currently facing some of these same transition issues. Internet and spectrum lessons are especially valuable for one of the most important emerging areas of commercial space, large constellations of low-earth orbit satellites to provide high speed global Internet and cellular communication.

**STATEMENT OF WORK**
- Discuss principal lessons of the Internet and spectrum commercialization process, including the core enabling economic drivers.
- Contrast the Internet experience to commercial space, including a historical perspective on commercial space regulation.
- Summarize key lessons for future regulatory changes to enable successful entrepreneurial space ventures.

**STATUS**
- Identified timeline and key steps of the Internet deregulation and commercialization process, as well as spectrum allocation auctions.
- Identified core economic drivers permitting rapid economic growth of the Internet sector.
- Identified important deregulation and commercialization steps for both the satellite services and the commercial launch industry.
- Assembling report.

**RESULTS TO DATE**
- Internet success driven by rapidly lowering supply and entry costs, "hands off" regulatory changes despite substantial system and security risks, and venture capital driven entrepreneurial successes despite excesses.
- Spectrum auctions succeeded in both allocating scarce frequencies and providing major governmental revenue.
- Launch commercialization strongly influenced by Space Shuttle factors during 1980s-1990s.
- Re-usability may provide major beneficial supply cost shock to commercial space, permitting diverse new space applications.

**FUTURE WORK**
- Discuss plans and constraints on LEO Internet satellite constellations with relevant companies.
- Compile results into report.

## COE CST STUDENTS, PARTNERS AND PUBLICATIONS

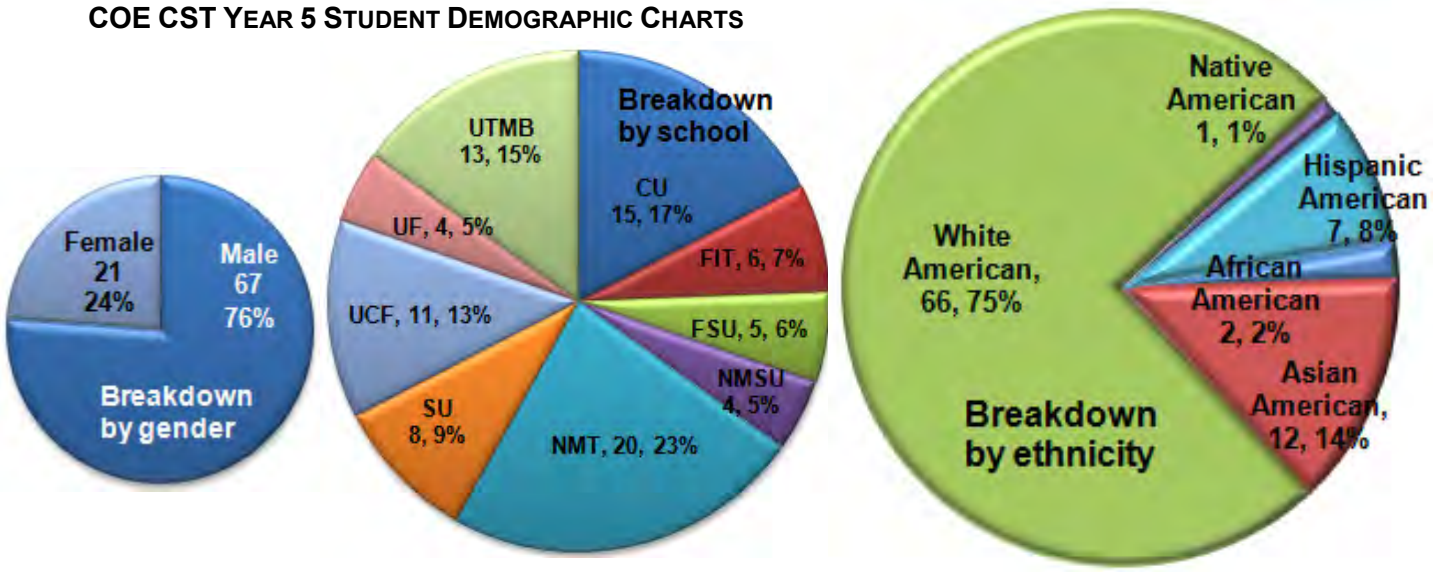
### COE CST YEAR 5 STUDENTS

The following is a list and demographic information of the 61 COE CST students working on research tasks during the year of operation.

- Anderson, Mary (NMT)
- Bal, Harman (FSU)
- Bayley, Steven (NMT)
- Borowski, Holly (CU)
- Brandon, Neugebauer (ERAU)
- Capristan, Francisco (SU)
- Cason, Kathryn (UF)
- Chamberlain, Christine (CU)
- Charalambides, Gabe (SU)
- Cheetham, Bradley (CU)
- Chough, Natcha (UTMB)
- Collins, Justin (FSU)
- Colvin, Thomas (SU)
- Daniel, Blood (UF)
- DiPaolo-Hanson, Andrea (MU)
- Dominic, Tournour (ERAU)
- Fanchiang, Christine (CU)
- Feldhacker, Juliana (CU)
- Francis, Griffin (FSU)
- Garbino, Alejandro (UTMB)
- Garcia, Antonio (NMT)
- Gehly, Steven (CU)
- Gray, Arion (FIT)
- Harris, Chris (UCF)
- Herman, Jon (CU)
- Hernandez, Lance (NMT)
- Howard, Diane (MU)
- Johansen, Benjamin (UTMB)
- Li, Alan (SU)
- Lipscomb, Caleb (CU)
- LoCrasto, Heather (CU)
- Loparo, Zachary (UCF)
- Lopez, Joseph (UCF)
- Michalenko, Joshua (NMSU)
- Mulcahy, Robert (UTMB)
- Neis, Stefan (CU)
- Newman, Tristan (UF)
- Nusbaum, Derek (UTMB)
- Ocampo, Robert (CU)
- Padial, Jose (SU)
- Pattarini, James (UTMB)
- Pryor, Owen (UCF)
- Richard, Day (ERAU)
- Sharma, Aneesh (FSU)
- Sjaardema, Tracy (NMT)
- Smith, Taylor (FIT)
- Smith, Andrew (SU)
- Stanley, June (NMT)
- Sweeney, Steven (NMT)
- Thurmond, Kyle (UCF)
- Tobin, Jessica (NMT)
- Trujillo, Blaine (NMT)
- Urso, Justin (UCF)
- Vedera, Kevin (NMT)
- Vemula, Rohit (FSU)
- Villar, Michael (UCF)
- Wilt, Dennis (FIT)
- Wimberly, Daniel (NMT)
- Yang, Hongjiang (UCF)
- Yosvany, Alsonso (ERAU)
- Zimmerman, Jonah (SU)

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 5 STUDENT DEMOGRAPHIC CHARTS



The following is a list of the 27 COE CST research organization partners that have contributed to the year 5 COE CST research tasks.

- Air Force Research Lab - Kirkland
- Air Force Research Lab - Maui
- Baylor College of Medicine
- FAA Civil Aerospace Medical Institute
- Los Alamos National Laboratory Engineering Institute
- Mayo Clinic - Rochester and Scottsdale
- Metropolitan State College of Denver
- MIT Lincoln Laboratory
- MITRE
- NASA Ames Research Center
- NASA Headquarters
- NASA Jet Propulsion Lab
- NASA Johnson Space Center
- National Science Foundation
- National Space Biomedical Research Institute
- National Space Grant Foundation
- NMSU Space Development Foundation
- Oak Ridge National Laboratory
- Pennsylvania State University, The
- Sandia National Laboratories
- Southwest Research Institute
- Universities Space Research Association
- University of Colorado LASP
- University of Missouri
- US Army
- Webster University
- Wright State University

### COE CST Year 5 Industry Partners

The following is a list of the 57 COE CST industry partners that have contributed to the year 5 COE CST research tasks.

- Altius Space machines
- American Institute of Aeronautics and Astronautics (AIAA)
- Analytical Graphics Inc.
- Arianespace
- ATK
- Bachner Consultants
- Ball Aerospace
- Bigelow Aerospace
- Blue Origin
- Boeing Company, The
- Braxton
- Cimmaron Software Services Inc.
- Clear Channel Satellite
- Commercial Space Flight Federation
- CSSI Inc.
- DigitalGlobe
- Digital Solutions
- Dynetics, Inc.
- Echostar
- Florida Space Grant Consortium
- Globalstar
- IBM
- Intelsat
- Iridium
- Jacobs Technology Inc.
- Locked On Inc.
- Lockheed Martin Space Systems Company
- LORD Microstrain
- Marketing Consultant
- Metis Design
- NASTAR Center
- Near Space Corporation
- New Mexico Spaceport Authority
- Orbital Sciences Corporation
- Orion America Technologies
- Qinetiq
- SAIC
- SolStar
- Scitor Corporation
- Sierra Nevada Corp
- Space Exploration Technologies (Space X)
- Space Florida
- Space News
- Space Ops
- Space Systems / Loral
- Space Works Enterprises
- Spaceport America Consultants
- Spaceport Sweden
- Spaceworks
- Special Aerospace Services
- Tauri Group, The
- Terminal Velocity Aerospace
- United Launch Alliance
- UP Aerospace
- Virgin Galactic
- Wyle Integrated Science and Engineering Group
- XCOR Aerospace, Inc.

COE CST would like to thank the Florida Space Grant Consortium for sponsoring the Welcome Reception at the Fifth Annual Technical Meeting in Arlington, VA.

## COE CST YEAR 5 PUBLICATIONS AND PRESENTATIONS

The following is a list of the 29 publications and presentations completed during COE CST Year 5.

*TASK 186 - SPACE ENVIRONMENT MMOD MODELING AND PREDICTION (SU)*

- Li, A., and Mason, J. Optimal Utility of Satellite Constellation Separation with Differential Drag 2014 AIAA/AAS Astrodynamics Specialist Conference. AIAA 2014-4112.
- Li, A., and Close, S. Mean Thermospheric Density Estimation derived from Satellite Constellations. Advances in Space Research 56 (2015),pp. 1645-1657. DOI: 10.1016/j.asr.2015.07.022

*TASK 220 – SPACE OPS FRAMEWORK (NMSU)*

- 32nd Annual International Test and Evaluation Symposium (ITEA) August, 2015, Arlington, Virginia - presentation by Hynes
- Range Commanders Council: February, 2015 Edwards Air Force Base

*TASK 241 - HIGH TEMPERATURE, OPTICAL SAPPHIRE PRESSURE SENSORS FOR HYPERSONIC VEHICLES (FSU)*

- 1. H. S. Bal, "Characterization of Sapphire: For Its Material Properties at High Temperatures," Master's Thesis, Florida State University, 2015.
- Bin, J., Oates, W., Hussaini, M.Y., “An analysis of the discontinuous spectral element method for elastic wave propagation in a heterogeneous material,” Computational Mechanics, v. 56(4), p. 789-804, 2015.
- J. Collins, W. Oates, D. Blood, D. Mills, M. Sheplak, "Experimental Investigation and Modelling of Laser Machining of Sapphire for High Temperature Pressure Transducers," AIAA SciTech Meeting, Orlando, FL, 2015.

*TASK 304 - INSURERS AS REGULATORS OF SPACE SAFETY AND SUSTAINABILITY (MCGILL UNIVERSITY)*

- Risk Management in the Intermediate Frontier, 3rd Manfred Lachs International Conference on NewSpace Commercialization and the Law (Montreal) March 2015
- Leveraging Insurance for Commercial Space: Managing Legal and Regulatory Challenges, 31st Space Symposium (Colorado Springs) April 2015
- Debris Mitigation as an Insurance Imperative, IAC (Jerusalem) October 2015
- Innovations for Insurers in Space Traffic Management and Weather Forecasting, Space Traffic Management (Daytona Beach, FL) November 2015
- Legal Considerations for Commercial Space: An Overview in New Space Volume 3: Issue 2 (2015)

*TASK 244 - AUTONOMOUS RENDEZVOUS & DOCKING FOR SPACE DEBRIS MITIGATION (UF)*

- Sharma, C. Ordonez, and E. Collins, “Robust Sampling-Based Trajectory Tracking for Autonomous Vehicles,” 2014 IEEE International Conference on Systems, Man, and Cybernetics, San Diego, CA, Oct 5 – 8, 2014

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

- Kyle Thurmond; Zachary Loparo; W.P. Partridge Jr.; Subith S. Vasu; “A Light-Emitting-Diode (LED) Based Absorption Sensor for Simultaneous Detection of Carbon Monoxide and Carbon Dioxide”, Applied Spectroscopy, accepted, 12/2015.
- 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.
- K. Thurmond, Z. Loparo, J. Urso, W. P. Partridge Jr., J. Kapat, S. S. Vasu**,** “A Robust Fire and Hazard Detection Sensor for Space Vehicles Using LEDs”, Commercial and Government Responsive Access to Space Technology Exchange (CRASTE) 2015, Chantilly, VA, 6/2015.

- K. Thurmond, Z. Loparo, W. P. Partridge Jr., J. Kapat, S. S. Vasu**,** “Low-mass, Robust, and Low-Cost LED Absorption Sensors for Simultaneous, Time-Resolved Measurements of CO & CO2”, 18th Annual FAA Commercial Space Transportation Conference, Washington, D.C., 2/2015.


*TASK 186 – MITIGATE THREATS THROUGH SPACE ENVIRONMENT MODELING/PREDICTION (CU)*


- Rastätter, L., J-S. Shim, M. M. Kuznetsova, L. M. Kilcommons, D. J. Knipp, M. Codrescu, T. Fuller-Rowell, B. Emery, D. R. Weimer, R. Cosgrove, M. Wiltberger, J. Raeder, W. Li, G. Tóth, and D. Welling (2016), GEM-CEDAR challenge: Poynting flux at DMSP 1 and modeled Joule heat, *Space Weather*.
- Fuller-Rowell, T. J., T.-W. Fang, H. Wang, V. Matthias, P. Hoffmann, K. Hocke, and S. Studer (2015), Impact of migrating tides on electrodynamics during the January 2009 sudden stratospheric warming, in *Longitude and Hemispheric Dependence and the Lower Atmosphere Connection, Geophys. Monogr. Ser.*, edited by S. Basu, T. J. Fuller-Rowell, E. Yizengaw, and P. Doherty, John Wiley & Sons, Ltd, Chichester, UK.
- Fong, W. C., X. Z. Chu, X. Lu, C. Chen, T. J. Fuller-Rowell, M. Codrescu, and A. D. Richmond (2015), Lidar and CTIPe model studies of the fast amplitude growth with altitude of the diurnal temperature "tides" in the Antarctic winter lower thermosphere and dependence on geomagnetic activity, *Geophys. Res. Lett*., *42*(3), 697–704, doi:10.1002/2014GL062784.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