Florida Institute of Technology

Florida State University

NM State University

New Mexico Tech
Science • Engineering • Research • University

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 4 Annual Report

Executive Summary

December 31, 2014

Federal Aviation Administration
Center of Excellence for Commercial Space Transportation
Year 4 Annual Report Executive Summary
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FAA Administrator, Michael Huerta, presents Drs. Tarah Castleberry and Charles Mathers with a plaque in recognition of UTMB's centrifuge testing conducted under the FAA COE CST program.

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 4 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, Ken Davidian, 202-267-7214, ken.davidian@faa.gov.

- December 31, 2014

ACKNOWLEDGEMENTS

Dr. George Nield, the Associate Administrator of FAA AST, and Dr. Patricia Watts, Program Director of all 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 COE CST and will be the source of any future accomplishments as well. The COE CST is very grateful for their support. Coming more recently to the COE CST world, the Director of the FAA William J. Hughes Technical Center, Dr. Dennis Filler, has demonstrated great support through his participation in the fourth Annual Technical Meeting. Long-time advocate, Dr. Joseph Rosenberg, leader of the COE CST Industry Advisory Committee, said farewell to the COE CST community when he retired from retirement (for a third time?) and took a full-time job with a small start-up located in the San Jose area. We wish him well. He will be missed.

The COE CST is a collection of nine incredible universities (described in detail later in this document), supplemented by a handful of 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, the government researchers, and everybody else. It is the collective effort of these individuals that make the research possible, provide matching in-kind contributions, generate and post the boat-load of technical and financial data for government-required reports, and fundamentally make the overall system function efficiently through their individual actions.

These important individuals represent the dozens of participating organizations and institutions. Words of thanks or acts of appreciation in recognition for their contributions of time, effort, and treasure cannot be adequately expressed. Thank you, all.

PICTURED TO THE RIGHT: The nine COE CST member universities posed for a picture at the fourth Annual Technical Meeting on October 29, 2014. From left to right: Dr. Dave Klaus (CU Boulder), Dr. Jay Kapat (UCF), Professor Scott Hubbard (Stanford), Dr. Norm Fitz-Coy (UF), Dr. Jim Vanderploeg (UTMB), Dr. Farrukh Alvi (FSU), Dr. Patricia Hynes (NMSU), Dr. Warren Ostergren (NMT), and Dr. Tristan Fiedler (FIT).

INTRODUCTION

This Executive Summary accompanies a more detailed, three volume annual report of the FAA COE CST, available on the COE CST web site.

- Volume 1 gives a full description of the FAA COE CST, 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 fourth Annual Technical Meeting in October 2014.
- Volume 3 is a comprehensive set of notes from all FAA COE CST teleconferences and face-to-face meetings.

This 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 member universities 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 and affiliate members. A new section has been added to the Executive Summary this year, introducing 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 fourth year of operation are listed. Quad charts provide the summary information for each task.

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

OVERVIEWS

FAA Office of Commercial Space Transportation

As of December 2013, the FAA Office of Commercial Space Transportation (AST) is comprised of approximately 80 full time equivalent (FTE) civil servants and operates with a budget of $16 million. (By contrast, the FAA has approximately 48,000 FTEs and a total budget of $16 billion.) Despite its relatively small size, 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 Center of Excellence (COE) program was established by the Omnibus Budget Reconciliation Act of 1990, Public Law 101-508, Title IX, Aviation Safety and Capacity Expansion Act.

COEs are intended to be a 10-year partnership of academia, industry, and government to create a world-class consortium that will address current and future challenges for commercial space transportation. The three main goals of every COE include research, training, and outreach.

A unique attribute of the COE program is the one-to-one matching requirement for every federal dollar granted to a COE university. The matching requirement can be satisfied through direct or in-kind contributions from any non-federal funding source, including industry, universities, and state and local government organizations.

Eight 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 in 1995.
- The National COE for Aviation Operations Research (NEXTOR), operated from 1996 to 2007.
- The Airworthiness 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 2013.
- The Joint Center for Advanced Materials (JAMS), in operation from 2003 to 2015.
- The Airliner Cabin Environment Research (ACER) Center, also called the COE for Research in the Intermodal Transport Environment (RITE), in operation from 2004 to 2014.

Since the creation of the COE CST in August 2010 and as of December 2013, two 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), announced in 2012.

FAA Center of Excellence for Commercial Space Transportation

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

COE CST Year 4 Highlights

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

- Fourth Annual Administrative Meeting held at the Florida Institute of Technology (FIT) in Melbourne, Florida, on April 22-23, 2014.
- Recognition of COE CST research work done by the University of Texas Medical Branch (UTMB) at the Aerospace Medical Association Annual Scientific Meeting in San Diego, California, on May 13-16, 2014.
- Fourth Annual Technical Meeting held in Washington, D.C. on October 28-30, 2014.
- The New Space Journal completed its second year of quarterly publications, featuring topics of spaceports, Mars, human spaceflight research, and the "space generation" of upcoming professionals.

At-A-Glance Metrics	Year 1	Year 2	Year 3	Year 4
# Active Tasks	34	24	28	26
# Funded Tasks	*34*	*22*	*22*	*11*
# Principal Investigators	27	28	29	25
# Students	31	37	55	47
# Reports	0	38	28	22
# Research Partners	-	17	20	27
# Industry Partners	-	29	44	55
# Affiliate Members	0	1	6	6
Funding Profile	$2M (FY10)	$2.4M (FY11/12)	$1.1M (FY13)	$1.1M (FY14)

In the fourth year of COE CST operation, there were 3 new tasks started, 18 ongoing from the previous year, 3 tasks on hold, 3 tasks completed, and 3 affiliate member tasks. The complete list of all tasks is given in the second half of this Executive Summary.

COE CST Students, Partners and Publications

In the fourth year of operation, the COE CST benefited from the services of 47 students, 27 research partners and 55 industry partners. The combined effort resulted in 22 technical or programmatic papers published in journals or presented at conferences. A complete list of students, partners (both industry and research organization) and publications are given after the research task summary charts in this report.

FAA AST TECHNICAL MONITORS

Technical monitors are the strategic link between the FAA's research requirements and the work 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, Office of the Chief Engineer, AST
- 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
- Ms. Yvonne Tran, Regulations & Analysis Division, AST
- Dr. Paul Wilde, Office of the Chief Engineer

The specific tasks for which each Technical Monitor is responsible are given in the research task table in the "COE CST RESEARCH TASKS" section and on each of the research task summary (quad) charts.

COE CST MEMBER UNIVERSITIES

The nine 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 nine universities bring over 50 other government, industry and academic organizations as research partners.

As a single entity, the nine COE CST member universities unite complementary strengths for the benefit of the overall COE and the FAA. Each team member provides highly respected and consummate experiences that directly address the research and education needs of the commercial space industry.

In 2012, McGill University of Montréal, Canada, joined the COE CST as the first Affiliate University. The remainder of this section provides more detail on each of the nine member universities and other affiliate and associate organizations.

Florida Institute of Technology (FIT)

Florida Tech (FIT) offers broad expertise in aerospace and space-related engineering, science, space traffic management and launch operations, vehicle and payload analysis and design, thermal systems and propulsion.

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 aero-structures.

New Mexico Institute of Mining and Technology (NMT)

NMT is a science, math and engineering university with a focus on applied research. Major research facilities include a rocket engine test fixture at the Energetic Materials Research and Testing Center, and a 2.4M fast tracking telescope at the Magdalena Ridge Observatory dedicated to the study of near earth objects.

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.

Map of COE CST Member and Affiliate University Geographic Distribution

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 (SatWest)

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.

COE CST ASSOCIATE MEMBERS AND PRIMARY PARTNERS

Baylor College of Medicine Center for Space Medicine (CSM)

Baylor College of Medicine Center for Space Medicine (CSM) is a collaborative enterprise involving Baylor College of Medicine, the National Space Biomedical Research Institute, NASA, Rice University, Texas Medical Center institutions, and other academic, industry and government organizations nationally and internationally. The affiliation with UTMB and the COE CST offers UTMB researchers the ability to work side-by-side CSM faculty and students in collaboration with NSBRI, NASA and other colleagues. Most recently, this included UTMB residents working with CSM faculty Dr. Jon Clark, providing medical support and research for the RedBull Stratos project, resulting in many publications and presentations.

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 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.

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 their work. Shown below are honors received during the past 12 months. The FAA would like to congratulate all the recognized recipients (listed in alphabetical order by last name) for their great achievements!

- **Dr. Rebecca Blue (UTMB)** was given the Julian E. Ward Memorial Award for superior performance and outstanding achievement in the art and science of aerospace medicine during residency training, and was noted for all of her work, including 18 publications.
- **Mr. Brad Cheetham (CU Boulder)** received the 2014 Aviation Week's Twenty-20s Award, listing the top 20 people in the aerospace industry under the age of 30.
- **Dr. Natacha Chough (UTMB)** was awarded the AsMA Jeffrey R. Davis, MD, Endowed Scholarship and the Society of NASA Flight Surgeons Outstanding Student Award.
- **Dr. Emmanuel Collins (FSU)** received the Black Engineer of the Year Award for College-Level Promotion of Education, and was named a Fellow of the American Society of Mechanical Engineer (ASME).
- **Dr. Dave Klaus (CU Boulder)** recently received the Aerospace Department Outstanding Graduate Teaching and Mentoring Award, 2014.
- **Dr. Robert Mulcahy (UTMB)** was awarded the Jeff Myers Young Investigator Award.
- **Dr. James Pattarini (UTMB)** was awarded the AsMA Jeffrey R. Davis, MD, Endowed Scholarship and the Space Medicine Association Wyle Scholarship.
- **Dr. Daniel J. Scheeres (CU Boulder)** was recently Named Distinguished Professor of The University of Colorado by the Board of Regents, 2014, and was named a Fellow of the American Institute of Aeronautics and Astronautics.
- **Dr. James Vanderploeg (UTMB)** was given the Louis H. Bauer Founders Award, the top honor from the Aerospace Medical Association (AsMA) for the most significant contribution in aerospace medicine.
- **Mr. Jonah Zimmerman (Stanford)** received the Best Student Paper at the AIAA Joint Propulsion Conference in 2013.

TEAM UTMB: Members of the UTMB researchers at the AsMA Conference, from left to right: Dr. Dana Levin, Dr. James Pattarini, Dr. Robert Mulcahy, Dr. Rebecca Blue, Mr. Ken Davidian, Dr. Alex Garbino, Dr. Jim Vanderploeg, Dr. Tarah Castleberry, Dr. Charles Mathers, and Dr. Eric Blacher. Not pictured: Dr. Natacha Chough.

COE CST RESEARCH TASKS

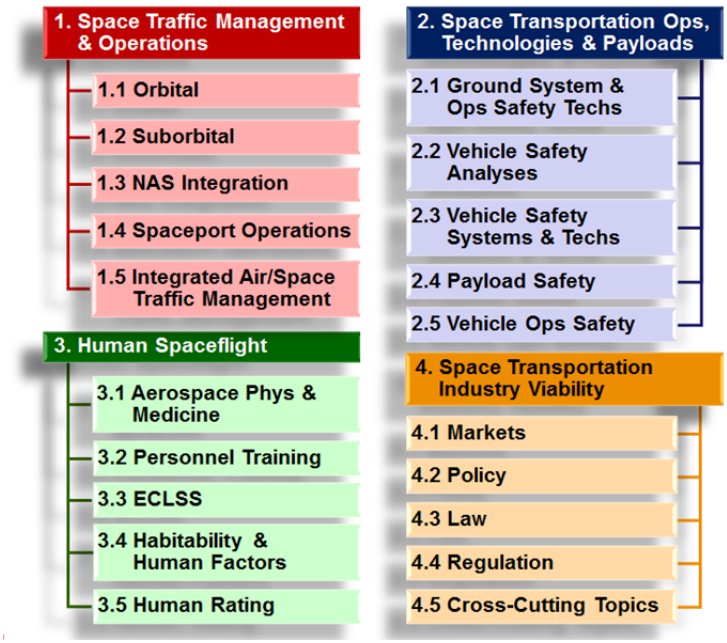
The research conducted within FAA AST is broken into four major research themes:

- Space Traffic Management & Operations
- Space Transportation Operations, Technologies & Payloads
- 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 fourth 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 COE CST R&D Tasks (as of 31 Dec 2014)

Task # Name / PI Name (Univ) - AST TM		Task # Name / PI Name (Univ) - AST TM	
185 Unified 4-Dimensional Trajectory Analysis Alonso (SU) - Wilde	F	**244 Autonomous Rendezvous and Docking** Collins (FSU) - Earle	F
186 Space Environment MMOD Modeling Close(SU)-Shelton-Mur	F	**244 Autonomous Rendezvous and Docking*** Rock (SU) - Earle	OH
186 Space Environment MMOD Modeling Fuller-Rowell(CU)-Shelton-Mur	NCE	**244 Autonomous Rendezvous and Docking** Axelrad (CU) - Earle	NCE
187 Space Situational Awareness Scheeres (CU) - Earle	OH	**253 Ultra High Temperature Composites** Gou & Kapat (UCF) - Demidovich	NCE
220 Space Operational Framework Hynes (NMSU) - Rey	F	**258 Multi-Disciplinary Analysis of Safety Metrics** Alonso (SU) - Wilde	NCE
257 Master's Launch and On-Orbit Operations Laboratory Born (CU) - Davidian	END	**293 Reduced Order Non-Linear Structural Modeling** Miller (NMT) - Demidovich	NCE
184 Human Rating of Commercial Spacecraft Klaus (CU) - Lampazzi	END	**298 Integration Evaluation of ADS-B Payloads** Hynes (NMSU) - Demidovich	END
256 Additional NASTAR Centrifuge Testing Vanderploeg (UTMB) - Lampazzi	NCE	**299 Nitrous Oxide Composite Tank Testing** Ostergren (NMT) - Tran	F
308 Suborbital Cabin Lethality Vanderploeg (UTMB) - Lampazzi	NEW	**306 Advanced ADS-B Prototype for RLVs** Stansbury (ERAU) – Demidovich	AFF
309 Suborbital Pilot Assessment Vanderploeg (UTMB) - Lampazzi	NEW	**307 COTS Satellite Communications Systems** Barnett (SatWest) – Demidovich	AFF
310 Reducing Cabin Lethality Vanderploeg (UTMB) - Lampazzi	NEW	**311 Low-Mass/Cost CO/CO2 Sensors** Vasu (UCF) - Demidovich	F
228 Magneto-Elastic Sensing for SHM Zagrai, Ostergren (NMT) -Demidovich	F	**193 Role of COE CST in EFP** Hubbard (SU) - Davidian	F
241 High Temperature Pressure Transducers Sheplak (UF) - Demidovich	NCE	**193 Role of COE CST in EFP** Born (CU) - Davidian	OH
241 High Temperature Pressure Transducers Oats (FSU) - Demidovich	NCE	**304 Definition and Delimitation of Outer Space** DiPaolo (MU) - Sloan	AFF
244 Autonomous Rendezvous and Docking Fitz-Coy (UF) - Earle	NCE	**305 Suborbital Industry Analysis** Benjamin (FIT) - Davidian	NCE

Note: Among the 30 COE CST tasks active in Year 4, 3 are new (NEW) and funded, 8 are continuations of previous tasks and funded (F) and in-work, 10 are in process with a no cost extension (NCE), 3 are on hold (OH), 3 ended (END), and there were 3 Affiliate Member tasks (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, SU-Stanford University, UCF-University of Central Florida, UF-University of Florida, UTMB-University of Texas Medical Branch. * Quad chart not included.

TASK 185. UNIFIED 4D TRAJECTORY APPROACH FOR INTEGRATED TRAFFIC MANAGEMENT

Stanford University

PROJECT AT-A-GLANCE

•UNIVERSITY: Stanford University
•PRINCIPAL INVESTIGATOR(S): Dr. Juan Alonso
•STUDENT(S): Thomas Colvin

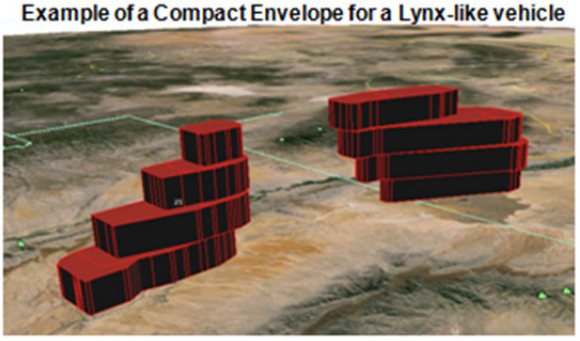
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

•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 that is associated with launch and reentry events so that all transportation providers will have fair and safe access to the national airspace.

STATEMENT OF WORK

•Developed initial Compact Envelope techniques (Apr 2012)
•Initial modifications of NASA FACET tool to enable Compact Envelopes (Nov 2012)
•Basic aircraft re-routing capabilities in FACET (May 2013)
•Worked with FAA Offices of NextGen and Commercial Space to develop realistic future launch/reentry scenarios (Jun 2013)
•First sub-orbital compact envelope generated (Aug 2013)
•Basic Kernel Density Estimation techniques are used to generate probabilistic compact envelopes (Sep 2013)
•Implemented Aircraft Vulnerability Models for improved risk calculations (Mar 2014)
•FACET modified to incorporate Terminal Area Forecast data for simulations of future air traffic (May 2014)
•Began running NAS-wide simulations to quantify the impact of Compact Envelopes on the national airspace (Nov 2014)
•Paper accepted to AIAA SciTech 2015 Conference (Dec 2014)

Example of a Compact Envelope for a Lynx-like vehicle



STATUS

• Running NAS-wide simulations with FAA Office of NextGen to demonstrate the superiority of our methods over traditional methods for air-and-space-traffic integration.
• Validation of our analysis environment by recreating the Space Shuttle Columbia accident and comparing with published values of aircraft risk.

FUTURE WORK

• Model aircraft and air traffic controllers as a Markov Decision Process and investigate futuristic aircraft rerouting techniques for dynamic airspaces
• Use a Monte Carlo simulation to estimate expected values of airspace disruption for our Compact Envelope method

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

STANFORD AERONAUTICS & ASTRONAUTICS

PROJECT AT-A-GLANCE

• UNIVERSITY: Stanford University
• PRINCIPAL INVESTIGATOR: Sigrid Close
• STUDENT RESEARCHER: Alan Li (MS)

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.

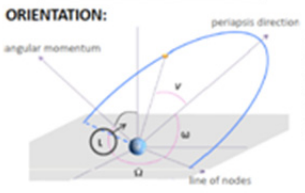
STATEMENT OF WORK

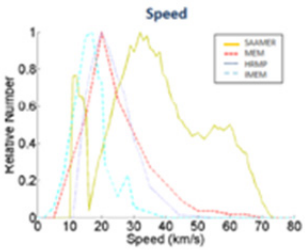
• Provide the first characterization of debris and meteoroid parameters, including e.g. energy flux, orbit, and bulk density, in order to assess MOD threat on-orbit.

STATUS

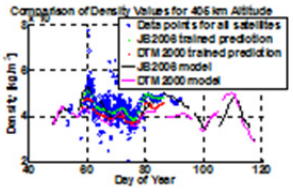
• Developed models to assess meteoroid threat to spacecraft (mass flux and speed as a function of orbit)
• Analyzed CubeSat data to determine atmospheric density as a function of orbit

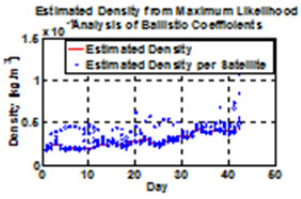
METEOROID RESULTS





DEBRIS RESULTS





FUTURE WORK

• Meteoroids
  • FDTD scattering model
  • Plasma instabilities
• Debris
  • Filtering methods for larger constellation of satellites
  • Propagation of debris using near real time density data

TASK 186. MITIGATING THREATS THROUGH SPACE ENVIRONMENT MODELING & PREDICTION

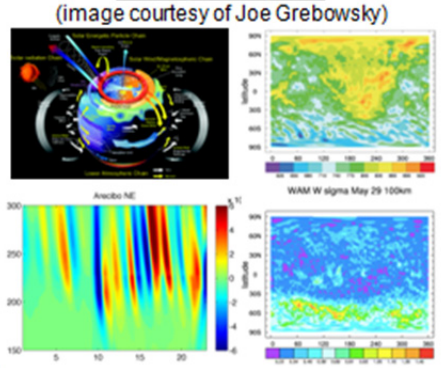
PROJECT AT-A-GLANCE
- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. Tim Fuller-Rowell
- STUDENT RESEARCHER: Catalin Negrea
- AST RDAB POC: Karen Shelton-Mur

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- An integrated air and space traffic management system requires real-time knowledge of environmental conditions and their impact on flight conditions from the ground to 600 km altitude, including:

1. Neutral atmosphere winds, wind shear, temperature, density, variability, turbulence, etc., for safe orbital, sub-orbital, re-entry, descent, and landing operations
2. Plasma density, D-region absorption, total electron content, ionospheric structure and irregularities, radiation conditions for impact on communications, navigation, and safety in flight

STATEMENT OF WORK
- Predict the terrestrial weather and atmospheric conditions, and space weather (e.g. solar flares, geomagnetic storms, solar proton events)
- Provide the information to determine impact on navigation, communications, and positioning for space vehicles
- Simulate the internal lower atmosphere sources of variability and its impact on the upper atmosphere and ionosphere, and space weather

The Physical System
(image courtesy of Joe Grebowsky)



STATUS
- WAM has been developed and is being integrated into the NOAA Environmental Modeling System (NEMS)
- NEMS-WAM is being validated and coupled to a plasma model

FUTURE WORK (combined COE-CST, NASA, and NOAA)
- Continue to validate WAM and ionospheric model and explore impact on neutral density and ionospheric structure
- Two-way coupling between WAM and ionospheric module
- Extend WAM data assimilation into the lower thermosphere
- Test higher resolution WAM T382 (35 km resolution) to resolve full wave field penetrating to the thermosphere.
- Assimilation of ground-based GNSS and radio occultation data for ionospheric specification

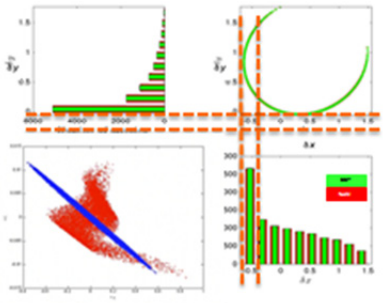
TASK 187. SPACE SITUATIONAL AWARENESS

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
- STUDENT RESEARCHER: Ms. Marianne Bowers

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

- Spaceport Directors were surveyed
- We have Identified and aggregated over XXX standards and procedures that are relevant to commercial spaceports from 12 different government/non-government reference sources.
- Presented a paper at the IAC conference, September 2014.

FUTURE WORK

- Prepare for dissemination to the industry at ATM-5
- Publish paper in a journal
- Submit two papers for publication
- Present at three conferences

TASK 257. MASTERS LEVEL COMMERCIAL SPACEFLIGHT OPERATIONS CURRICULUM

PROJECT AT-A-GLANCE

- AST RDAB POC: Ken Davidian
- AST RESEARCH AREA: 2.1 Ground Systems & Ops Safety
- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. George Born
- STUDENT RESEARCHER: Mr. Bradley Cheetham (PhD)
- PERIOD OF PERF: Jan 1, 2011 – May 31, 2015
- STATUS: Ongoing

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

Research - student projects investigate current constraints and explore potential solutions

Training - preparing students to enter industry

Outreach - educating academia and industry

STATEMENT OF WORK

- Develop one-semester course and one-semester lab and refine content based on student and industry feedback.
- Draft academic objectives based on industry discussion; solicit feedback on academic objectives; and define curriculum topics and solicit feedback.
- Academic objectives include: (a) Comprehension of total mission sequence; (b) Constraints on design and operations including: Technical, Policy/Legal, Business, and Practical; (c) Understanding of and insight into current industry practices: Past to present; (d) Overview of project management and team dynamics; (e) Cross cutting theme of Risk (through all objectives).

Commercial Spaceflight Operations Lab

STATUS

- Lecture offered for four semesters.
- Lab evolved for second offering in spring 2014
- Total of 102 students have participated in curriculum effort

FUTURE WORK

- Fall 2014: Fourth lecture offering, lab refinement
- Fall 2014: Begin formalizing certificate
- Spring 2015: Third lab offering

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TASK 184. HUMAN-RATING OF COMMERCIAL SPACECRAFT

PROJECT AT-A-GLANCE
- UNIVERSITY: University of Colorado-Boulder
- PRINCIPAL INVESTIGATOR: Prof. David Klaus
- STUDENTS: Christine Chamberlain, Roger Huang

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
This task aims to define and assess the criteria and protocols typically employed for ensuring human-rating objectives (primarily safety) are met, including extension beyond the crew and space flight participants toward an era of passenger carrying spacecraft, and while also minimizing risk to the uninvolved public

STATEMENT OF WORK *(6/1/11-12/31/14)*
- **2011/12**
  Historical Perspectives on Human-Rating
  Human-Rating Terms and Definitions
- **2012/13**
  FAA Human-Rating Ground Rules and Assumptions
  FAA Established Practices for Human Spaceflight Occupant Safety
- **2013/14**
  FAA Recommended Practices for Human Space Flight Occupant Safety
  Medical 'Levels of Care' for Commercial Spaceflight
  Crew Survival Methods
  Risk Perception / Communication

STATUS *(2013/14 outcomes)*
1. Neis, S.M. and Klaus, D.M. (2014) **Considerations toward Defining Medical 'Levels of Care' for Commercial Spaceflight**. New Space [in press]
2. Klaus, D.M., Ocampo, R.P. and Fanchiang, C. (2014) **Spacecraft Human-Rating: Historical Overview and Implementation Considerations**. IEEE Aerospace Proceedings (978-1-4799-1622-1/14, no. 2272)
3. Ocampo, R.P. and Klaus, D.M. (2013) **A Review of Spacecraft Safety: from Vostok to the International Space Station**. New Space 1(2): 73-80

FUTURE WORK (*ongoing through 12/31/14*)
1. Medical Levels of Care for Commercial Space Transportation
2. Emergency Crew Survival Methods
3. Risk Perception / Communication

TASK 256. TOLERANCE OF CENTRIFUGE-INDUCED G-FORCE BY DISEASE STATE

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: James Pattarini, MD; David Reyes, MD; Robert Mulcahy, MD; Natacha Chough, MD; Eric Blacher, MD

RELEVANCE TO COMMERCIAL SPACEFLIGHT INDUSTRY
- There is little to no data on how individuals with chronic diseases will perform in a high-performance environment such as commercial spaceflight. This study provides data on how individuals with chronic diseases responded to G-force.

STATEMENT OF WORK
- Characterization of responses of individuals with common medical conditions to G-force
- Development of risk mitigation strategies for individuals with those medical conditions

STATUS
- Completed testing and evaluation using the NASTAR centrifuge
- Performed data analysis
- Published results

FUTURE WORK
- Develop optimal acceleration training protocols for passengers
- Further evaluate role of training in reducing anxiety

TASK 308. ASSESSMENT OF SCREENING AND TRAINING REQUIREMENTS FOR SFPs REGARDING ANXIETY DURING REPEATED EEPOSURES 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: **Robert Mulcahy, MD**; Eric Blacher, MD; Ben Johansen, DO; James Pattarini, MD; Natacha Chough, MD

RELEVANCE TO COMMERCIAL SPACEFLIGHT IINDUSTRY

- Psychological stressors can be significant challenges in the operational environment. This study will provide data on how individuals with high anxiety levels can best be prepared for suborbital spaceflight through training and anxiety mitigation techniques.

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

- Research protocol submitted to IRB
- Psychological testing methods defined

FUTURE WORK

- Complete IRB approval process
- Recruit test subjects
- Conduct training and testing at NASTAR centrifuge throughout 2015

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: **Eric Blacher, MD**; Benjamin Johansen, DO; Robert Mulcahy, MD; James Pattarini, MD; Natacha Chough, MD

RELEVANCE TO COMMERCIAL SPACEFLIGHT IINDUSTRY

- 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

- Preliminary monitoring techniques for use in the Extra acrobatic plane are being conducted.
- IRB research protocol being prepared

FUTURE WORK

- Complete IRB approval process
- Recruit pilots for research study
- Conduct aerobatic flights and NASTAR testing throughout 2015
- Conduct physiological monitoring during spaceflights in 2015 and 2016

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; Eric Blacher, MD; 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.

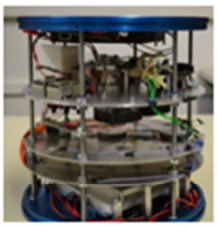
STATUS
- Literature search underway
- Students being trained in conducting and evaluating relevant literature review

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.

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

TASK 228. MAGNETO-ELASTIC SENSING FOR STRUCTURAL HEALTH MONITORING

NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH UNIVERSITY



PROJECT AT-A-GLANCE
- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR: Dr. Andrei Zagrai and Dr. Warren Ostergren.
- STUDENTS: Blaine Trujillo (MS), Joel Runnels (UG) and William Masker (UG)

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.

STATUS
- 038S NASA FOP Flight completed & analyzed
- Acoustic emission measurements of fatigue damage is explored. PWAS AE validated.
- Development of portable EMI board started

STATEMENT OF WORK
- Demonstrate utility of various SHM strategies during suborbital space flight
- Investigate potential of magneto-elastic active sensors and embeddable thin wafer piezoelectric sensors to record acoustic emission activity due to structural fatigue and thermal damage
- Develop portable hardware for electro-mechanical impedance measurements in space environment.

FUTURE WORK
- Electro-mechanical impedance manifestation of dynamic behavior of bolted joints
- Modeling of temperature effects on electro-mechanical impedance

TASK 241. HIGH-TEMPERATURE PRESSURE SENSORS FOR HYPERSONIC VEHICLES

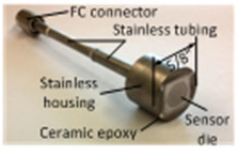
UF UNIVERSITY of FLORIDA

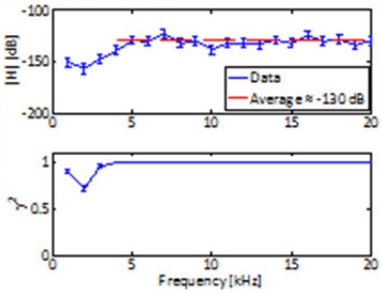
PROJECT AT-A-GLANCE
- UNIVERSITY: University of Florida
- PRINCIPAL INVESTIGATOR: Dr. Mark Sheplak
- STUDENT RESEARCHERS: Dr. David Mills, Dr. Daniel Blood

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- The study of hypersonic boundary layers is critical to the efficient design of hypersonic vehicles for rapid global and space access. The harsh environment makes conventional instrumentation unsuitable for these measurements. The development of a high-temperature pressure sensor will provide insight into critical vehicle characteristics such as lift, drag, and propulsion efficiency.

STATEMENT OF WORK
- Identify a suitable sensing method, material, and process flow for a high-bandwidth pressure sensor capable of continuous operation in temperatures in excess of 1000°C
- Fabricate a prototype sensor and create a robust high-temperature package
- Characterize the packaged sensor at room temperature and in high-temperature environments
- Implement the packaged sensor in a hypersonic or hot jet flow facility and/or a gas turbine

PACKAGED FIBER-OPTIC SENSOR AND FREQUENCY RESPONSE





STATUS
- Packaged sensor characterized in multiple test setups to determine linearity, frequency response, and noise floor
- Tube furnace capable of operation up to 1700°C purchased to perform high-temperature dynamic characterization

FUTURE WORK
- Complete characterization of SPS bonding process
- Identify of leakage path preventing dc pressure measurement
- Configure tube furnace for high-temperature sensor testing
- Characterize the packaged sensor at high temperatures
- Demonstrate the sensor in a high-temperature flow facility or gas turbine

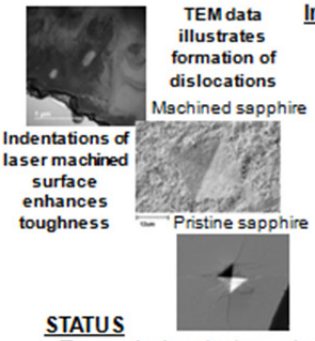
TASK 241. HIGH TEMPERATURE PRESSURE SENSORS FOR HYPERSONIC VEHICLES (FRACTURE MECHANICS)

PROJECT AT-A-GLANCE
- AST RDAB POC: Nick Demidovich
- AST RESEARCH AREA: 2.3 Vehicle Safety Systems & Technologies
- UNIVERSITY: Florida State University
- PRINCIPAL INVESTIGATOR: Dr. William Oates
- STUDENT RESEARCHER: Mr. Justin Collins (PhD)
- PERIOD OF PERF: May 1, 2013 – May 31, 2014
- STATUS: Ongoing

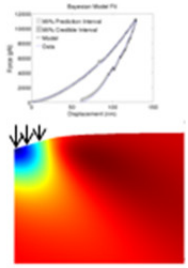
RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- Orbital commercial space vehicles require high-temperature sensors (~1000°C/1600°F) or various phases of flight (e.g. hypersonic flight, high speed reentry) or to monitor system and subsystem performance (e.g., for gas turbines or scramjets). Current commercial sensors are only capable of up to ~300°C/600°F.

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

Material Characterization



Single Crystal Dislocation Indent Mechanics and Bayesian Uncertainty Analysis



STATUS
- Transmission electron microscopy motivated development of new finite deformation dislocation mechanics modeling of indentations
- Results illustrate an increase in modulus during nanoindentation during damage evolution under the indent

FUTURE WORK
- Rigorous assessment of damage evolution during loading and unloading near indents in pristine and laser damage specimens
- Preliminary finding show elastic properties vary significantly after laser machining
- Pressure transducer testing

TASK 244. AUTONOMOUS RENDEZVOUS AND DOCKING FOR SPACE DEBRIS MITIGATION

UF UNIVERSITY of FLORIDA

PROJECT AT-A-GLANCE

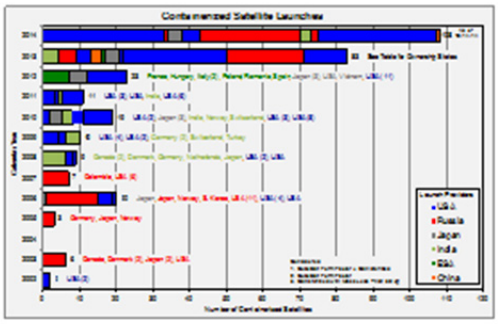
- AST RDAB POC: Stephen Earle, Ken Davidian
- UNIVERSITY: University of Florida
- PRINCIPAL INVESTIGATOR: Dr. Norman Fitz-Coy
- STUDENT(s): Tristan Newman (MS)

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.



STATUS

- Identified some potential impact factors (e.g., launch rate, satellites per launch, orbit, etc.)
- Drafting survey questions
- Identified POC for dissemination of survey

FUTURE WORK

- Survey the "containerized" satellite community to assess their impact on space debris in LEO
- Complete 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)

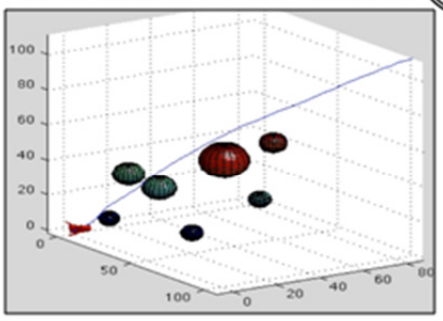
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- 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

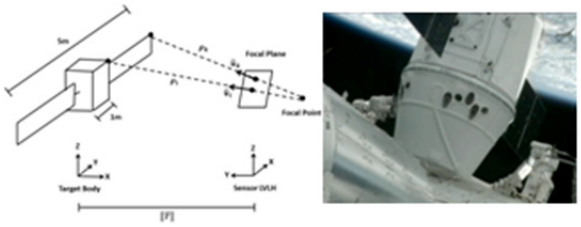
TASK 244. AUTONOMOUS RENDEZVOUS AND DOCKING (BASIS OF REQUIREMENTS AND METHODS)

PROJECT AT-A-GLANCE
- UNIVERSITY: University of Colorado Boulder
- PRINCIPAL INVESTIGATOR: Penina Axelrad
- RESEARCH PROFESSOR: Jay McMahon
- STUDENT(S): Heather LoCrasto, Steve Gehly, Caleb Lipscomb

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- Commercial missions require flexible and efficient methods for rendezvous and docking. This task develops a framework for autonomous rendezvous and docking in LEO that enables multiple vehicles to perform AR&D functions safely and without unnecessarily constraining vehicle design.

STATEMENT OF WORK
- Define framework for AR&D profile for cooperative & non-cooperative, unmanned & manned chaser & target objects.
- Identify technologies and risks – for each mission phase analyze the key safety and success risks and candidate technologies (sensing, guidance, control, capture, software).
- Construct compatible requirements – establish draft requirements for each phase that ensure safe operation and maximize likelihood of mission success. Assess whether technologies exist to support these requirements.

Flash LIDAR as key sensor for AR&D



STATUS
- Identified and analyzed key mission types, discrete phases, key sensor technologies, critical requirements, and profile. Developed list of quantitative requirements and sources.
- Developed model and simulation for flash LIDAR as a key enabling technology for phasing through mating. Looks to be capable of providing position and relative attitude to enhance flexibility.

FUTURE WORK
- Evaluate maturity/risk of technologies and applicability to various mission classes – non/cooperative, un/manned, etc.
- Improve capability of Flash LIDAR simulation to include unknown target configuration and sensor calibration issues.

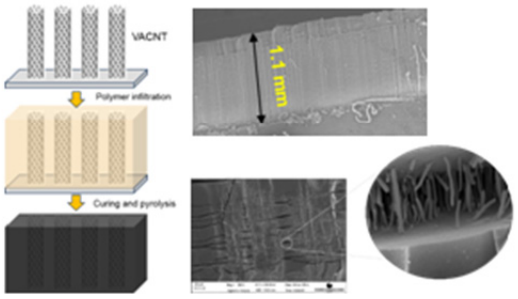
TASK 253. ULTRAHIGH TEMPERATURE COMPOSITES TPS

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

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- Ultra-high temperature, lightweight, and cost effective ceramic matrix composites (CMCs) and ceramic nanocomposites are enabling technologies for thermal protection systems of viable commercial spacecraft and launch vehicle system.

STATEMENT OF WORK
- Develop high temperature structural ceramic composites using polymer derived ceramics (PDC) matrix
- Develop high temperature ceramic nanocomposites using carbon nanotube preforms in forms of VACNT arrays and Buckypapers
- Ground testing of ceramic composites and nanocomposites using Oxyacetylene Exposure Test, Shock Tube Test and Hot Jet facilities.
- Develop ablation sensing techniques to monitor the structural health of ultrahigh temperature composites thermal protection system.

CARBON NANOTUBE PREFORM AND CERAMIC NANOCOMPOSITES



STATUS
- Oxyacetylene exposure testing of high temperature ceramic fiber reinforced PDC matrix composites
- Preform development with VACNT arrays and buckypapers and process development for PDC matrix nanocomposites

FUTURE WORK
- Process optimization of high temperature ceramic fiber reinforced PDC matrix composites
- Shock tube testing and hot jet testing of ceramic fiber reinforced composites
- Characterization and thermo-mechanical testing of VACNT array/buckypaper reinforced PDC matrix ceramic nanocomposites

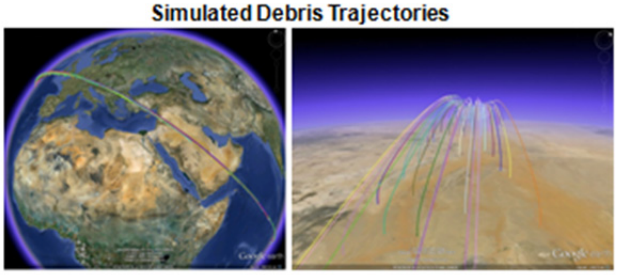
TASK 258. ANALYSIS ENVIRONMENT FOR SAFETY ASSESSMENT OF LAUNCH AND REENTRY VEHICLES

PROJECT AT-A-GLANCE
- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR: Juan J. Alonso
- STUDENT RESEARCHER: Francisco M. Capristan

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- The ability to identify acceptable bounds of range safety and vehicle parameters that limit the risk to the uninvolved public will provide valuable information to be used by vehicle designers and in the licensing of launch and reentry vehicles.

STATEMENT OF WORK
- Provide the FAA and the community with an independent multi-disciplinary analysis capability based on tools of the necessary fidelity.
- Develop and establish quantitative safety metrics appropriate for commercial space transportation (launch and re-entry).
- Validate the resulting tool with existing and proposed vehicles so that the resulting tool/environment can be confidently used.
- Increase the transparency of the safety assessment of future vehicles via a common analysis tool that is entirely open source and, thus, streamline the licensing process for a variety of vehicle types.

Simulated Debris Trajectories



STATUS
- Debris propagation (inert and explosive), gas dispersion, and blast overpressure have been implemented.
- The tool has a probabilistic framework to compute the probability of debris impact for a certain region (e.g. Kernel density estimation).
- Computation of casualties that account for sheltering categories and population centers already implemented.
- In house trajectory optimization code provides trajectories for safety assessment and modeling of 3DOF malfunction turns.
- Currently investigating methodologies that could help identify acceptable input ranges that limit risks to uninvolved public.

FUTURE WORK
- Identify the main drivers of risk to the uninvolved public.
- Evaluate the proposed methodology with a variety of vehicles to investigate its applicability.

TASK 293. NONLINEAR STRUCTURAL MODELS

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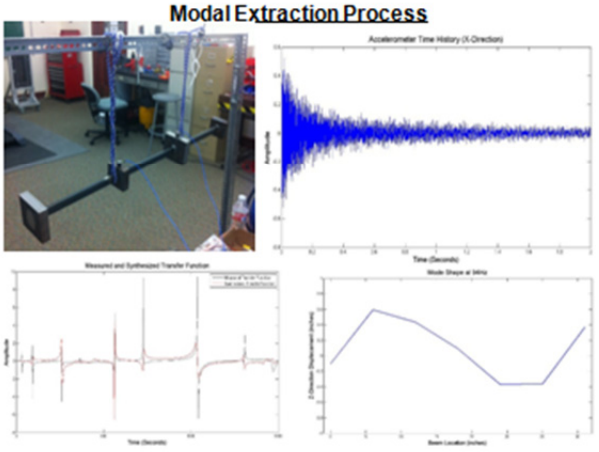
PROJECT AT-A-GLANCE
- **UNIVERSITY**: New Mexico Tech
- **PRINCIPAL INVESTIGATORS**: Dr. A. Keith Miller, Dr. Warren Ostergren
- **STUDENTS:** Mr. Lance Hernandez
- **FAA TECHNICAL MONITOR:** Mr. Nickolas Demidovich

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.

Modal Extraction Process



STATUS
- Modal extraction codes have been validated by physical testing of beam structure.

FUTURE WORK
- More physical testing will take place with increased damping on the beam structure to further validate our results.
- Next step is to begin testing second beam structure and begin the sub-structuring phase of the project.

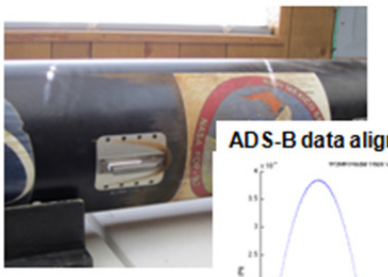
TASK 298. EVALUATION OF ADS-B PAYLOADS

PROJECT AT-A-GLANCE
- AST RDAB POC: Nick Demidovich, Ken Davidian
- UNIVERSITY: New Mexico State University, Las Cruces, NM
- PRINCIPAL INVESTIGATOR: Dr. Pat Hynes
- TECHNICAL INVESTIAGTOR: Dr. Laura Boucheron
- STUDENT RESEARCHER: Joshua Michalenko

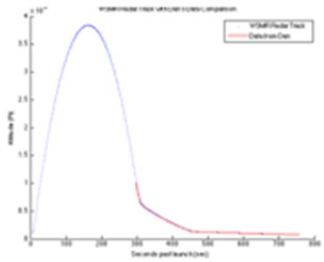
RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- Once procedures and separation standards are developed in conjunction with ADS-B for various classes of rockets, air traffic control would not have to sterilize air space and disrupt other NAS users for most rocket launches (large expendable rockets would be the exception). Most reusable rockets would be able to file a flight plan, making them much easier to launch, as aircraft are today, enabling routine commercial space operations in the NAS.

STATEMENT OF WORK
- FAA will request truth data (acceleration) from Up Aerospace payload on SL6 on board avionics (IMU)
  - Dr. Boucheron will do comparative analysis of data transmitted from SL 6, SL7m and SL8
- Develop a plan, for integration of ADS-B receivers and data flow for use by commercial spaceports based on lessons learned from this task.

Scorch pattern on ADS-B blade antenna



ADS-B data aligned with radar data



STATUS
- Code infrastructure developed to analyze ADS-B and compare to radar data.
- Lack of absolute timestamp in radar data requires a shifted window approach to minimize the error between the data.
- Data can be aligned and the error plots as well as the statistics of the errors can be analyzed.

FUTURE WORK
- Finish final report on SL-7 and SL-8 data.

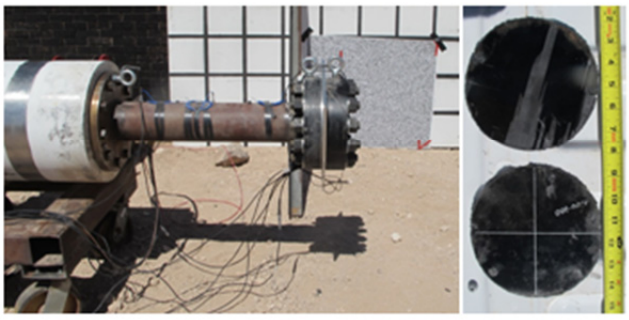
TASK 299. NITROUS OXIDE COMPOSITE CASE TESTING

PROJECT AT-A-GLANCE
- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR(S): Warren Ostergren, Robert Abernathy, Michael Hargather, Andrei Zagrai
- STUDENT(S): Jessica Tobin, Blaine Trujillo, Steven Bayley

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 composite panels to understand fragmentation hazards
- Develop methods to predict fragmentation conditions
- 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
- Establish standard test procedures for high-rate loading of composites

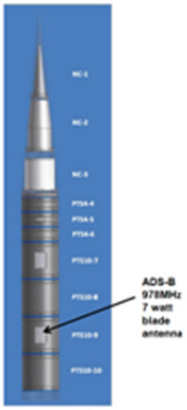
Test fixture and composite panel section that failed in shear and was delaminated by the shock wave loading



STATUS
- Tests have been performed with aluminum plates and with one composite plate material. Both tests showed shear failures of the plate material.
- The test of the composite material resulted in the delamination of the composite at approximately mid-thickness, even though failure was through shear at edge

FUTURE WORK
- Test and analysis of cylindrical sections
- Develop predictive models
- Validate with full composite vessel test

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 (in progress)
- Integrate advanced ADS-B unit on SpaceShip2 (in progress)
- Establish further research opportunities (in progress)

STATUS

- Demonstrate on board SL-8
- Results presented at ICNS 2014
- Delivery of prototype to Terminal Velocity Aerospace for re-entry vehicle integration
- Four of nine prototypes completed and deployed
- Whitepapers prepared for future opportunities

FUTURE WORK

- Future flight tests: SL-10, NSC HASS, VirginGalactic's SS2
- Firmware upgrade to meet DO-282B specifications
- Dual antenna design

TASK 307. FLIGHT TEST OF COMMUNICATIONS IN SPACE VIA COMMERCIAL SATELLITE NETWORKS ON SUBORBITAL SPACECRAFT: IMPLICATIONS FOR SPACE TRAFFIC MANAGEMENT

PROJECT AT-A-GLANCE

- INDUSTRY MEMBER: Satwest
- UNIVERSITY: New Mexico State University
- PRINCIPAL INVESTIGATOR(S):
- M. Brian Barnett PI
- Dr. Pat Hynes Co-PI

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Space Traffic Management (ADS-B)
- On-board Wi-Fi/Internet and voice communications for commercial crew
- Two-way payload communications for ground-based researchers
- Commercial communications services for spacecraft operators and government agencies

STATEMENT OF WORK

- Conduct flight tests to determine if commercial satellite networks in LEO and GEO can be used to provide data and voice communications to/from suborbital and orbital spacecraft in space and at rocket velocities.
- Could commercial satellites be used to transmit space-based ADS-B data

Satwest Satellite Communications and Aerospace

#TextToSpace Results

1ST Known COMMERCIAL TEXT TO SPACE, 67.4 miles

Nov. 12, 2013, 72.7 miles 383,556 ft.

STATUS

- Have successfully tested 2-way data capability via satellite on payload above 100km traveling at rocket velocities
- Payload has flown on NASA–Flight Opportunities Program (FOP) high altitude balloon and on UP Aerospace sounding rocket

FUTURE WORK

- Flight on Virgin Galactic's SS2 in 2015 through NASA's FOP to test:
  - Flight tracking
  - 2-way messaging
  - Internet/Wi-Fi
  - 2-way Voice communication

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

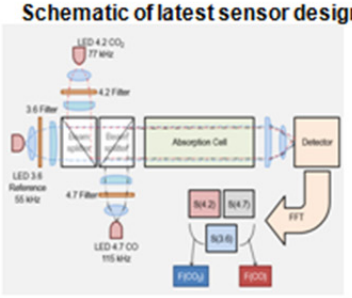
University of Central Florida

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 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 Roamap 2.0

Workshop Lead PIs and Locations

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

STATUS
- Theme 3 workshop held on 9/24-9/25
- Planning underway for future workshops

FUTURE WORK
- Upcoming workshops:
  - Theme 1a – 11/13-11/14
  - Theme 1b – 11/17
  - Theme 2 – 11/3-11/4
  - Theme 4 – 12/2-12/3
- Obtain summaries from lead PIs – 1/15/14
- Presentation summarizing workshop output – 3/15/14
- Delivery of Roadmap 2.0 – 5/15/14

TASK 193. ROLE OF COE CST IN EFP

PROJECT AT-A-GLANCE
- AST RDAB POC: Ken Davidian
- AST RESEARCH AREA: 4 Space Transportation Industry Viability
- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. George Born
- STUDENT RESEARCHER: Mr. Bradley Cheetham (PhD)
- PERIOD OF PERF: Jan 1, 2011 – May 31, 2015
- STATUS: Ongoing

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 Impact

STATUS
- 6th & 7th Emerging Space Industry Leaders (ESIL) Workshops Held in 2014
- 83 total participants and 3 publications presented

FUTURE WORK
- TBD – Awaiting funding clarification
- 2015: Ongoing support of relevant EFP activities
- 2015: Franchise event to broaden impact with reduced direct support

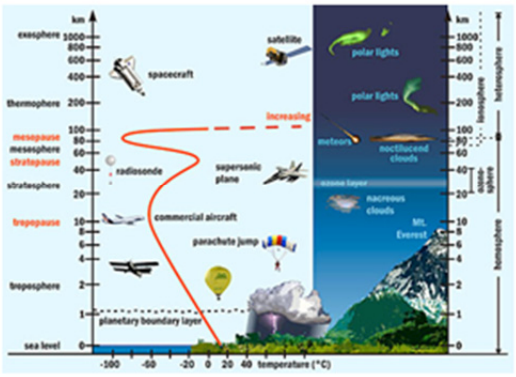
Bit.ly/ESIL_Home

TASK 304. DEFINITION AND DELIMITATION OF OUTER SPACE

PROJECT AT-A-GLANCE
- UNIVERSITY: McGill University
- PRINCIPAL INVESTIGATOR(S): Ram S. Jakhu
- STUDENT(S): Andrea DiPaolo

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- Whether an activity is treated as an "air" or "space" activity has significant implications for the manner in which the activity is regulated, including but not limited to licensing/permitting and liability concerns. The lack of a definition of what constitutes an air or space activity leads to regulatory uncertainty, and a mis-match of standards across international boundaries, hampering the development of the commercial space transportation industry.

STATEMENT OF WORK
- Identify activities and enterprises likely to fall within "near space" – or the area which is not clearly either air space or outer space.
- Promote an understanding of the urgency of the issue for these activities.
- Provide options and explanations for potential ways to define "air space" and "outer space," including the benefits and detriments of each potential solution.
- Keep track of international and national efforts to define air space and outer space.
- Make recommendations regarding the competency of international organizations to move forward on an answer to the question.



STATUS
- A paper has been prepared detailing the current and developing issues increasing the urgency of the question, and the need for a solution.
- This paper was presented at the UN COPUOS meeting in March 2014.

FUTURE WORK
- Create awareness of the issue
- Continue updating research as industry and regulations develop
- Provide research in other areas of the law (ITARs?)

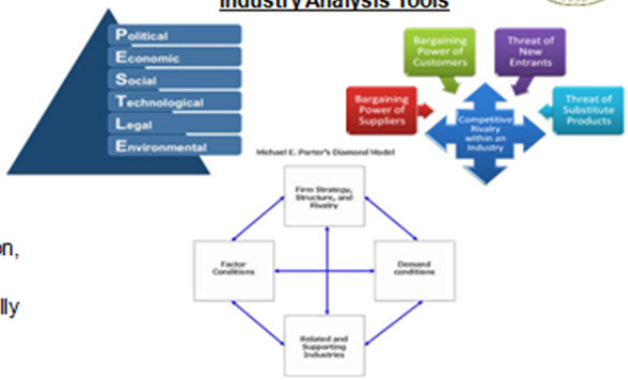
TASK 305. SUBORBITAL CSTI ANALYSIS

PROJECT AT-A-GLANCE
- **UNIVERSITY**: Florida Institute of Technology
- **PRINCIPAL INVESTIGATOR**: Dr. Scott Benjamin
- **STUDENTS:** Taylor Smith, Alex Rumsey
- **Collaborator:** Dr. Greg Autry

- **RELEVANCE TO COMMERCIAL SPACE INDUSTRY**
- With the commercial space industry on the cusp of adoption, information concerning suborbital industry characteristics, market sizing, segmentation, demand factors and general environmental conditions are needed in order to strategically plan for the future.

STATEMENT OF WORK
- Gather existing industry research concerning market data
- Apply Porter's Diamond Model to the commercial space transportation industry.
- Using the PESTLE analysis, identify key general environmental conditions that will affect the adoption of the industry.
- Apply Porter's Five Forces Model to the competitive landscape within the industry.
- Synthesize and analyze data to assemble a comprehensive industry analysis for the commercial space transportation industry.

Industry Analysis Tools



STATUS
- Scope of work has been defined and team has been assembled.

FUTURE WORK
- Gathering data and application of the various models.
- Project market demand in each segment.
- Develop comprehensive report

Dr. Tristan Fiedler (FIT) making a presentation at the COE CST Fourth Annual Technical Meeting held in Washington, DC.

COE CST STUDENTS, PARTNERS AND PUBLICATIONS

COE CST YEAR 4 STUDENTS

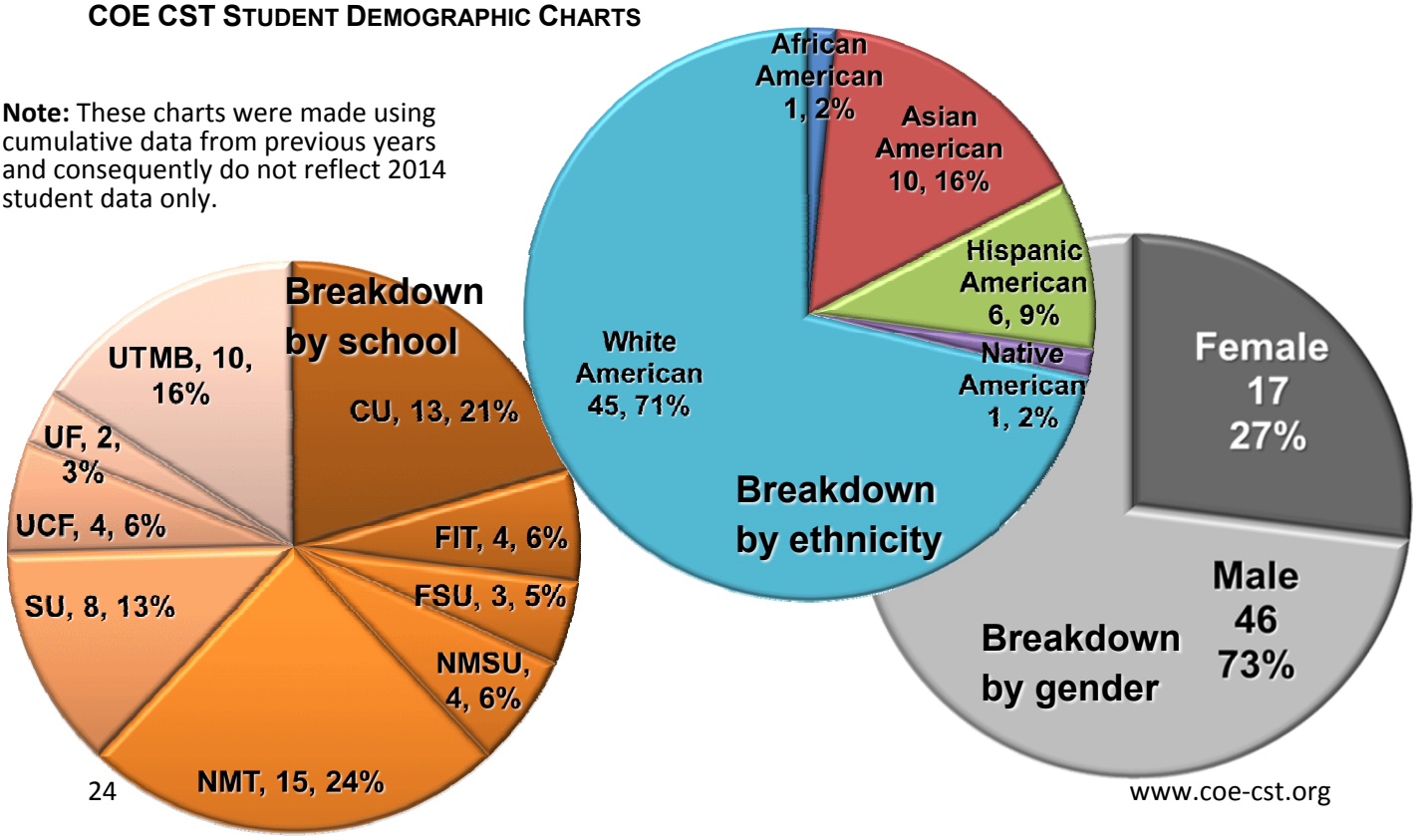
The following is a list and demographic information of the 47 COE CST students working on research tasks during the fourth year of operation.

- Bayley, Steven (NMT)
- Blacher, Eric (UTMB)
- Blood, Dan (UF)
- Bowers, Marianne (NMSU)
- Capristan, Francisco (SU)
- Carpenter, Cassandra (UCF)
- Chamberlain, Christina (CU)
- Cheetham, Bradley (CU)
- Chough, Natcha (UTMB)
- Collins, Justin (FSU)
- Colvin, Thomas (SU)
- Day, Richard (ERAU)
- DiPaolo, Andrea (MU)
- Francis, Griffin (FSU)
- Gehly, Steven (CU)
- Hernandez, Lance (NMT)
- Huang, Roger (CU)
- Johansen, Benjamin (UTMB)
- Li, Alan (SU)
- Lipscomb, Caleb (CU)
- LoCrasto, Heather (CU)
- Loparo, Zachary (UCF)
- Masker, William (NMT)
- Meisner, Daniel (NMT)
- Mendoza, Joshua (NMT)
- Mills, David (UF)
- Mulcahy, Robert (UTMB)
- Negrea, Catalin (CU)
- Neugebauer, Brandon (ERAU)
- Newman, Tristan (UF)
- Ow, Andrew (SU)
- Park, In-Kwan (CU)
- Pattarini, James (UTMB)
- Reyes, David (UTMB)
- Rumsey, Alex (FIT)
- Runnels, Joel (NMT)
- Sharma, Aneesh (FSU)
- Smith, Taylor (FIT)
- Stanley, June (NMT)
- Stotts, Jarrett (NMT)
- Thurmond, Kyle (UCF)
- Tobin, Jessica (NMT)
- Tounour, Dominic (ERAU)
- Trujillo, Blaine (NMT)
- Yang, Hongjiang (UCF)
- Yosvany, Alonso (ERAU)
- Zimmerman, Jonah (SU)

Note: Not all students' names are given on the quad charts in the preceding section so this list has some names not found in the charts. **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 STUDENT DEMOGRAPHIC CHARTS

Note: These charts were made using cumulative data from previous years and consequently do not reflect 2014 student data only.



COE CST Year 4 Research Partners

The following is a list of the 27 COE CST research organization partners that have contributed to the year four 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
- May 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
- Nation 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 4 Industry Partners

The following is a list of the 55 COE CST industry partners that have contributed to the year four 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
- CSSI Inc.
- DigitalGlobe
- Digital Solutions
- Dynetics, Inc.
- Echostar
- 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
- SatWest
- Scitor Corporation
- Sierra Nevada Corp
- 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 Fourth Annual Technical Meeting in Washington, DC.

UTMB Students, Dr. Robert Mulcahy, Dr. Natacha Chough, and Dr. James Pattarini, receiving awards at the 2014 Aerospace Medical Association Conference.

COE CST YEAR 4 PUBLICATIONS

The following is a list of the 22 publications published or presented during COE CST year four.

TASK 184-CU HUMAN RATING OF COMMERCIAL SPACECRAFT

- Klaus, D.M., Ocampo, R.P. and Fanchiang, C. (2014) Spacecraft Human-Rating: Historical Overview and Implementation Considerations. IEEE Aerospace Proceedings (978-1-4799-1622-1/14, no. 2272).
- Neis, S.M. and Klaus, D.M. (2014) Considerations toward Defining Medical 'Levels of Care' for Commercial Spaceflight. New Space [accepted].

TASK 185-SU UNIFIED 4-DIMENSIONAL TRAJECTORY ANALYSIS

- Capristan, Francisco M., and Juan J. Alonso. "Range Safety Assessment Tool (RSAT): An analysis environment for safety assessment of launch and reentry vehicles," 52nd Aerospace Sciences Meeting, 2014, 10.2514/6.2014-0304.

TASK 187-CU SPACE SITUATIONAL AWARENESS

- Rosengren, Aaron J., Daniel J. Scheeres, and Jay W. McMahon. "The classical Laplace plane as a stable disposal orbit for geostationary satellites." Advances in Space Research 53.8 (2014): 1219-1228.

TASK 193-CU ROLE OF COE CST IN EFP

- Bandla, S., Cheetham, B., Hakeem, R., Zea, L. "Applying Insights Of Game Theory To The Microgravity Utilization Market", IAC-14,E6,3,3, x24346, October, 2014.

TASK 193-SU ROLE OF COE CST IN EFP

- Ow, A., Zimmerman, J., Hubbard, S. "A qualitative analysis of opportunities and processes for secondary and hosted payloads." IAC-14-B4.5.12, October 2014.

TASK 220-NMSU SPACE OPERATIONS FRAMEWORK

- Bachner, H., Hynes, P., Schneider, I., Hayhoe, J., Lee, N., and Bowers, M. "The development of a framework to capture a body of knowledge (BOK) for commercial spaceport practices." IAC-14.D6.1.7, October 2014.

TASK 228-NMT MAGNETO-ELASTIC SENSING FOR STRUCTURAL HEALTH MONITORING

- Masker, W., Runnels, J., and Zagrai, A., (2014) "Small-factor Electromechanical Impedance Measurement Board for Space Applications", presentation at SPIE's 21th Annual International

Symposium on Smart Structures and Materials + NDE for Health Monitoring and Diagnostics, 9 - 13 March 2014, CA.

- Trujillo, B. and Zagrai, A., (2014) "Monitoring of Acoustic Emission Activity using Thin Wafer Piezoelectric Sensors", paper at SPIE's 21th Annual International Symposium on Smart Structures and Materials + NDE for Health Monitoring and Diagnostics, 9 -13 March 2014, CA.
- Trujillo, Blaine, et al. "Monitoring of acoustic emission activity using thin wafer piezoelectric sensors." SPIE Smart Structures and Materials+ Nondestructive Evaluation and Health Monitoring. International Society for Optics and Photonics, 2014.
- Zagrai, A., (2014) "High-frequency Sensor Technology", presentation at AFOSR Workshop on Microsecond State Monitoring of Multicomponent Structures, 8 April 2014, Niceville, Florida 32578-1295
- Zagrai, A, Cooper, B., Schlavin, J., Clemens, R., White, C., Kessler, S., (2014) "Assessing structural condition during suborbital space flight," Technical presentation at ASME Conference on Smart Materials, Adaptive Structures and Intelligent Systems, September 9, 2014, Newport, RI, presentation: SMASIS2014-7726.

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

- Mills, D., D. Alexander, G. Subhash, and M. Sheplak, "Development of a sapphire optical pressure sensor for high-temperature applications," Proc. SPIE 9113, Sensors for Extreme Harsh Environments, Baltimore, MD, 6/5/2014.

TASK 244-CU AUTONOMOUS RENDEZVOUS AND DOCKING

- McMahon, J., S. Gehly, and P. Axelrad, "Enhancing Relative Attitude and Trajectory Estimation for Autonomous Rendezvous Using Flash LIDAR," AIAA/AAS Astrodynamics Specialist Conference, San Diego, CA, August 4-8, 2014.

TASK 244-FSU AUTONOMOUS RENDEZVOUS AND DOCKING

- Francis, G., Collins, E., Chuy, O., and Sharma, A. "Rapid Trajectory Generation for Autonomous Spacecraft in Stochastic Environments" (in preparation), for submission to Journal of Guidance, Control, and Dynamics.
- Sharma, A., Ordonez, C., and Collins, E. "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 256-UTMB ADDITIONAL NASTAR CENTRIFUGE TESTING

- Blue, Rebecca S., et al. "Tolerance of centrifuge-simulated suborbital spaceflight by medical condition." Aviation, space, and environmental medicine 85.7(2014): 721-729.
- Mulcahy RA, Blue RS, Vardiman JL, Mathers CH, Castleberry TL, Vanderploeg JM. Subject Anxiety and Psychological Considerations for Centrifuge-Simulated Suborbital Spaceflight. Aviat Space Environ Med 2014; 85(8): 847-851.
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TASK 307-SATWEST/NMSU TEST OF COTS SATELLITE COMMUNICATIONS SYSTEMS

- Barnett, B. "Flight Test of Communications in Space via Commercial Communications Satellite Networks on-board Suborbital RLV and High Altitude Balloon: Implications for Space Traffic Management", Embry Riddle Space Traffic Management Conference, Florida, Nov. 2014.
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