Federal Aviation Administration
Center of Excellence for Commercial Space Transportation
Year 3 Annual Report Executive Summary

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Pictured below: Participants of the COE CST Emerging Space Industry Leaders Workshop #3, held in Washington, D.C. on October 29 - 31, 2013. This picture taken at Sierra Nevada Corporation Space Systems.
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 3 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, 2013
INTRODUCTION

This executive summary accompanies a more detailed annual report of the FAA Center of Excellence for Commercial Space Transportation (COE CST).

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 CST became operational on August 18, 2010 with nine member and affiliate universities.

Brief introductions to each of the nine Member University and six Affiliate Members are provided with general descriptions as well as specific strengths the universities bring to the COE CST.

The scope of COE CST research areas are given and each of the research tasks initiated, conducted and concluded by the COE CST during the third year of operation are listed and summary information of each is provided.

The Executive Summary concludes with the COE CST students and partners, both from industry and other research organizations highlighted.

OVERVIEWS

FAA Office of Commercial Space Transportation

As of December 2012, 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 approximately $15 million. (By contrast, the FAA has approximately 48,000 FTEs and a total budget of about $15 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, or 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 1995.
• 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 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, one new COE has been created and another two COEs have been announced. 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, announced in 2012.

FAA Center of Excellence for Commercial Space Transportation

**COE CST YEAR 3 HIGHLIGHTS**

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

- Third Annual Administrative Meeting held near the FAA Technical Center in Somers Point, NJ on June 11-13, 2013.
- Induction of the second set of Affiliate Members, including three universities (Embry Riddle Aeronautical University, University of Nebraska – Lincoln and Baylor College of Medicine) and two industry members (Satwest and NASTAR Center).

In the third year of COE CST operation, there were no new tasks started. 25 ongoing from the previous year and 3 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 third year of operation, the COE CST benefited from the services of 55 students, 20 research partners and 44 industry partners. The combined effort resulted in 28 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.

**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 60 other government, industry and academic organizations as research partners.

As a single entity, the nine 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.

In 2013, five organizations joined the COE CST as new Affiliate Members. The remainder of this section provides more detail on each of the nine member universities and six affiliate members of the COE CST.

**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.
EXECUTIVE SUMMARY

Florida State University (FSU)

FSU brings a range expertise and unique infrastructure in many areas relevant to the COE CST, including but not limited to: cryogenics, thermal management, vehicle aerodynamics and controls, sensors, actuators and system health monitoring and high performance simulations.

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 Werner Von Braun to the current era of commercial sub-orbital space transportation with Virgin Galactic. New Mexico Space Grant Consortium, the 21st Century Space related aerospace research focuses on annual access to space for student and faculty experiments, unmanned aerial vehicles, scientific ballooning and nano-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, 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

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 Red Bull Stratos project, resulting in many publications and presentations.
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.

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 foundations 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.

Satellite Communications Systems (SatWest)

SatWest is developing low-cost, internet-based data and voice communications services via commercial satellites for payloads and crew located in LEO and suborbital platforms and for ground-based crew interacting with research payloads and space-based crew.

University of Nebraska

The University of Nebraska, a collaboration of 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.

Below: COE CST Member and Affiliate University Geographic Distribution
COE CST RESEARCH TASKS

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

- Space Traffic Management & Operations
- Space Transportation Operations, Technologies & Payloads
- Human Spaceflight
- Space Transportation Industry Viability

Each of these major research areas (which are analogous to programs) are divided into sub-areas (analogous to projects) and these, in turn, are further subdivided into lower level divisions (e.g., tasks).

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

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

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<thead>
<tr>
<th>All FAA AST R&amp;D Tasks (as of 31 Dec 2013)</th>
</tr>
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<tbody>
<tr>
<td>Task # Name / PI Name (Univ) - AST TM</td>
</tr>
<tr>
<td>------------------------------------------</td>
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<tr>
<td>115 United 4 Dimensional Trajectory Analysis Alonso (SU) - Wilde</td>
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<td>168 Space Environment NMMOD Modelling and Prediction Close (SU), Fuller-Rowell (CU)-Shelton-Mur</td>
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<td>187 Space Situational Awareness Scheeres (CU) - Earle</td>
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<td>247 Air and Space Traffic Considerations for CST Villare (ITI) - Murray</td>
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<td>184 Human Rating of Commercial Spacecraft Klaus (CU) - Lampazzi</td>
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<td>255 Wearable Biomedical Monitoring Equipment Jeffries (UTMB) - Lampazzi</td>
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<tr>
<td>256 Additional NASA TRAC Testing Vanderploeg (UTMB) - Lampazzi</td>
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<tr>
<td>294 Minor Injury Severity Scale Jennings (UTMB) - Gerlach</td>
</tr>
<tr>
<td>295 EMF Effects on Implantable Devices Vanderploeg (UTMB) - Lampazzi</td>
</tr>
</tbody>
</table>

Note: Among the 28 COE CST tasks active in Year 3, 0 are new (NEW), 25 are in process (IP) and 3 ended (END).

Abbreviations: CU-University of Colorado Boulder, 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 3 ANNUAL REPORT

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

MAJOR MILESTONES-PAST
- Development of 4D compact envelope techniques
- Modifications to NASA FACET (Future Air-traffic Concepts Evaluation Tool) for use with 4D envelopes
- Improvements to aircraft re-route capabilities in FACET
- Completed assessment of future launch/recovers (including frequency, location, and vehicle type) scenarios with FAA SVO
- Completion of rapid space vehicle mission generation and visualization for impact analysis
- Generalization to arbitrary launch/re-entry vehicles for 4D envelope concept
- Kernel Density Estimation methods for probabilistic analysis

SCHEDULE
- Finalize KDE probabilistic analysis capability to create 4D envelopes with user-specified safety level — Feb 2014
- Development of Integrated Airspace Traffic Management alternatives — May 2014
- Improved re-routing algorithms in FACET — Jul 2014
- Formal validation and verification of analysis environment, including comparisons to AirToP software (FAA) — Oct 14
- Quantitative assessment of IASTM alternatives — Feb 15
- Integration of techniques and demonstrations of dynamic airspace management, including interactions with FAA SVO (Space Vehicle Operations) group — Jul 15

MAJOR MILESTONES-FUTURE
- Finalize direct connection with baseline trajectory and debris computation capabilities in Task 258
- Development of plausible architectures for integrated airspace traffic management
- Improved aircraft re-routing capabilities for dynamic airspaces in FACET
- Validation of environment capabilities with FAA’s AirToP software
- Assessment of integrated air-space traffic management architectures on specific operations
- Development of dynamic techniques for traffic management

TASK 186. MITIGATING THREATS THROUGH SPACE ENVIRONMENT MODELING & PREDICTION

PROJECT AT A GLANCE
- ASTRDAB POC: Karen Shelton-Mur
- AST RESEARCH AREA: 1.1 STM & Ops – Orbital STM
- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. Tim Fuller-Rowell
- STUDENT RESEARCHER: None
- PERIOD OF PERF: Jun 1, 2012 – May 31, 2013
- STATUS: Ongoing

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 wind/velocity, turbulence, etc.
  2. Plasma density, electron content, irregularities, radiation conditions for impact communications and navigation

STATEMENT OF WORK
- Predict the terrestrial weather and atmospheric conditions, and space weather (e.g., solar flares, geomagnetic storms, solar proton events) for safe orbit, sub-orbit, re-entry, descent, and landing operations
- Provide the information to determine impact on navigation, communications, and positioning for space vehicles
- Simulate the internal atmospheric sources of variability; WAM-GIP is designed to forecast the environmental conditions from ground to 600km (previous model ~60km)

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 plasmas model

FUTURE WORK (combined COE-CST and NOAA activities)
- Continue to validate WAM and GIP and explore impact on density, drag, and ionospheric structure
- Complete full two-way coupling between WAM and GIP module
- Extend WAM data assimilation into the lower thermosphere
- Test higher resolution WAM T382 (25 km resolution) to resolve full wave field penetrating to the thermosphere
- Explore assimilation of ionospheric data for density prediction
- Develop whole atmosphere/ionosphere data assimilation
TASK 186. SPACE ENVIRONMENT METEOROID AND ORBITAL DEBRIS MODELING & PREDICTION

PROJECT AT A GLANCE
- AST RIDAB POC: Karen Shelton-Mur
- AST RESEARCH AREA: 1.1 STM & Ops – Orbital STM
- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR: Sigrid Close
- STUDENT RESEARCHER: Alan Lu (MS)
- STATUS: Ongoing

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.

FUTURE WORK
- Meteoroids
  - Impact model
  - Initial threat assessment model
- Debris
  - Impact models
  - Comparison of radar data with MASTERS/ORDEM
  - Initial threat assessment model

TASK 187. SPACE SITUATIONAL AWARENESS IMPROVEMENTS

PROJECT AT A GLANCE
- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. Dan Scheeres
- STUDENT RESEARCHER: Dr. Kohei Fujimoto (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 purposes of quantifying and qualifying space-based activities.
- Maximize the information extracted from usual sources of SSA data (minimize uncertainty)
- Identify how data should be collected to maximize information content (maximize efficiency)
- Recover and predict the space domain with more accuracy
- Timely estimation of the space-based environment to create actionable information.

STATUS
- Graduated one PhD student: Kohei Fujimoto, May 2013
- Combined student team focused on relevant SSA research topics of direct interest to the COE
- Presented over 22 distinct papers at 12 conferences
- 5 papers published, 4 more in preparation

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
ASTRDAB 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 all 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
- Ensure 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)

<table>
<thead>
<tr>
<th>Reference</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0</td>
<td>AIRFIELD &amp; LAUNCH OPERATIONS</td>
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<tr>
<td>2.0</td>
<td>SITE SECURITY</td>
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<tr>
<td>3.0</td>
<td>EMERGENCY RESPONSE</td>
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<tr>
<td>4.0</td>
<td>VISITOR MANAGEMENT</td>
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<td>GROUND AND FLIGHT SAFETY</td>
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<td>MISSION READINESS</td>
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<td>ITAR REQUIREMENTS</td>
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<td>9.0</td>
<td>INTERNATIONAL COORDINATION AMONG SPACEPORTS</td>
</tr>
<tr>
<td>10.0</td>
<td>SELF-INSPETION</td>
</tr>
</tbody>
</table>

STATUS
- Development of a draft Framework was completed and reviewed by Spaceport Directors in 2012
- We have identified and aggregated over 200 standards and procedures that are relevant to commercial spaceports from 12 different government/nongovernment references sources.
- Presented work to CONSTAC Operations Working Group and received support from KSC and Boeing.

FUTURE WORK
- Develop GAP Analysis
- List project limitations
- Prepare documentation discussing the development of the project and the steps taken to create the Framework for Commercial Spaceport Operations

TASK 247. AIR & SPACE TRAFFIC CONSIDERATIONS FOR CST

PROJECT AT A GLANCE
ASTRDAB POC: Pam Melroe, René Rey, Ken Davidian
UNIVERSITY: Florida Institute of Technology
PRINCIPAL INVESTIGATOR: Dr. Nathaniel Vilaire, Professor Emeritus
STUDENT RESEARCHER: Sebastian Rainer
STUDENT RESEARCHER: Dennis W. Willet
INDUSTRY PARTNER: Space Florida

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
Current NAS closures due to space vehicle launch and reentry is very expensive for commercial atmospheric traffic. While costs were absorbed in the past by commercial airlines, the advent of commercial space travel has raised issues with prioritizing traffic in the NAS.

STATEMENT OF WORK
- Develop proof of concept software that suggests alternate routes around closed airspace based on cost.
- Provide information for alternate flight paths which may be selected based on meteorological, time and monetary data.

STATUS
- Program calculates Flight Diversion on a specific Oceanic Route
- Provides Flight Location Entering Diversion Airspace
- Provides Time of Diversion
- Provides Distance to Normal Airspace
- Provides Cost of sending the aircraft to the nearest comer of the closed airspace
- Datasaved to a text file

FUTURE WORK
- Divert all aircraft around the entire restricted launch area
- Provide the delta costs for the diversion vs. original flight path
- Calculate Diversion for Any Flight in the Data Base
- Place all Data in an Excel Data Base File
- Collaborate with outside expertise in Air Traffic Management for diversion models
- Simplify installation, setup, and operation of the program
- Update to a code compiler that is backwards compatible
EXECUTIVE SUMMARY

TASK 257. MASTERS LEVEL COMMERCIAL SPACEFLIGHT OPERATIONS CURRICULUM

PROJECT AT A GLANCE
- AST RDAB POC: Ken Davidson
- AST RESEARCH AREA: 2.1 Ground Systems & Ops Safety
- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. George Born
- STUDENT RESEARCHER: Mr. Bradley Chestnurn (PhD), Ms. Jules Feldhecker (PhD), Jon Herman (PhD)
- PERIOD OF FERF: Jan 1, 2011 – May 31, 2014
- 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).

STATUS
- Lecture offered for three semesters.
- Lab offered first time in spring 2013.
- Total of 81 students have participated in curriculum effort.

FUTURE WORK
- Fall 2013: Third lecture offering, lab refinement.
- Spring 2014: Second lab offering.
- Summer 2014: Begin formalizing certificate.

ccar.colorado.edu/CSO

TASK 181. PHYSIOLOGICAL DATABASE DEFINITION & DESIGN

PROJECT AT A GLANCE
- AST TECH MONITOR: Henry Lampazzi
- UNIVERSITY: University of Texas Medical Branch
- PRINCIPAL INVESTIGATOR: Dr. Jim Vanderploeg, MD
- STUDENT RESEARCHERS: Dr. Jennifer Law, MD, Dr. Charles Mathers, MD, Dr. David Reyes
- STATUS: Ongoing.

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- The emerging commercial space transportation industry will soon involve hundreds to thousands of individuals covering a wide range of ages and medical conditions about which very limited information has been collected. This task will improve pre-flight medical screening criteria on which operators can make informed decision about the suitability of prospective customers by including a wide range of individuals with a variety of existing medical problems. Collection and management of this information will better inform the need for and development of best practices and regulations for commercial human spaceflight.

STATEMENT OF WORK
- Identify appropriate data elements about the health and physiologic status of commercial space flight participants. Recommend a scalable system design.
- Identify the infrastructure and processes for capturing data from pre-flight, in-flight, and post-flight assessments and from research studies performed during spaceflight.

UNDERSTANDING HUMAN COMPLEXITY

STATUS
- Conducted workshop in March 2012.
- Identified desired data elements for pre-flight, in-flight, and post-flight data.
- Identified desired elements of vehicle parameters.
- Secured NASA interest in hosting database on LSAH system.

FUTURE WORK
- Obtain commitment from commercial companies to participate.
- Draft SOP for control, security, confidentiality, and access.
**TASK 184. HUMAN-RATING OF COMMERCIAL SPACECRAFT**

- **PROJECT AT A GLANCE**
  - ASTRAL POC: Henry Lampazzi, Jeff Sugar, Randy Repechek, Rene Rey, Ken Davidson
  - ASTRAL RESEARCH AREA: 3.3 Human Spaceflight - Human Rating
  - UNIVERSITY: University of Colorado Boulder
  - PRINCIPAL INVESTIGATOR: Dr. David Klaus
  - STUDENT RESEARCHERS: Ms. Christine Fanchang (PhD) and Mr. Robert Ocampo (PhD)
  - PERIOD OF PERFORMANCE: June 1, 2013 – May 31, 2014
  - STATUS: Ongoing in year 3 of 5 planned

- **RELEVANCE TO COMMERCIAL SPACE INDUSTRY**
  - The commercial space industry has no clear definition of the human-rating criteria for an integrated commercial spacecraft and launch vehicle system. The outcome from this task will support the FAA’s safety regulatory responsibilities.

- **STATEMENT OF WORK**
  - Solicit Human-Rating Working Group feedback against a list of pertinent terminology & definitions
  - Assess existing FAA aviation design, production, and operation certification processes to facilitate open discussion aimed at identifying best practices to anticipate and guide future regulatory needs
  - Contribute to definition of the FAA’s “Established Practices for Human Spaceflight Occupant Safety” through systematic discussion amongst industry and public participants.
  - Focus on “safe return to Earth”

- **STATUS**
  - 7 publications and presentations to date

- **FUTURE WORK**
  - Develop report on “Human-Rating Guidelines and Considerations for Commercial Space Transportation” addressing requirements, validation & verification, and regulatory practices

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**TASK 255. EVALUATION OF WEARABLE BIOMEDICAL MONITORING EQUIPMENT**

- **Project At A Glance**
  - UNIVERSITY: The University of Texas Medical Branch
  - PRINCIPAL INVESTIGATOR: Tarah Castleberry, DO, MPH
  - STUDENT RESEARCHERS: Alejandro Garbino, MD, PhD

- **Relevance to Commercial Spaceflight Industry**
  - Commercial spaceflight participants (CSFPs) represent a population with potentially significant medical problems that may warrant in-flight medical monitoring.
  - Commercial CSFPs may be hesitant to wear highly invasive, obstructive monitoring equipment.

- **Statement of Work**
  - Identify the utility of a commercial, non-invasive, biomedical monitoring device to support operational monitoring needs in a centrifuge-simulated suborbital spaceflight experience.
  - Volunteers wearing the monitoring device experienced G-forces simulating a commercial spaceflight.

- **Status**
  - Complete evaluation using the NASTAR centrifuge

- **Future Work**
  - Perform data analysis
  - Publish results
EXECUTIVE SUMMARY

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

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
- STUDENT RESEARCHERS: James Pallarini, MD, David Reyes, MD, Robert Mulcahy, MD

Relevance to Commercial Spaceflight Industry
- There is little to no data on how individuals with chronic disease will perform in a high-performance environment such as commercial spaceflight. This study will provide data on how individuals with chronic disease respond 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

Past Medical History of Participants

Status
- Complete training and evaluation using the NASTAR centrifuge

Future Work
- Perform data analysis
- Publish results
- Develop optimal acceleration training protocols for passengers

TASK 294. DEVELOPMENT OF MINOR INJURY SEVERITY SCALE FOR ORBITAL HUMAN SPACE FLIGHT

Project At-A-Glance
- UNIVERSITY: The University of Texas Medical Branch
- PRINCIPAL INVESTIGATOR: Richard T. Jennings, MD, MS
- Tarah Castleberry, DO, MPH
- Co-I: Eric Kerstman, MD, MPH
- Co-I: Jonathan Clark, MD, MPH
- STUDENT RESEARCHERS: James Cushman, MD, MPH

Relevance to Commercial Spaceflight Industry
- Minor injuries of small consequence on the ground may have a large operational impact if they were to occur in space.
- A Minor Injury Severity Scale (MISsS) for human space flight (HSF) was developed for identification of unacceptable injuries that could disrupt HSF operations.

Statement of Work
- Investigate and develop a Minor Injury Severity Scale (MISsS) for Orbital Human Space Flight (HSF)

Status
- Completed literature review and MISsS Development

Future Work
- Manuscript editing
- Publish results
**TASK 295. EFFECTS OF EMI AND IONIZING RADIATION ON IMPLANTABLE MEDICAL DEVICES**

**Project At-A-Glance**
- UNIVERSITY: The University of Texas Medical Branch
- PRINCIPAL INVESTIGATOR: James Vanderploeg, MD, MPH
- STUDENT RESEARCHERS: David Reyes, MD, MPH

**Relevance to Commercial Spaceflight Industry**
- Commercial spaceflight participants (SFPs) represent a population with potentially significant medical problems, including use of implantable medical devices (IMDs).

**Statement of Work**
- Investigate known effects of radiation environments on the performance of implanted medical devices (IMDs).
- Extrapolate impacts on function of IMDs in commercial spaceflight participants flying at suborbital and LEO altitudes.

**Status**
- Completed literature review and preliminary manuscript

**Future Work**
- Review by radiation specialists
- Publish results

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**TASK 228: MAGNETO-ELASTIC SENSING FOR STRUCTURAL HEALTH MONITORING**

**PROJECT AT-A-GLANCE**
- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR: Dr. Andrei Zagral 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 relaunch.

**STATEMENT OF WORK**
- Demonstrate utility of various SHM strategies during high altitude stratospheric balloon 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 guidelines for sensor installation and measurement procedures in acoustic emission SHM of space vehicles.

**STATUS**
- 038B NASA FOP Flight completed
- Acoustic emission measurements of fatigue damage is conducted
- Utility of PWAS for AE testing is investigated

**FUTURE WORK**
- Sound speed data analysis
- 038S Suborbital SL-8 flight
- PWAS design for AE testing
- Thermal damage assessment
EXECUTIVE SUMMARY

TASK 241. HIGH-TEMPERATURE PRESSURE SENSORS FOR HYPersonic VEHICLES

• PROJECT AT-A-GLANCE
  • ASTRDAB POC: Pam Melroy, René Rey, Ken Davidian
  • UNIVERSITY: University of Florida
  • PRINCIPAL INVESTIGATOR: Dr. Mark Sheplak
  • STUDENT RESEARCHERS: Mr. David Mills (PhD), Mr. Daniel Blood (PhD)

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.

STATUS
• Selected a sapphire fiber-optic lever sensor design
• Developed laser micromachining and spark plasma sintering (SPS) bonding processes for the fabrication of 3D sapphire sensing structures
• Fabricated and packaged prototype sensor capable of operation to 900°C

FUTURE WORK
• Complete characterization of SPS bonding process
• Room-temperature and high-temperature characterization of the packaged sensor
• Demonstration of 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
  • ASTRDAB POC: Nick Demidovich
  • ASTR RESEARCH AREA: 2.3 Vehicle Safety & Systems
  • UNIVERSITY: Florida State University
  • PRINCIPAL INVESTIGATOR: Dr. William G. Oates
  • STUDENT RESEARCHER: Mr. Justin Collins (PhD)
  • PERIOD OF PERF: May 1, 2012 – May 31, 2013
  • STATUS: Re-started pending funding

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
• Orbital commercial spacecraft require high-temperature sensors (~1000°C/1800°F) or various phases of flight (e.g., hypersonic flight, high-speed entry) or to monitor system and subsystem performance (e.g., for gas turbines or scramjets). Current commercial sensors are only capable of up to ~800°C.

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 micro-machining
• Combined studies of fracture mechanics theory and experimental testing focused on sensor reliability

Material Characterization
• Laser damage
• TEM data illustrates formation of dislocations
• Indentation of laser machined surface enhances toughness
• Comparison of anisotropic end isotropic fracture

Single Crystal Fracture & Dislocation Mechanics
• Transmission electron microscopy has been compared to a nonlinear fracture model containing dislocation evolution
• Crack tip driving forces are shown to explicitly depend on dislocation formation along specific crystallographic planes
• The direction of slip planes are found to influence the fracture behavior

FUTURE WORK
• 3D finite element correlation of slip planes with experimental results
• TEM characterization after high temperature annealing of laser machined specimen
• Pressure transducer testing
**TASK 244. AUTONOMOUS RENDEZVOUS AND DOCKING**

**PROJECT AT-A-GLANCE**
- AST RDAB POC: Stephen Earle, Ken Davidian
- UNIVERSITY: University of Florida
- PRINCIPAL INVESTIGATOR: Dr. Norman Fitz-Coy
- STUDENT RESEARCHER: Ms. Kathryn Cason (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.

**STATUS**
- Literature review and assessment of SOA completed
- Removal of non-cooperative debris most challenging
- Strategies for safe removal are being investigated
- 1 PhD generated (Takashi Hirama)
- 2 papers (IEEE) published

**FUTURE WORK**
- Continue evaluation of removal strategies
- Better understand the impact of small satellites (e.g., CubeSats) on the space debris population
- Continue to contribute to space debris mitigation strategies

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**TASK 244. AUTONOMOUS RENDEZVOUS AND DOCKING**

**PROJECT AT-A-GLANCE**
- AST RDAB POC: Nick Chernilovich
- UNIVERSITY: Florida State University
- PRINCIPAL INVESTIGATOR: Dr. Emmanuel Collins
- STUDENT RESEARCHER: Mr. Griffin Francis (PhD)

**RELEVANCE TO COMMERCIAL SPACE INDUSTRY**
- Continued by recent NASA studies, there is an immediate need to develop space debris mitigation technology. The development of an automated “Space Tow Truck” is a promising approach toward direct debris removal. This concept requires automated guidance to navigate in pursuit of targeted debris.

**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 (SBMPC).

**STATUS**
- Demonstrated 3D trajectory planning that is 25x faster than previous methods.
- Shown effective for planning both position and orientation.
- Computes time optimal trajectories that end in zero relative velocity.
- Established method to use previous planning data for rapid replanning in non-deterministic environments.

**FUTURE WORK**
- Develop an “anytime” version of SBMPC.
- Configuration of lab equipment for hardware implementation.
- Formulate approach for determining minimum energy trajectories subject to actuator constraints.
EXECUTIVE SUMMARY

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

- PROJECT AT A GLANCE
  - ASTRIDAB POC: Stephen Earle, Ken Davidian
  - UNIVERSITY: University of Colorado at Boulder
  - PRINCIPAL INVESTIGATOR: Dr. Panina Axelrad,
    RESEARCH PROFESSOR: Dr. Jay McMahon
  - STUDENT RESEARCHERS: Mr. Steven Gehly (PhD),
    Ms. Heather LoCristo (MS)

- 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.

- STATUS
  - Identified and analyzed key mission types, discrete phases, key sensor technologies, critical requirements, and profile.
  - 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
  - Complete draft requirements incorporating relevant concepts from existing recommendations and regulations.
  - Evaluate maturity/risk of technologies and applicability to various mission classes – non-cooperative, unmanned, etc.
  - Improve capability of Flash LIDAR simulation to include unknown target configuration and sensor calibration issues.

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TASK 244: AUTONOMOUS RENDEZVOUS AND DOCKING
(Using nano-satellites for inspection and proximity operations)

- PROJECT AT A GLANCE
  - ASTRIDAB POC: Stephen Earle
  - UNIVERSITY: Stanford University
  - PRINCIPAL INVESTIGATOR: Dr. Steve Rock
  - STUDENT RESEARCHERS: Jose Padial (PhD), Andrew Smith (PhD)

- RELEVANCE TO COMMERCIAL SPACE INDUSTRY
  - Inspection, safe approach and successful capture of uncooperative space debris or damaged vehicles requires the ability to map the target of interest and identify its motion vectors autonomously. Nano-sats offer a potential solution.

- STATEMENT OF WORK
  - Develop and demonstrate robust autonomous rendezvous and docking (AR&D) sensing technology for
    - Targets undergoing complex, potentially tumbling motion
    - Damaged and/or uncommunicative spacecraft
    - Orbital debris.
  - Develop and demonstrate algorithms to enable the fusion of vision and LIDAR for pose estimation and target reconstruction that are implementable on a nano-satellite observing platform.

- STATUS
  - Graduated one PhD student: Kohei Fujimoto, May 2013
  - Combined student team focused on relevant SSA research topics of direct interest to the COE
  - Presented over 22 distinct papers at 12 conferences
  - 5 papers published, 4 more in preparation

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

- **PROJECT AT A GLANCE**
  - AST RDAB POC: Nick Demidovich, Ken Davidian
  - UNIVERSITY: University of Central Florida
  - PRINCIPAL INVESTIGATOR: Dr. Jan Gou, Dr. Jay Kapat, Dr. Ali Gordon
  - STUDENT RESEARCHER: Mr. Donovan Lui, Ms. Cassandra Carpenter, Mr. Hongjiang Yang (PhD)

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

**STATEMENT OF WORK**
- Develop new composites thermal protection systems with embedded health monitoring for inherent safety and real-time assessment of hypersonic applications.
- Provide an analysis tool for the aerothermal modeling of reentry vehicles and rocket propulsion.
- Provide an analysis tool for thermal degradation modeling of composites ablative thermal protection systems.
- Provide ablation sensing to monitor the structural health of the thermal protection system.

**ABLATION TESTING AND THERMAL DAMAGES**

**STATUS**
- Studied on carbon nanotube (CNT) reinforced polymer derived ceramics (PDC) composites for TPS
- Investigated three different technical methods: direct mixing CNTs with PDC, buckypaper reinforced PDC composites, and vertically aligned carbon nanotube (VACNT) array reinforced PDC composites

**FUTURE WORK**
- Processing, characterization, and testing of CNT based PDC composites for thermal protection system
- Reviewing TPS requirements for thermal protection of reentry vehicles and rocket propulsion
- Scaling up of the CNT based PDC composites technologies in the aspects of cost and production rate for CST applications

TASK 258. ANALYSIS ENVIRONMENT FOR SAFETY OF LAUNCH AND RE-ENTRY VEHICLES

**MAJOR MILESTONES S-PAST**
- Development of analysis framework including debris propagation, blast overpressure, and gas dispersion
- Validation of analysis environment with STS-107 (Columbia re-entry) and STS-111
- Kernel density approaches for expected casualty measurements
- Development of preliminary sheltering capabilities
- Development of trajectory optimization code to obtain nominal trajectories
- Development of trajectory modules to obtain off-nominal trajectories

**SCHEDULE**
- Basic environment development – Jun 2012
- Basic environment validation – Dec 2012
- Complete environment development - Dec 2013
- Complete environment validation - Dec 2013
- Development of probabilistic debris catalogs for commercial space – Jun 2014
- Safety metric identification, inverse licensing problem – Dec 2014
- Full environment demonstration, Jun 2015
- Seeking partnerships with prospective users/operators

**MAJOR MILESTONES S-FUTURE**
- Addition of malfunction turns to simulation environment
- Investigate sources of uncertainty and variance in ES calculations (principally debris catalogs)
- Assessing the impact of safety metric choice on licensing requirements
- Establish and maintain an open environment for safety analysis
- Demonstrate inverse solutions for input to licensing process
EXECUTIVE SUMMARY

TASK 293. NONLINEAR STRUCTURAL MODELS

- **PROJECT AT-A-GLANCE**
  - AST RDAB POC: Pam Metz, René Rey, Ken Davidian
  - UNIVERSITY: New Mexico Tech
  - PRINCIPAL INVESTIGATORS: Dr. A. Keith Miller, Dr. Warren Ostergren
  - STUDENT RESEARCHER: Mr. Lance Hernandez (Sr.), Mr. Joshua Mendoza (MS graduate)

- **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 polynomials (RFP).
  - Develop MatLab™ scripts for combining finite element modeled components with experimentally defined (modal) components in structural assemblies.
  - Provide help to commercial companies desiring to use modal extraction in assembly codes.

- **STATUS**
  - Industrial advisory board member initiated
  - Literature review: RFP modal extraction methods selected
  - Code completed to extract structural modal parameters from experimental data
  - Equipment purchased and installed for modal testing
  - Nonlinear structural assembly methods researched

- **FUTURE WORK**
  - Validate modal extraction algorithms using noisy data
  - Review with industrial representatives useful constructs of codes
  - Write code for assembly of non-linear components and interfaces

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 INVESTIGATOR: Dr. Laura Boucheron
  - STUDENT RESEARCHER: Joshua Michaelenko

- **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 SL6, SL7/B 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.

- **STATUS**
  - Code infrastructure is developed and ready to analyze the addition of data as soon as we receive it.

- **FUTURE WORK**
  - Receive data from SL-7 (c-band radar and WSMR radar data)
TASK 299. NITROUS OXIDE COMPOSITE CASE TESTING

PROJECT AT-A-GLANCE
ASTROAB POC: Yvonne Tran, Donald Sargent, Ken Davidson
UNIVERSITY: New Mexico Tech
PRINCIPAL INVESTIGATORS: Drs. Warren Osterhagen, Michael Hargrave, Robert Abernathy, Andrei Zagrai
STUDENT RESEARCHERS: Steven Bayley (Sr.), Jessica Tobin (MS graduate)

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
Safety will be enhanced by providing guidelines to protect the public from hazards associated with the failure of space vehicle components. This task will develop an understanding of fragmentation hazards from composite tanks used for fuel/oxidizer storage.

STATEMENT OF WORK
Test composite panels to understand fragmentation patterns and hazards.
Develop methods to predict fragmentation conditions.
Develop standard test procedures for composite materials under shock and high-rate loading.
Develop analytical models to compare to experiments.
Utilize test and analysis results to validate or modify existing predictive models.
Provide data to help set guidelines for safe distances during launch of commercial vehicles.

STATUS
High-pressure test section completed.
Low-pressure section in final machining.
Pressure gages and instrumentation procured.
Instrumentation testing underway.
Examples of composite N2O tank materials obtained.
Computer simulations have been initiated.

FUTURE WORK
Complete computational model of tank liner.
Test composite materials.
Incorporate data from composite tests into computational model.
Test full composite N2O tank.
Establish safety standards for composite tanks under dynamic loading.

TASK 193. ROLE OF COE CST IN ENCOURAGE, FACILITATE AND PROMOTE (SECONDARY & HOSTED PAYLOADS)

PROJECT AT-A-GLANCE
ASTROAB POC: Ken Davidson
UNIVERSITY: Stanford University
PRINCIPAL INVESTIGATOR: Prof. Scott Hubbard
STUDENT RESEARCHER: Mr. Jonah Zimmerman (PhD) & Mr. Andrew Ow (MBA)

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
The inclusion of SHPs on NASA missions could provide additional business opportunities for many within the commercial space industry, including launch vehicle, satellite, and other aerospace hardware manufacturers.

STATEMENT OF WORK
Demonstrate that significant excess capacity exists on the majority of NASA launches by compiling database of information on payload mass and launch vehicle capacity for previous missions.
Compare rate of inclusion of SHPs on commercial and non-commercial launches.
Estimate monetary value of the excess capacity using previous studies of the space transportation industry.
Identify advantages and limitations of missions performed as SHPs. This will be accomplished via specific case studies.
Present results to policymakers at NASA and open discussion for possible policy updates and implications.

STATUS
Determined excess payload capacity for NASA launches from 2006-2013.
Spoke to industry partners and NASA employees to understand reasons for excess payload.
Identified presence or absence of secondary payloads on >500 commercial and non-commercial launches.
1 conference paper (IAC) presented so far in FY13.

FUTURE WORK
Estimate capacities for orbits with no published values.
Identify case studies for SHP missions utilizing excess capacity.
Discuss with NASA launch experts whether a policy change is warranted.
EXECUTIVE SUMMARY

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), Ms. Jules Feldhacker (PhD)
- PERIOD OF PERF: Jan 1, 2011 – May 31, 2014
- 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

STATUS
- 4th & 5th Emerging Space Industry Leaders (ESIL) Workshops held in 2013
- Post-workshop efforts and publications in progress

FUTURE WORK
- Spring 2014: ESIL-06 in Washington DC
- 2014: Ongoing support of relevant EFP activities
- 2015: Franchise event to broaden impact with reduced direct support

TASK 302. INTERNATIONAL COMMERCIAL SPACE REGULATIONS

PROJECT AT A GLANCE
- AST TECH MONITOR: John Sloan, Mahamane Touré
- UNIVERSITY: McGill University
- PRINCIPAL INVESTIGATOR: Prof. Ram Jakhu
- STUDENT RESEARCHER: Mr. Paul Fitzgerald (PhD)
- STATUS: Completer

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
In anticipation of future inter-country travel via Spacecraft in Low Earth Orbit, a legal framework is required to deal with Air Traffic Management and Safety issues. This has the potential to impact the financial viability of such initiatives.

STATEMENT OF WORK
- Phase I: Define scope of study, terms, infrastructure
- Phase II: Historical examination; laws as they are
- Phase III: Comparative exercise
- Phase IV: Analysis and recommendations
- Phase V: Disseminate results (accepted for publication)

STATUS
- Phase I – complete
- Research will be published in Journal of Air Law & Commerce, Southern Methodist University, Dallas, Texas in 2014.

FUTURE WORK
- None
COE CST Year 3 Students

The following is a list and demographic information of the 55 COE CST students working on research tasks during the second year of operation.

- Bayley, Steven (NMT)
- Blue, Rebecca (UTMB)
- Borowski, Holly (CU)
- Bowers, Marianne (NMSU)
- Capristan, Francisco (SU)
- Carpenter, Cassandra (UCF)
- Cason, Kathryn (UF)
- Charalambides, Gabe (SU)
- Cheetham, Bradley (CU)
- Collins, Justin (FSU)
- Colvin, Thomas (SU)
- Conrad, David (NMT)
- Cooper, Benjamin (NMT)
- Cushman, James (UTMB)
- Deaven, Jacob (NMSU)
- Fanchiang, Christine (CU)
- Feldhacker, Juliana (CU)
- Francis, Griffin (FSU)
- Fujimoto, Kohei (CU)
- Gehly, Steven (CU)
- Gutierrez, Jaclene (NMT)
- Hammond, Marcus (SU)
- Herman, Jon (CU)
- Kasdaglis, Nicholas (FIT)
- Kruse, Walter (NMT)
- Law, Jennifer (UTMB)
- Lawrence, Jeremy (UCF)
- Lewis, Leigh (UTMB)
- Li, Alan (SU)
- LoCrasto, Heather (CU)
- Lui, Donovan (UCF)
- Maillet, Nicole (FIT)
- Masker, William (NMT)
- Mathers, Charles (UTMB)
- McGranaghan, Ryan (CU)
- Meisner, Daniel (NMT)
- Mendoza, Joshua (NMT)
- Menon, Anil (UTMB)
- Michalenko, Joshua (NMSU)
- Mills, David (UF)
- Mulcahy, Robert (UTMB)
- Padial, Jose (SU)
- Pattarini, James (UTMB)
- Phillips, Homer (CU)
- Reiner, Sebastian (FIT)
- Reyes, David (UTMB)
- Runnels, Joel (NMT)
- Sharma, Aneesh (FSU)
- Smith, Andrew (SU)
- Stanley, June (NMT)
- Strevel, Hank (NMSU)
- Trujillo, Blaine (NMT)
- Wilt, Dennis (FIT)
- Yang, Hongjiang (UCF)
- Zimmerman, Jonah (SU)

Abbreviations: CU-University of Colorado Boulder, 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 3 Student Demographics
EXECUTIVE SUMMARY

COE CST YEAR 3 RESEARCH PARTNERS
The following is a list of the 20 COE CST research organization partners that have contributed to the year 3 COE CST research tasks.

- Air Force Research Lab - Kirtland
- Air Force Research Lab - Maui
- Baylor College of Medicine
- FAA Civil Aerospace Medical Institute
- Mayo Clinic - Jacksonville
- Mayo Clinic - Scottsdale
- Metropolitan State College of Denver
- NASA Ames Research Center
- NASA Headquarters
- NASA Jet Propulsion Lab
- NASA Johnson Space Center
- National Science Foundation (Student Fellowships)
- National Space Grant Foundation
- NMSU Space Development Foundation
- Pennsylvania State University, The
- Southwest Research Institute
- Universities Space Research Association
- University of Colorado LASP
- University of Missouri
- US Army

COE CST YEAR 3 INDUSTRY PARTNERS
The following is a list of the 44 COE CST industry partners that have contributed to the year 3 COE CST research tasks.

- Altius Space Machines
- American Institute of Aeronautics and Astronautics (AIAA)
- Analytical Graphics Inc.
- Arianespace
- ATK
- Bachner Consultants, Inc.
- Ball Aerospace
- Bigelow Aerospace
- Boeing Company, The
- Cimmaron Software Services Inc.
- Clear Channel Satellite
- CSSI Inc.
- Digital Solutions
- DigitalGlobe
- Dynetics, Inc.
- Futron
- GeoEye
- Jacobs Technology Inc.
- Locked On Inc.
- Lockheed Martin Space Systems Company
- Marketing Consultant
- NASTAR Center
- New Mexico Spaceport Authority
- Orbital Sciences Corporation
- Orion America Technologies, LLC
- Paris Surgical Assoc.
- Qinetiq
- Scitor Corporation
- Sierra Nevada Corp.
- Space Exploration Technologies (SpaceX)
- Space Florida
- Space News
- Space Systems / Loral
- Space Works Enterprises
- Spaceport America Consultants
- Spaceport Sweden
- Spaceworks
- Special Aerospace Services
- Tauri Group, The
- United Launch Alliance
- Virgin Galactic
- Webster University
- Wyle Integrated Science and Engineering Group
- XCOR Aerospace, Inc.

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COE CST YEAR 3 PUBLICATIONS
The following is a list of the 28 publications published or presented during COE CST year 3.

**Task 182-UTMB Human System Risk Management Approach**

**Task 184-CU Human Rating of Commercial Spacecraft**

**Task 185-SU Unified 4-Dimensional Trajectory Analysis**

**Task 186-SU Space Environment MMOD Modeling and Prediction**


**Task 187-CU Space Situational Awareness**


**Task 193-SU Role of COE CST in EFP**


**Task 193-CU Role of COE CST in EFP**


**Task 228-NMT Magneto-Elastic Sensing for Structural Health Monitoring**


**Task 244-FSU Autonomous Rendezvous and Docking**
