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 3 Annual Report

Executive Summary

December 31, 2013

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 National COE for Aviation Operations Research (NEXTOR), operated from 1996 to 2007.
- 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 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).
- Third Annual Technical Meeting held in Washington, D.C. on October 28-30, 2013.

At-A-Glance Metrics	Year 1	Year 2	Year 3
# Active Tasks	34	24	25
# Principal Investigators	27	28	23
# Students	31	37	55
# Reports	0	38	28
# Research Partners	NA	17	20
# Industry Partners	NA	29	44
# Affiliate Members	0	1	6
Funding Profile	$2M (FY10)	$2.4M (FY11/12)	$1.1M (FY13)

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.

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 and 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 RedBull 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

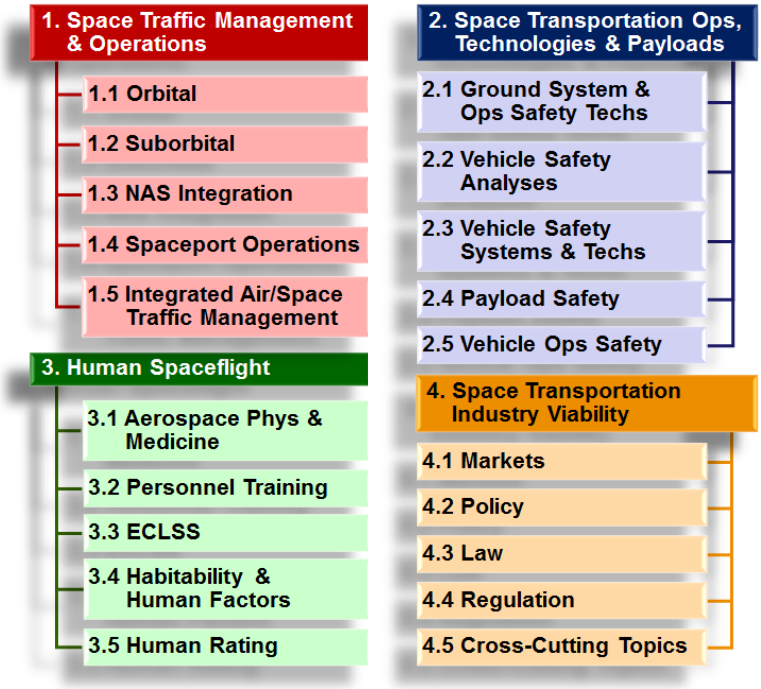
The research conducted within FAA AST is broken into four major research areas:

- 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 sub-divided 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.



All FAA AST R&D Tasks (as of 31 Dec 2013)

Task # Name / PI Name (Univ) - AST TM		Task # Name / PI Name (Univ) - AST TM	
185 Unified 4-Dimensional Trajectory Analysis Alonso (SU) - Wilde	IP	228 Magneto-Elastic Sensing for SHM Zagrai, Ostergren (NMT) -Demidovich	IP
186 Space Environment MMOD Modeling and Prediction Close(SU), Fuller-Rowell(CU)-Shelton-Mur	2xIP	241 High Temperature Pressure Transducers Sheplak (UF), Oats (FSU) - Demidovich	2xIP
187 Space Situational Awareness Scheeres (CU) - Earle	IP	244 Autonomous Rendezvous and Docking Fitz-Coy (UF), Collins (FSU), Rock (SU), Axelrad (CU) -Earle	4xIP
220 Space Operational Framework Hynes (NMSU) - Rey	IP	253 Ultra High Temperature Composites Gou & Kapat (UCF) - Demidovich	IP
247 Air and Space Traffic Considerations for CST Villaire (FIT) - Murray	IP	258 Multi-Disciplinary Analysis of Safety Metrics Alonso (SU) - Wilde	IP
257 Master's Launch and On-Orbit Operations Laboratory Born (CU) - Rey	IP	293 Reduced Order Non-Linear Structural Modeling Miller (NMT) - Demidovich	IP
181 Physiological DB Definition and Design Vanderploeg (UTMB) - Lampazzi	END	298 Integration Evaluation of ADS-B Payloads Hynes (NMSU) - Demidovich	IP
184 Human Rating of Commercial Spacecraft Klaus (CU) - Lampazzi	IP	299 Nitrous Oxide Composite Tank Testing Ostergren (NMT) - Tran	IP
255 Wearable Biomedical Monitoring Equipment Jennings (UTMB) - Lampazzi	IP	193 Role of COE CST in EFP Hubbard (SU), Born (CU) - Davidian	2xIP
256 Additional NASTAR Centrifuge Testing Vanderploeg (UTMB) - Lampazzi	IP	302 International Commercial Space Regulations Jakhu (MU) - Touré	IP
294 Minor Injury Severity Scale Jennings (UTMB) - Gerlach	END		
295 EMF Effects on Implantable Devices Vanderploeg (UTMB) - Lampazzi	END		

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.

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/recovery (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

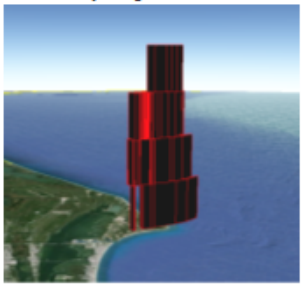
Kernel Density Estimation methods for probabilistic analysis

SCHEDULE

- Finalize KDE probabilistic analysis capability to create 4D envelopes with user-specified safety level – Feb 2014
- Development of Integrated Air/Space 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

Current: static Special Use Airspace (SUA)

Future: dynamic 4D envelopes with guaranteed safety margins and reaction times



MAJOR MILESTONES-FUTURE

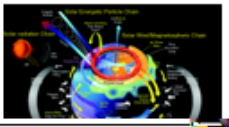
- Finalize direct connection with baseline trajectory and debris computation capabilities in Task 258
- Development of plausible architectures for integrated air-space traffic management
- Improved aircraft re-routing capabilities (for dynamic airspaces) in FACET
- Validation of environment capabilities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

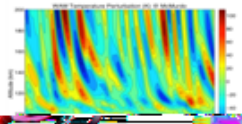
TASK 186. MITIGATING THREATS THROUGH SPACE ENVIRONMENT MODELING & PREDICTION

PROJECT AT-A-GLANCE

- AST RDAB 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

The Physical System (image courtesy of Joe Grebowsky)





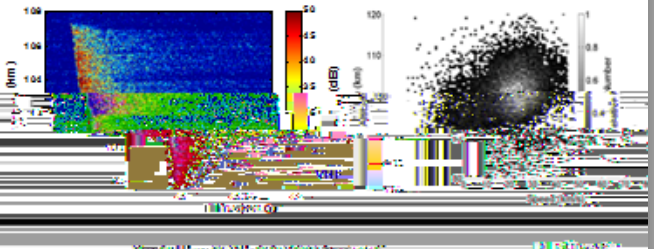
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- An integrated air and space traffic management system

1. [illegible]

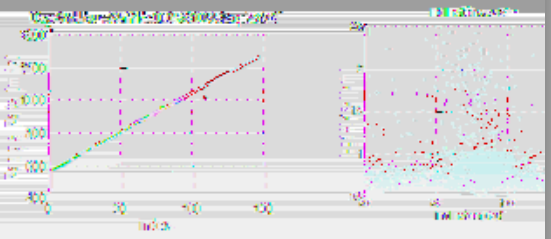
STATUS:

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



PROJECT AT-A-GLANCE

- AST RDAB POC: Karen Shelton-Mur



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

Association of space debris observations

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

STATUS

- Graduated one PhD student Kohei Fujimoto (May 20
- Garnered student team focused on relevant SSA proc topics directly linked to the FAA
- Presented over 20 distinct papers at 12 conferences
- 3 papers published, 4 more in preparation

FUTURE WORK

- Next stage of direct FAA funded research will focus on developing rapid assessment in conjunction analysis to
- Non-directly funded research will focus on
  Long-term space debris dynamics (orbit and attitude)
  Modeling and estimation of debris non-gravitational for

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-V	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

- 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/non-government reference sources.
- Presented work to COMSTAC 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**
- AST RDAB POC: Pam Melroy, René Rey, Ken Davidian
- UNIVERSITY: Florida Institute of Technology
- PRINCIPAL INVESTIGATOR: Dr. Nathaniel Villaire, Professor Emeritus
- STUDENT RESEARCHER: Sebastian Rainer
- STUDENT RESEARCHER: Dennis W. Wilt
- INDUSTRY PARTNER: Space Florida

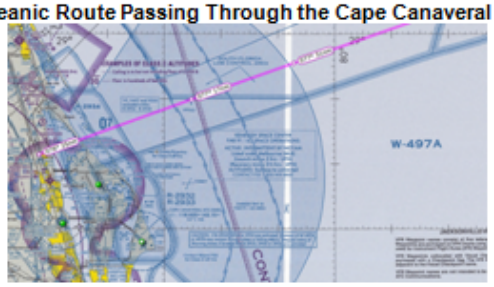
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- 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.

An Oceanic Route Passing Through the Cape Canaveral Range



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 corner of the closed airspace
- Data saved 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

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), Ms. Jules Feldhacker (PhD), Jon Herman (PhD)
- PERIOD OF PERF: 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).

Commercial Spaceflight Operations Lab

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

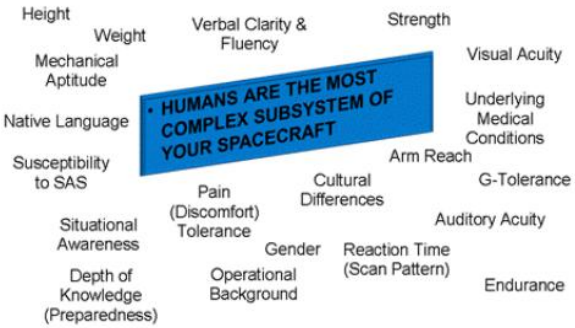
TASK 181. PHYSIOLOGICAL DATABASE DEFINITION & DESIGN

- **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 medica 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

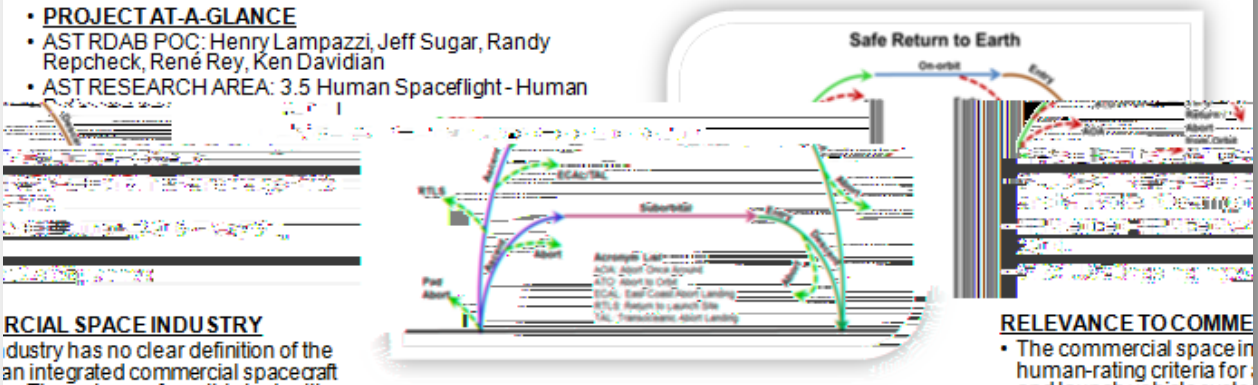


STATUS
- Conducted workshop in March 2012
- Identified desired data elements for pre-flight, in-flight, and post-flight data.
- Identified desired elements of vehicle parameters.
- Secured NASA interest in hosting database on LSAH system.

FUTURE WORK
- Obtain commitment from commercial companies to participate.
- Draft SOP for control, security, confidentiality, and access.
- Final report and recommendations – Dec. 2012.

TASK 184. HUMAN-RATING OF COMMERCIAL SPACECRAFT

- **PROJECT AT-A-GLANCE**
- AST RDAB POC: Henry Lampazzi, Jeff Sugar, Randy Repcheck, René Rey, Ken Davidian
- AST RESEARCH AREA: 3.5 Human Spaceflight - Human



RCIAL SPACE INDUSTRY

dustry has no clear definition of the an integrated commercial spacecraft m. The outcome from this task will regulatory responsibilities.

rking Group feedback against a list & definitions

tion design, production and ocesses to facilitate open discussion practices to anticipate and guide

f the FAA's 'Established Practices ccupant Safety' through systematic stry and public participants.

Earth'

STATUS

- Human Spaceflight Terminology and Definitions -rev Oct 2013
- Human Spaceflight Safety Terms and Definitions -rev Oct 2013
- Human Spaceflight Safety Perspectives -rev Oct 2013
- 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

RELEVANCE TO COMME

- The commercial space in human-rating criteria for and launch vehicle syste support the FAA's safety

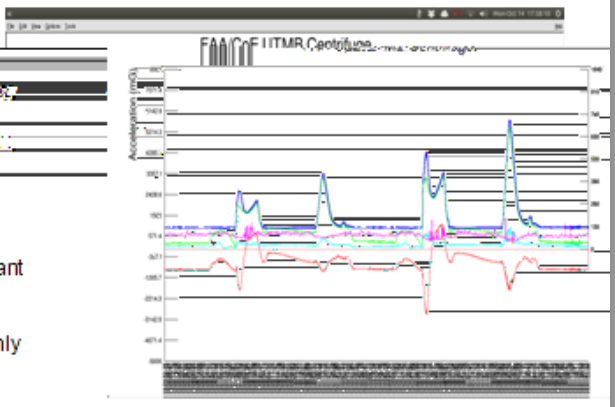
STATEMENT OF WORK

- Solicit Human-Rating Wo of pertinent terminology &
- Assess existing FAA avia operation certification pro aimed at identifying best future regulatory needs.
- Contribute to definition o for Human Spaceflight O discussion amongst indu
- Focus on 'safe return to E

TASK 255. EVALUATION OF WEARABLE BIOMEDICAL MONITORING EQUIPMENT

Project At-A-Glance

- UNIVERSITY: The University of Texas Medical



Relevance to Commercial Spaceflight Industry

- Commercial spaceflight participants (SFPs) represent a population with potentially significant medical problems that may warrant in-flight medical monitoring
- Commercial SFPs may be hesitant to wear highly invasive, obtrusive 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.

ge

Status

- Complete evaluation using the NASTAR centrifu

Future Work

- Perform data analysis
- Publish results

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

utmb Health

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 Pattarini, MD David Reyes, MD; Robert Mulcahy, MD

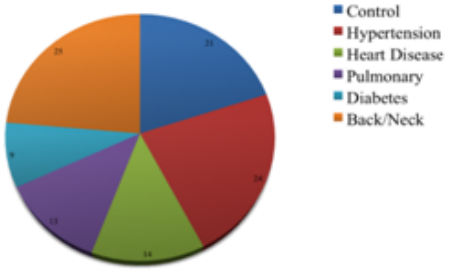
Relevance to Commercial Spaceflight Industry

- 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 respondto 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

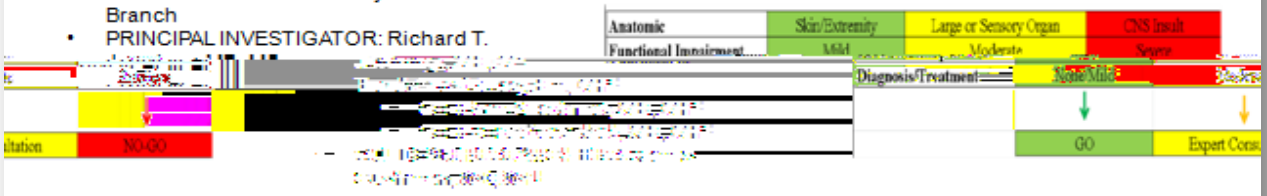
- Perform data analysis
- Publish results
- Develop optimal acceleration training protocols for passengers

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

utmb Health

Project At-A-Glance

- UNIVERSITY: The University of Texas Medical Branch
- PRINCIPAL INVESTIGATOR: Richard T.



Development

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 (MISS) 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 (MISS) for Orbital Human Space Flight (HSF).

Status

- Completed literature review and MISS

Future Work

- Manuscript editing
- Publish results

TASK 295. EFFECTS OF EMI AND IONIZING RADIATION ON IMPLANTABLE MEDICAL DEVICES

utmb Health

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 implanted medical devices

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

TASK 228: MAGNETO-ELASTIC SENSING FOR STRUCTURAL HEALTH MONITORING

NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH UNIVERSITY

PROJECT AT-A-GLANCE

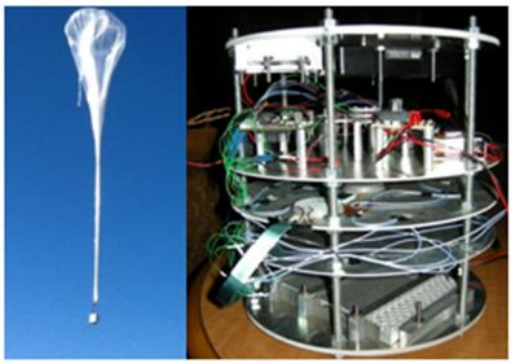
- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR: Dr. Andrei Zagrai and Dr. Warren Ostergren.
- STUDENTS: Blaine Trujillo (MS), Joel Runnels (UG) and William Masker (UG)

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.

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

TASK 241. HIGH-TEMPERATURE PRESSURE SENSORS FOR HYPERSONIC VEHICLES

- **PROJECT AT-A-GLANCE**
- AST RDAB 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)

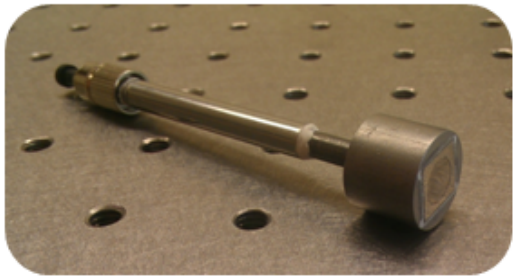
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- 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.

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 sapphire fiber-optic pressure sensor



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**
- 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, 2012 – May 31, 2013
- STATUS: Restarted pending funding

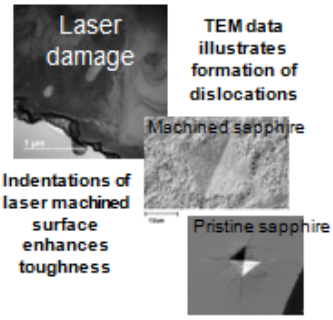
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- 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 ~600°C.

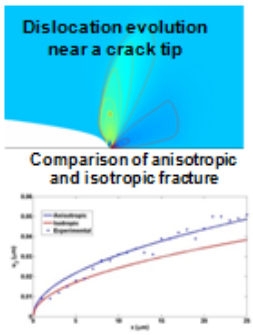
STATEMENT OF WORK

- 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 micromachining
- Combined studies of fracture mechanics theory and experimental testing focused on sensor reliability

Material Characterization



Single Crystal Fracture & Dislocation Mechanics



STATUS

- 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 specimens
- Pressure transducer testing

TASK 244. AUTONOMOUS RENDEZVOUS AND DOCKING

UF

- **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)

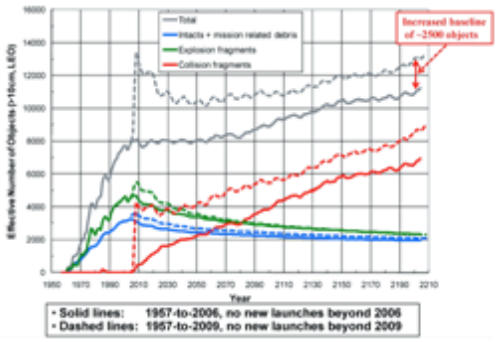
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- 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.

Orbital Debris Affects Safe Operations



STATUS

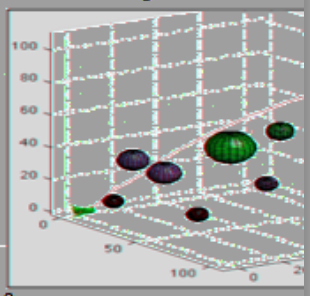
- Literature review and assessment of SOA completed
- Removal of non-cooperative debris most challenging
- Strategies for safe removal are being investigated
- 1 PhD generated (Takashi Hiramatsu)
- 2 papers (IEEE) published

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

TASK 244. AUTONOMOUS RENDEZVOUS AND DOCKING

3D Planning in Cluttered E



that is 25x faster than

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PO.
rdware implementation.
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ints.

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

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Confirmed 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.
- 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).

STATUS

- Demonstrated 3D trajectory planning
previous methods.
- Shown effective for planning both po
- Computes time-optimal trajectories t
velocity.
- Established method to use previous
replanning in nondeterministic enviro
- Presented results at the 2013 AIAA G
and Control Conference.

FUTURE WORK

- Develop an "anytime" version of SBM
- Configuration of lab equipment for ha
- Formulate approach for determining
trajectories subject to actuator constra

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

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

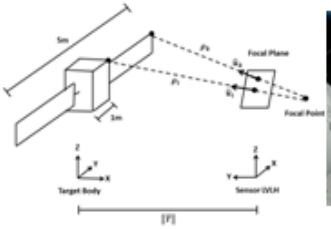
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- 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.

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 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, un/manned, etc
- Improve capability of Flash LIDAR simulation to include unknown target configuration and sensor calibration issues.

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

PROJECT AT-A-GLANCE

- AST RDAB POC: Stephen Earle
- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR: Dr. Steve Rock
- STUDENT RESEARCHERS: Jose Padial (PhD), Andrew Smith (PhD)

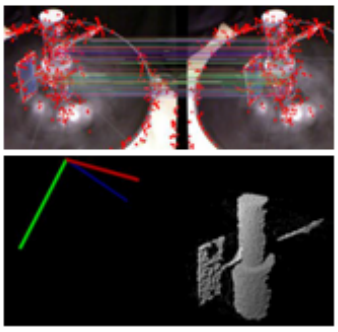
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- 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-sat observing platform.

Fusion of vision and LIDAR for pose estimation and target reconstruction



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)

University of Central Florida

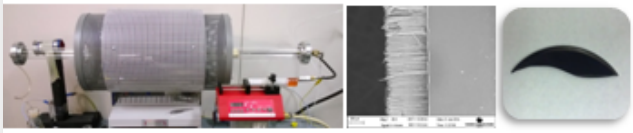
- **PROJECT AT-A-GLANCE**
- AST RDAB POC: Nick Demidovich, Ken Davidian
- UNIVERSITY: University of Central Florida
- PRINCIPAL INVESTIGATOR: Dr. Jan Gou, Dr. Jay Kapat, Dr. Ali Gordon
- STUDENT RESEARCHER: Mr. Donovan Lui, Ms. Cassandra Carpenter, Mr. Hongjiang Yang (PhD)

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

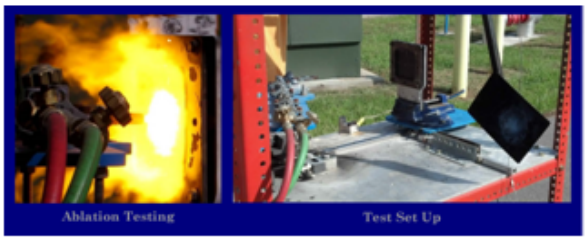
- Ultra-high temperature, light weight, low erosion, and cost effective thermal protection systems (TPS) are enabling technologies for viable commercial spacecraft and launch vehicle system.

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 aero-thermal 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

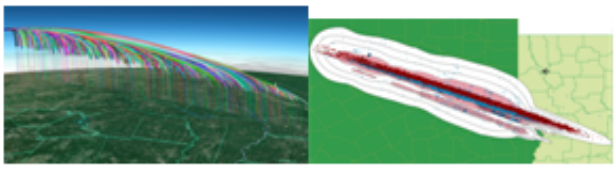
- Processing, characterization and testing of CNT based PDC composites for thermal protection system
- Reviewing TPS requirements for thermal protection of reentry vehicles and rocket propulsion
- Scaling up of the CNT based PDC composites technologies in the aspects of cost and production rate for CST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

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

MAJOR MILESTONES-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

Columbia Debris Simulations and Comparisons with Recovered Debris



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-FUTURE

- Addition of malfunction turns to simulation environment
- Investigate sources of uncertainty and variance in E_c 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

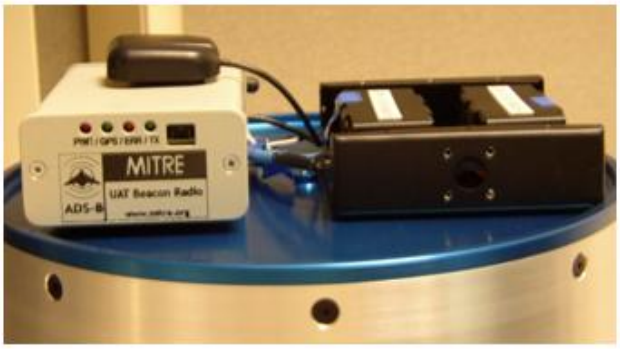
TASK 293. NONLINEAR STRUCTURAL MODELS

- PROJECT AT-A-GLANCE
- AST RDAB POC: Pam Melroy, René Rey, Ken Davidian
- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATORS: Dr. A. Keith Miller, Dr. Warren Ostergren
- STUDENT RESEARCHER: Mr. Lance Hernandez, Mr.

Component Modal Testing and System Assemb

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.

STATUS

- Code infrastructure is developed and ready to analyze the additional data s soon as we receive it.

FUTURE WORK

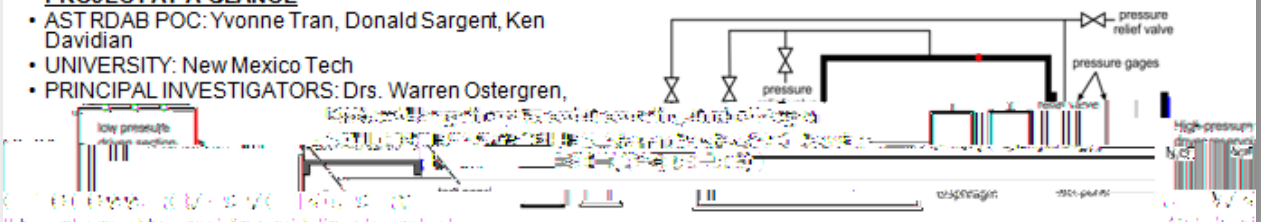
- Receive data from SL-7 (c-band radar and WSMR radar data)

TASK 299. NITROUS OXIDE COMPOSITE CASE TESTING

NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH • UNIVERSITY

- **PROJECT AT-A-GLANCE**
- AST RDAB POC: Yvonne Tran, Donald Sargent, Ken Davidian
- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATORS: Drs. Warren Ostergren,

Test Panels of Composite Materials Under Dynamic, Shock Loading



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

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

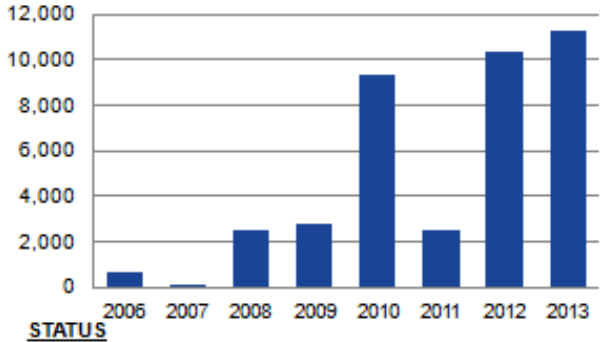
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- 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.

Annual Unused Capacity in NASA launches [kg]



STATUS

- Determined excess payload capacity for NASA launches from 2006-2013
- Spoke to industry partners and NASA employees to understand reasons for excess capacity
- 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

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

ESIL Workshop Impact

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

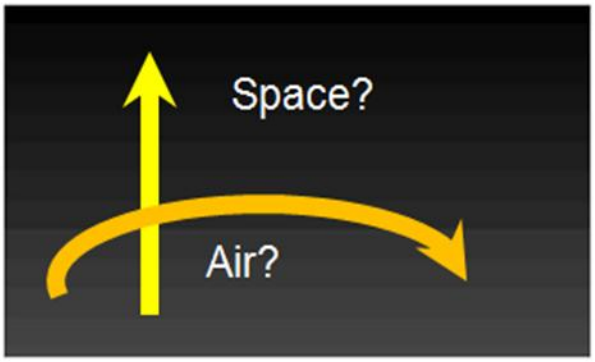
FUTURE WORK
- Spring 2014: ESIL-06 in Washington DC
- 2014: Ongoing support of relevant EFP activities
- 2015: Franchise event to broaden impact with reduced direct support

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

FUTURE WORK
- None.

COE CST STUDENTS, PARTNERS AND PUBLICATIONS

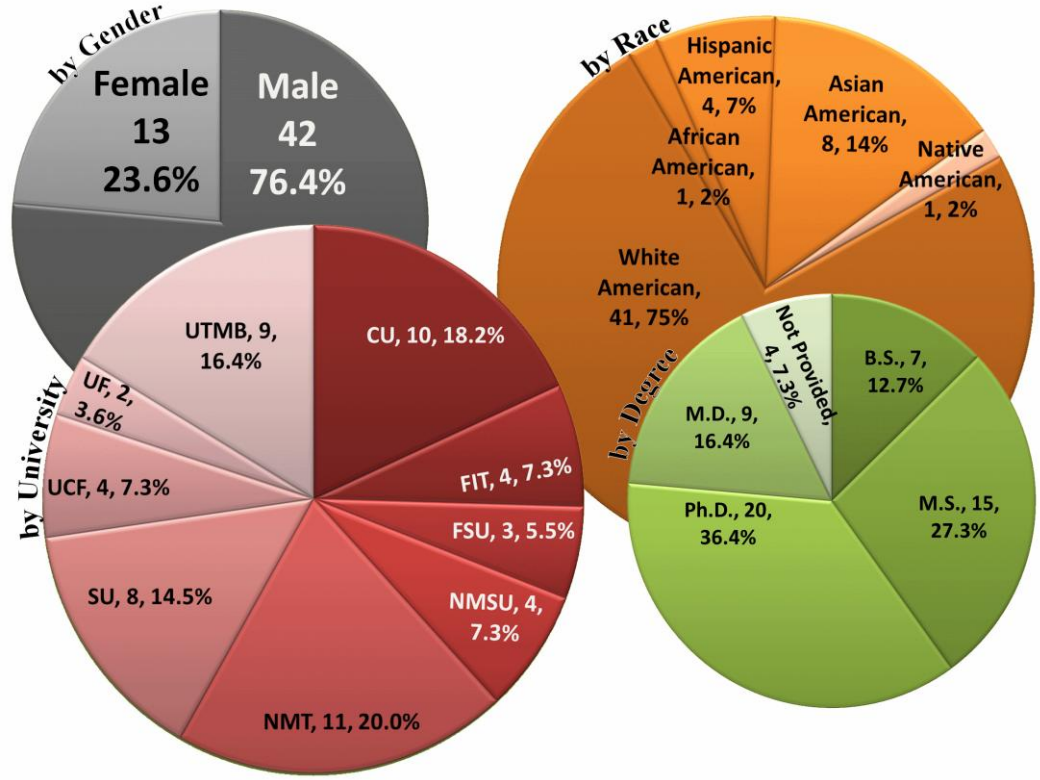
COE CST YEAR 3 STUDENTS

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, Jeremey (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



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.

COE CST would like to thank United Launch Alliance and Craig Technologies for sponsoring the Welcome Reception at the Annual Technical Meeting in Washington, DC.

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

- CH Mathers, EL Kerstman. J. Law, JM Vanderploeg, and SRE Fondy. (2013). and "NASA's Human System Risk Management Approach and Its Applicability to Commercial Spaceflight"; Aviation, Space, and Environmental Medicine, Vol. 84, No. 1, January 2013.

TASK 184-CU HUMAN RATING OF COMMERCIAL SPACECRAFT

- Fong et al., (2013). Winter temperature tides from 30 to 110 km at McMurdo: Lidar observations and comparison with WAM, J. Geophys. Res., submitted, 2013.
- D.M. Klaus and R.P. Ocampo (2013) A Review of Spacecraft Safety: from Vostok to the International Space Station. New Space 1(2): 73-80

TASK 185-SU UNIFIED 4-DIMENSIONAL TRAJECTORY ANALYSIS

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

TASK 186-SU SPACE ENVIRONMENT MMOD MODELING AND PREDICTION

- A. Li and S. Close. (2013). Orbital debris parameter estimation from vertical pointing radar, IAC, Conference Proceedings.

- A. Goel, A. Mocker, D. Lauben, D. Strauss, I. Linscott, N. Lee, R. Srama, S. Bugiel, S. Close, and T. Johnson. (2013). Detection of electromagnetic pulses produced by hypervelocity micro particle impact plasmas, Physics of Plasmas, 20, 092102, 1–8, doi:10.1063/1.4819777.
- A. Goel, A. Mocker, D. Lauben, D. Strauss, I. Linscott, N. Lee, R. Srama, S. Bugiel, S. Close, and T. Johnson. (2013). Theory and experiments characterizing hypervelocity impact plasmas on biased spacecraft materials, Physics of Plasmas, 20, 032901, 1–9, doi:10.1063/1.4794331.
- N. Lee, R. Srama, and S. Close. (2013). Composition of plasmas formed from debris impacts on spacecraft surfaces, Sixth European Conference on Space Debris.
- D. Janches, D. Nesvorny, J. J. Sparks, S. Close, S. Pifko, and T. Nakamura. (2013)., The Meteoroid Input Function and predictions of mid-latitude meteor observations by the MU radar, Icarus, 223, 444–459, doi:10.1016/j.icarus.2012.12.014.

TASK 187-CU SPACE SITUATIONAL AWARENESS

- D.J. Scheeres and K. Fujimoto. (2013). "Applications of the Admissible Region to Space- Based Observations," Advances in Space Research 52: 696-704.
- A.J. Rosengren and D.J. Scheeres. (2013). "Long-term Dynamics of High Area-to-mass Ratio Objects in High-Earth Orbit," Advances in Space Research 52: 1545-1560.
- A. Albuja and D.J. Scheeres. (2013). "Evolution of Angular Velocity for Large Space Debris as a Result of YORP," paper presented at the 64th International Astronautical Congress, Beijing, China, October 2013. Paper IAC-13.A6.2.6.
- A.J. Rosengren, D.J .Scheeres and J.W. McMahon. (2013). "The Classical Laplace Plane and its use as a Stable Disposal Orbit for GEO," paper presented at the 2013 AMOS Meeting, Maui, September 2013.
- A. Albuja and D.J .Scheeres. (2013). "Defunct Satellites, Rotation Rates and the YORP Effect," paper presented at the 2013 AMOS Meeting, Maui, September 2013.
- D.J. Scheeres, J. Herzog, K. Fujimoto, and T. Schildknecht. (2013). "Improvements to Optical Track Association with the Direct Bayesian Admissible Region Method," paper presented at the 2013 AMOS Meeting, Maui, September 2013.
- D.J .Scheeres and K. Fujimoto. (2013). "Analytical Non-Linear Conjunction Assessment Via State Transition Tensors In Orbital Element Space," paper presented at the 2013 AAS/AIAA Astrodynamics Specialist Conference, Hilton Head Island, South Carolina, August 2013. Paper AAS 13-913.
- A.J. Rosengren, D.J .Scheeres and J.W. McMahon. (2013). "Long-Term Dynamics And Stability Of Geo Orbits: The Primacy Of The Laplace Plane," paper presented at the 2013 AAS/AIAA Astrodynamics Specialist Conference, Hilton Head Island, South Carolina, August 2013. Paper AAS 13-865.
- D.J. Scheeres, J. Herzog, K. Fujimoto, and T. Schildknecht. (2013). "Applying the Direct Bayesian Admissible Region Approach to The Association of GEO Belt Optical Obser- vations," paper presented at ISTS 2013, The 29th International Symposium on Space Technology and Science, Nagoya-Aichi, Japan, June 2013.
- D.J. Scheeres, J. Herzog, K. Fujimoto, and T. Schildknecht. (2013). "Association Of Short-Arc Optical Tracks Via The Direct Bayesian Admissible Region: Theory And Application," paper presented at the 6th European Conference on Space Debris, ESA/ESOC Darmstadt, Germany, April 2013.
- A.J. Rosengren and D.J. Scheeres. (2013). "Averaged Dynamics Of High Area-To-Mass Ratio Space Debris In Geo," paper presented at the 6th European Conference on Space Debris, ESA/ESOC Darmstadt, Germany, April 2013.
- A. Albuja, D.J. Scheeres, J.W. McMahon. (2013). "Evolution of Angular Velocity for Space Debris as a Result of YORP," paper presented at the 23rd AAS/AIAA Space Flight Mechanics Meeting, Kauai, Hawaii, February 2013. Paper AAS 13-316

TASK 193-SU ROLE OF COE CST IN EFP

- A. Ow, J. Zimmerman, and S. Hubbard. (2013). "Potential Opportunities for Secondary and Hosted Payloads on NASA Missions", IAC-13-B4.5.7, September, 2013.

TASK 193-CU ROLE OF COE CST IN EFP

- B. Cheetham, B. Henwood, J. Crowell, J. Feldhacker, J. Stark, K. Davidian, K. Raimalwala, L. Kennick, M. Cannella, N. Wong, and S. Bandla,. "The 'Game' of Training Humans for Commercial Suborbital Spaceflight," 64th International Astronautical Congress, Beijing China, IAC-13-E6.2.3

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

- A. Zagrai, B. Cooper, B. Trujillo, C. White, J. Gutierrez, J. MacGillivray, J. Schlavin, K. Tena, L. Magnuson, L. Puckett, N. Demidovich, S Chesebrough, S. Kessler, T. Gonzales. (2013). "Structural Condition Assessment during High Altitude Stratospheric Balloon Flight," Presentation at Next-Generation Suborbital Researchers Conference 2013, June 3-5, 2013, Broomfield, Colorado.
- A. Zagrai, B. Cooper, B. Trujillo, C. White, J. Gutierrez, J. MacGillivray, J. Schlavin, K. Tena, L. Magnuson, L. Puckett, N. Demidovich, S Chesebrough, S. Kessler, T. Gonzales. (2013). "Structural Health Monitoring using COTS Equipment during High Altitude Stratospheric Balloon Flight," Presentation at Commercial and Government Responsive Access to Space Technology Exchange, Bellevue, Washington, June 26, 2013.
- A. Zagrai, B. Cooper, C. White, J. Schlavin, and S. Kessler. (2013). "Structural Health Monitoring in Near-Space Environment, a High Altitude Balloon Test," Proceedings of International Workshop on Structural Health Monitoring, Stanford University, September 10, 2013.
- A. Zagrai, B. Cooper, and S. Kessler. (2013). "Effects of Altitude on Active Structural Health Monitoring," Proceedings of SMASIS-13, ASME Conference on Smart Materials, Adaptive Structures and Intelligent Systems, September 16 – 18, 2013, Snowbird, Utah, paper: SMASIS2013-3269.

TASK 244-FSU AUTONOMOUS RENDEZVOUS AND DOCKING

- A. Sharma, E. Collins, G. Francis, and O. Chuy. (2013). "Sampling-Based Trajectory Generation for Autonomous Spacecraft Rendezvous and Docking," AIAA Guidance, Navigation, and Control Conference, Boston, MA, August 2013.

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