BCM

Florida Institute of Technology

Florida State University

NM State University

New Mexico Tech
Science • Engineering • Research • University

Leland Stanford Junior University

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 10 Annual Report

Executive Summary

December 31, 2020

Table of Contents

LETTER FROM THE EXECUTIVE DIRECTOR

As with everything else in 2020, the COVID-19 pandemic significantly impacted our COE CST. Just after the final round of FAA funding was released in February and the PIs started to ramp up their various research tasks, the pandemic closures began forcing schools to transition to remote operations, with most in-person activities essentially ceasing by early spring. Lacking direct interaction with students and colleagues made it challenging to initiate new projects, but as the year went on and we adjusted to the circumstances, we all adapted to life on Zoom and things started to get back on track.

Administratively, we continued our normal weekly meetings this year where we worked to get pending task closures off the books, focused on updating our associate and affiliate member status and contact information, revised the bylaws and prepared for the regular monthly executive telecons, as well as made plans for the annual admin and technical meetings.

Our 10th annual admin meeting (AAM 10) was held, virtually, on July 15, which, in addition to the usual matters of business, included discussion of forward directions for the post-COE CST era as the Center begins to wind down. To facilitate potential new opportunities, a template was established that serves as a ‘past-present-future’ roadmap to graphically illustrate prior and current tasks in each of the research areas and couple this foundation to anticipated future FAA needs. The annual technical meeting (ATM 10) was held, again virtually, on October 28. Skirting around a possible government shutdown and ice storm-induced Zoom outages, we managed to pull off a successful online technical meeting supported by Rigil Corp. The format of making pre-recorded presentations by all PIs available online for viewing ahead of time, followed by a panelist Q/A discussion webinar worked well, and included recorded intros by the students that looped during the breaks. More than 100 individuals representing academia, government and industry – from coast-to-coast, across the Atlantic, and in the southern hemisphere – were in attendance throughout the day-long event.

Although there has been some discussion of extending the COE due to COVID, the existing cooperative agreements all end on August 19, 2022, and research tasks are currently being targeted for completion between December 2021 and May 2022 to allow time for required closeout paperwork to be processed. In any event, we look forward to hosting ATM 11 in late 2021 or early 2022, hopefully with handshakes and hugs again, as a grand finale celebrating a decade of research aimed at paving the way for future commercial space transportation. And here’s to 2021, may the pandemic be receding in the rear-view mirror!

David Klaus, PhD
Professor, Aerospace Engineering Sciences
University of Colorado Boulder
Executive Director, COE CST

COE CST Center of Excellence for Commercial Space Transportation

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 10 Annual Report Executive Summary.

In 2017, the number of COE CST member universities grew to ten. Supplemented by private organizations and individuals as research affiliates, associates and contributors, the total number of organizations participating in the COE CST exceeds 60 in number. The collective effort of these organizations and individuals, including the principal investigators (PIs), students, financial officers, contractors, business women (and men), executives, and administrators, makes the COE CST research possible. They provide matching cash and in-kind contributions, post the extensive technical and financial data for government-required reports, and fundamentally make the overall system function efficiently.

During the first half of the planned ten-year lifetime of the COE CST, operations focused on building the many required relationships (e.g., research, administrative, financial, personal, etc.) between university and government organizations and individuals. Even during the years when the budget of the Center was relatively small, the number of these relationships created a complex network that was as challenging to manage as are COEs more participating organizations and larger budgets. Despite this complexity, the COE CST has successfully emerged as a fully functional, cohesive unit.

Year 6 began the second half of the ten-year program. Starting in 2016, the FAA emphasized raising the COE CST profile with industry, to better familiarize universities with needs of the evolving commercial space marketplace, and to be better understood by the major marketplace actors. The Center began flourishing as the next two years progressed, but then 2018 ushered in tumultuous times for all COEs. Increased administrative oversight on the award of grant funding, combined with leadership changes in and above the COE Program Office, interrupted the cadence of COE CST funding and research. The repercussions and delays caused by these changes were felt throughout the COE CST membership and management. The required COE CST Annual Technical Meetings for years 8 and 9 were both cancelled for funding reasons. Only recently, with the start of 2020, has the sense of stability and operational normalcy returned to our Center, and principal investigators (PIs) and government officials directly involved are all glad to get back to work.

During Year 10, the COE CST entered its final phase of operation. Due to the delays described above, the Center period of performance was extended through August 2022 to ensure the universities' ability to spend the final round of grant funding that was awarded in February 2020, then the global pandemic hit. Government and university processes were interrupted as the entire workforce shifted to telework of some sort, delaying the funding as it made its way through the individual systems and to the PIs. This resulted in students not being hired in time for the summer, and some tasks didn't begin until the fall semester. At the time of this writing, FAA Headquarters is contemplating extending the period of performance of all COEs by 6-12 months to provide universities more time to do their research, accumulate the required matching funds, etc. This means the period of performance of the COE CST may be extended, but we just don't know that yet for sure.

In the meanwhile, amidst all this uncertainty, I want to thank all the COE CST individuals, representing the dozens of participating organizations and institutions, for their patience and continuing support of this research consortium. I cannot thank them enough for their contributions of time and effort. For more information about the content of this report, please visit the COE CST web site (www.coe-cst.org). Please address any questions or corrections to Dr. Ken Davidian (202-267-7214, ken.davidian@faa.gov) or Dr. Karl Garman (202-267-0614, karl.e.garman@faa.gov).

Ken Davidian
Director of Research, FAA Office of Commercial Space Transportation
Program Manager, FAA Center of Excellence for Commercial Space Transportation

INTRODUCTION

This executive summary accompanies a more detailed annual report of the FAA COE CST. The annual report volume will be available on the COE CST web site, www.coe-cst.org. The full report provides a description of the FAA COE CST including its research, structure, member universities, funding, and research tasks, a comprehensive set of presentation charts of each research task, and a comprehensive set of notes and links to recordings from all FAA COE CST teleconferences and face-to-face meetings.

The Executive Summary begins with overviews of the FAA Office of Commercial Space Transportation (the sponsoring organization), the FAA COE Program and the COE CST. The COE CST became operational on August 18, 2010, with nine members. It has subsequently added an additional core university, as well as numerous Affiliate and Associate organizations, representing both academia and industry. Brief introductions and general descriptions are provided for each of the COE CST Member Universities, the Affiliate Members, and the FAA Technical Monitors for the COE CST research tasks. Next, this document describes the overall scope of COE CST research areas, and lists each of the research tasks initiated, conducted and concluded by the COE CST during the tenth year of operation. The report provides summary information about each task in the form of quad charts. The Executive Summary concludes with a listing of the COE CST students, the partnering institutions from industry, the research organizations, and the technical publications delivered during the year.

OVERVIEWS

FAA OFFICE OF COMMERCIAL SPACE TRANSPORTATION

The FAA Office of Commercial Space Transportation (AST) has an important set of responsibilities as described in their mission and defined in the Code of Federal Regulations, Title 51 US Code Subtitle V, Ch. 509. AST's was established to:

- Regulate the U.S. commercial space transportation industry, 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 interests of the United States;
- Encourage, facilitate, and promote commercial space launches and reentries by the private sector;
- Recommend appropriate changes in Federal statutes, treaties, regulations, policies, plans, and procedures; and
- Facilitate the strengthening and expansion of the United States space transportation infrastructure.

FAA CENTER OF EXCELLENCE PROGRAM

The FAA Air Transportation Centers of Excellence (COE) program was established by the Omnibus Budget Reconciliation Act of 1990, PL 101-508, Title IX, Aviation Safety and Capacity Expansion Act. The text of this legislation is provided on the inside back cover of this report.

COEs are intended to be multi-year, multi-disciplinary partnerships of academia, industry, and government to combine world-class resources that will address current and future challenges for the aviation and aerospace communities, including commercial space transportation. The main goals of every COE include research, training & education, and technology transfer & outreach.

The absolute uniqueness of the program partnerships is the mandatory one-to-one matching requirement for every federal dollar granted to a COE university to establish, operate and conduct research. The matching requirement can be satisfied through direct or in-kind contributions from any non-federal funding source, including industry, universities, or state and local government organizations. COE efforts which are jointly supported provide the U.S. citizens a return on their tax dollars. To date, the COE members have generated more than $312M in matching contributions to offset the research costs incurred by the government organizations.

In addition to the COE CST, there are currently five more active FAA COEs, including:

- **The Center of Excellence for Technical Training and Human Performance (TTHP)** (on the web at coetthp.org), was established in 2016. The core focus of the COE for TTHP includes curriculum architecture, content management and delivery, simulation and part task training, human factors, analytics, safety, and program management. Core members include Auburn University, Drexel University, Embry-Riddle Aeronautical University (technical co-lead), Inter American University, Oklahoma State University, Purdue University, Tennessee State University, the Ohio State University, the University of Akron, the University of Oklahoma (technical co-lead), Tulsa Community College, University of Nebraska-Omaha, University North Dakota, University of Wisconsin – Madison, Western Michigan University, and Wichita State University (administrative lead).
- **The Center of Excellence for Unmanned Aircraft Systems (UAS),** aka the "Alliance for System Safety of UAS through Research Excellence" (ASSURE, on the web at www.assureuas.org), was established in 2015. The core focus of the COE UAS includes air traffic integration, airworthiness, control and communication, detect and avoid, human factors, and low altitude operations safety. Core members include Mississippi State University (Lead), Drexel University, Embry-Riddle Aeronautical University, Kansas State University, Montana State University, New Mexico State University, North Carolina State University, Oregon State University, University of Alabama – Huntsville, University of Alaska – Fairbanks, University of California Davis, University of Kansas, University of North Dakota, The Ohio State University, Wichita State University, and Auburn University.
- **The Center of Excellence for Alternative Jet Fuels and Environment (AJFE)**, also known as the "Aviation Sustainability Center, (ASCENT, on the web at ascent.aero), was established in 2013. The core focus areas of ASCENT include alternative jet fuels: feedstock development, processing and conversion, regional supply and refining infrastructure, environmental benefits analysis, aircraft component deterioration and wear, fuel performance testing, environment: aircraft noise and impacts, aviation emissions and impacts, aircraft technology assessment, environmentally and energy efficient gate-to-gate aircraft operations, and aviation modeling and analysis. Core members include Washington State University (Lead), Massachusetts Institute of Technology (Co-lead), Boston University, Georgia Institute of Technology, Missouri University of Science & Technology, Oregon State University, Pennsylvania State University, Purdue University, Stanford University, University of Dayton, University of Hawaii, University of Illinois – Champagne Urbana, University of North Carolina – Chapel Hill, University of Pennsylvania, University of Tennessee, and the University of Washington.
- **The Center of Excellence for General Aviation,** aka the "Partnership to Enhance General Aviation Safety, Accessibility and Sustainability" (PEGASAS, on the web at www.pegasas.aero), and established in 2012. Major areas of focus include the enhancement of general aviation safety, accessibility, and sustainability by partnering the FAA with a national network of world-class researchers, educators, and industry leaders. Core members include Purdue University (lead), Florida Institute of Technology, Georgia Institute of Technology, Iowa State University, the Ohio State University, and Texas A&M University.
- **The Joint Center for Advanced Materials (JAMS),** in operation since 2003, works closely with industry and government agencies on safety and certification initiatives that are related to existing and near- and long-term applications of composites and other advanced materials and manufacturing processes to aircraft applications, including large transport commercial aircraft, general aviation and unmanned aircraft system products. The overall goal is to ensure safe and reliable use of these materials in aircraft applications. Lead universities are Wichita State University and the University of Washington supported by University of Utah, Oregon State University, Florida International University, and University of California, San Diego.

Other COEs established by the FAA, who have completed their ten-year agreements and phased out of operation, include:

- Joint Center for Computational Modeling of Aircraft Structures, 1992 to 1996.
- The Center of Excellence for Airport Technology (CEAT), established 1995.
- The National COE for Aviation Operations Research (NEXTOR), operated from 1996 to 2008.
- The Airworthy Assurance COE (AACE) operated from 1997 to 2007.
- The COE for General Aviation Research (CGAR), in operation from 2001 to 2013.
- The Partnership for Aircraft Noise & Aviation Emissions Mitigation Research (PARTNER), in operation from 2003 to 2014.
- The Airliner Cabin Environment and Intermodal Research (ACERite) Center, in operation from 2004 to 2014.

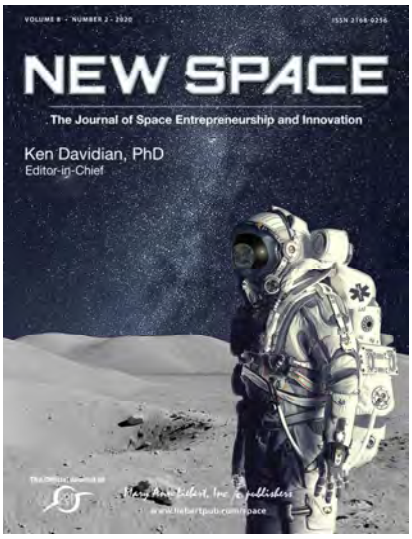
FAA CENTER OF EXCELLENCE FOR COMMERCIAL SPACE TRANSPORTATION

Below is a quick look at the major highlights and special mentions of COE CST year 10. The basic metrics of COE CST performance has also been updated to reflect the most recent events and activities.

COE CST YEAR 10 HIGHLIGHTS

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

- **The Tenth Annual Administrative Meeting (AAM10)** was held virtually on July 15, 2020. Administrative agenda items included a review of the COE by-laws and management plan, the status of quarterly reporting and close-out activities for all research tasks, planning for the upcoming Annual Technical Meeting (ATM10), and a discussion of post-COOE CST operations. Technical planning discussions focused on the AST research road map, a strategic planning exercise that encompasses the research area typology, the research goals corresponding to AST's safety and promotional missions, identification of the major milestones for each research project, and the relationships between the milestones across the entire map.
- **The Tenth Annual Technical Meeting (ATM10)** was conducted virtually as a half-day event on Wednesday, October 28. Videos of full presentations (10-15 minutes) and executive summaries (1-2 minutes) were available for viewing prior to the event, and panels were held for each research area on the day of the event. The videos are still available for viewing from the COE CST web site, or on the COE CST YouTube channel.
- **Process Research Workshop** – Dr. Andy Aldrin (FIT) conducted a workshop on December 10, 2020, focusing on the data collection methods of research tasks 380-NMSU, 395-FIT, and 402-FIT. Management scholars from outside the space community were invited to provide insights and answer questions about process research concepts and data collection.
- ***New Space*** (the official journal of the COE CST) completed its eighth year, featuring a wide range of topics pertaining to non-governmental aspects of space activities. *New Space* volume 8, issue 2 included a special section of COE CST research publications, one of which was featured on the cover (shown right).



COE CST YEAR 10 METRICS

Every year, COE CST performance is tracked through the measurement of basic metrics, including the number of active research tasks (a function of the level of funding available from the FAA AST), the number of principal investigators (an indicator of COE CST's research diversity), the number of students (an indicator of COE CST's impact), the number of publications (an indicator of the degree of COE CST knowledge creation). The number of unfunded tasks, research partners, industry partners, affiliate members, and associate members, are all a function of how well member universities are partnering with non-member research organizations. Finally, the amount of funding is provided for each fiscal year.

Year 10 of COE CST operation accounted for 22 principal investigators (PIs) and 34 students conducted 20 research tasks, resulting in 16 technical publications. This Executive Summary presents summary charts (aka "quad charts") for each research task, and provides a complete list of students and the resulting publications.

COE CST Year	1	2	3	4	5	6	7	8	9-10
Fiscal Year(s)	10	11-12	13	14	15	16	17	18	19
Active Tasks	34	24	28	28	36	22	14	27	20
Unfunded Tasks	34	22	22	11	6	5	2	5	14
Principal Investigators	27	28	29	25	31	22	21	22	22
Students	31	37	55	47	61	28	23	38	34
Publications	0	38	28	22	29	19	36	23	16
Affiliate Members	0	1	6	6	6	6	8	10	14
Associate Members	-	-	-	3	6	3	3	8	8
Funding Profile ($M)	2.0	2.4	1.1	1.1	1.0	1.0	1.4	1.6	2.1

Since the beginning of the Center, the annual administrative costs average just under 18% of the total budget. The annual administrative costs (expressed as a percentage of total budget) were removed from the table because of the extreme variation year-on-year, stemming from the timing of actual administrative funding allocations as opposed to the even distribution of administrative expenses (e.g., paying for three bi-annual meetings from a single fiscal year's budget, instead of two, or the absence of funding in a given year).[1]

FAA AST Technical Monitors

FAA AST Technical Monitors (TMs) are the links between FAA's research requirements and the work being performed by COE CST member universities. Below is a listing of the FAA COE CST TMs who contributed to the research efforts of the COE CST in Year 10:

- Dr. Ken Davidian
- Mr. Nickolas Demidovich
- Mr. Steph Earle
- Dr. Karl Garman
- Mr. Henry Lampazzi
- Dr. Paul Wilde

COE CST MEMBER ORGANIZATIONS

COE CST member organizations include four categories of organizations: Core Members, Collaborating Members, Affiliate Members, and Associate Members. Core Member universities include the Baylor College of Medicine (BCM), Florida Institute of Technology (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 the University of Texas Medical Branch at Galveston (UTMB). Collaborating Members are those universities conducting research under sub-grant to a Core Member university.

CORE AND COLLABORATING MEMBERS

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. As a single entity, the COE CST bring

[1] All information presented in this report is accurate as of the date of publication (December, 2020). Any corrections identified after this date will be updated in the digital version of this report, available on the COE CST web site.

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. Combined, the universities bring a large number of organizations (government, industry, and academic) into the COE CST network as research partners.

BAYLOR COLLEGE OF MEDICINE (BCM)

Baylor College of Medicine (BCM) is a health sciences university and home to the Center for Space Medicine (CSM). At the forefront of space biomedical research, education and aerospace medicine, BCM CSM is the lead institution for the NASA-supported Translational Research Institute for Space Health. Major subcontractors are Caltech and MIT. CSM offers a unique and popular four-year Space Medicine Pathway for medical students and supports graduate and postgraduate training opportunities in space medicine. The mission, programs and faculty of CSM align well with the FAA COE CST. More information can be found on the web at www.bcm.edu.

FLORIDA INSTITUTE OF TECHNOLOGY (FLORIDA TECH)

Florida Institute of Technology performs doctoral research and undergraduate and graduate education through its six academic colleges and schools with emphases on aviation, aeronautics, science, technology, engineering and mathematics. Research at Florida Tech focuses on mechanical and aerospace engineering, software and hardware resilient systems, biomedical engineering, space resource utilization, corrosion and space-related engineering, cloud physics and space weather, space traffic management and launch operations, vehicle and payload analysis and design, thermal systems, propulsion, and commercial space industry viability. Florida Tech serves as the primary COE CST liaison to industry for research partnership, and affiliate membership to the government, the private sector as well as academia. Historically known as FIT, Florida Tech's preeminent research centers and institutes include the Buzz Aldrin Space Institute, the FAA Center of Excellence for General Aviation Research (PEGASAS), the COE CST, the School of Human-Centered Design, Innovation & Arts, the Harris Institute for Assured Information, and more. More information can be found on the web at www.fit.edu.

FLORIDA STATE UNIVERSITY (FSU)

FSU brings a range expertise and unique infrastructure and unparalleled testing facilities in many areas relevant to the COE CST. These include but are not limited to: cryogenics, thermal management, vehicle aerodynamics and controls, sensors, actuators, system health monitoring and high-performance simulations including multi-physics mechanics and flow surface interactions. We have substantial expertise in simulating, experimentally and numerically, the Vehicle Launch Environment and the associated challenges in aeroacoustics and aero-structures. More information can be found on the web at www.fsu.edu.

NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY (NMT)

NMT is a science, math and engineering university that has more than a dozen research divisions that work with private industry, government agencies and other universities. The research divisions include the Petroleum Research and Recovery Center, the Institute for Complex Additive Systems Analysis, the Energetic Materials Research Testing Center, the world's largest lending library of seismology equipment, the Magdalena Ridge Observatory, the National Center for Genome Resources, the National Cave and Karst Research Institute, and the Langmuir Laboratory for Atmospheric Research. More information can be found on the web at www.nmt.edu.

NEW MEXICO STATE UNIVERSITY (NMSU)

NMSU and its Physical Sciences Laboratory have led space and aerospace research in areas of suborbital investigations from the time of Robert Goddard and Werner von Braun to the current era of commercial sub-orbital space transportation with Spaceport America and its operators, Virgin Galactic. SpaceX and UP Aerospace. New Mexico Space Grant Consortium, the 21st Century Aerospace Space Group and related aerospace research focuses on annual access to space for student and faculty experiments, unmanned aerial vehicles, and cube-satellite development. More information can be found on the web at www.nmsu.edu.

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. More information can be found on the web at www.stanford.edu.

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. More information can be found on the web at www.ucf.edu.

UNIVERSITY OF COLORADO AT BOULDER (CU BOULDER)

CU offers the COE CST their experience in spacecraft life support systems and habitat design, spaceflight risk assessment, human factors engineering analysis, payload experiment integration, and expertise in space environment and orbital mechanics. More information can be found on the web at www.colorado.edu.

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. More information can be found on the web at www.ufl.edu.

UNIVERSITY OF TEXAS MEDICAL BRANCH (UTMB)

UTMB has a long history of medical support and human spaceflight physiological research with NASA. UTMB doctors have been involved in the commercial orbital and suborbital spaceflight industry, supporting space flight participant visits to the ISS, and preparing passengers and crew for suborbital space flights. More information can be found on the web at www.utmb.edu.

Two universities are currently working with COE CST member universities as “subcontractor researchers.” These universities are listed and described below.

UNIVERSITY OF SOUTHERN CALIFORNIA (COLLABORATOR TO FLORIDA TECH)

The University of Southern California, Lloyd Grief Center for Entrepreneurial Studies, within the Marshall School of Business, offers a wide range of courses in entrepreneurship designed for students who want to start or own a high-growth business, join an emerging business or

participate in an entrepreneurial venture in a mature corporation (intrapreneurship). Students can develop an entrepreneurial mindset, gain confidence that they can be successful entrepreneurs, learn about the entrepreneurial process and enhance their conceptual and practical skills to pursue new business opportunities. Wide exposure is given to all types of entrepreneurs and industries. The highly experiential courses span the entrepreneurial process from opportunity discovery to venture initiation, growth and exit, and are designed to teach relevant frameworks and theory as well as to develop an entrepreneurial mindset and skills through hands-on application. The Greif Center also offers co-curricular programs such as venture competitions, speaker events and a new venture incubator, and it actively provides contact with and support for its alumni. More information can be found on the web at www.marshall.usc.edu/departments/lloyd-greif-center-entrepreneurial-studies.

UNIVERSITY OF TEXAS AT AUSTIN (UT AUSTIN, COLLABORATOR TO NMSU)

The Cockrell School of Engineering at The University of Texas at Austin is a top-ranked epicenter of engineering education, and knowledge creation and distribution. Comprised of renowned educators, researchers and thought leaders, the Cockrell School addresses the grand challenges of the world, drives economic progress and improves quality of life. The Cockrell School educates future engineering leaders who think creatively, work collaboratively, and push technological boundaries; develops innovative solutions through groundbreaking research; and improves lives throughout the world by leveraging the school's entrepreneurial ecosystem and partnerships with industry to translate research into practice. More information can be found on the web at www.engr.utexas.edu/about.

Affiliate & Associate Members

With a limited budget and ever-tightening budget pressures on all federal agencies, the COE CST sponsoring organization, FAA AST, cannot provide funding to all the research universities and organizations that deserve it. In recognition of all the meaningful work being done outside the COE CST membership, two different categories of membership were developed to encourage additional members into the COE CST without incurring any additional budget obligations. The two different categories are called Affiliate and Associate Memberships. Each of these is described below.

AFFILIATE MEMBERS

To become a COE CST Affiliate Member, an organization must (a) be conducting research that is self-funded, or is funded by some non-government organization, that fits within the commercial space transportation road map framework (discussed below), and that can be openly disclosed at COE CST public meetings, such as the Annual Technical Meeting (ATM), (b) partner with one of the current COE CST member universities who will act as the Affiliate's 'host,' and (c) voluntarily pay for all costs associated with attendance at the ATM. In exchange for these commitments, the COE CST will (a) welcome the organization as an Affiliate Member, (b) provide the Affiliate Member with "podium time" at the ATM, equal to that provided to any full COE CST member. The strategy of Affiliate Membership is to gain benefits derived from being part of the overall COE CST research network. As the network grows, so do the possible benefits that can be gained. Florida Tech serves as the primary COE CST liaison to industry for research partnerships, and Associate and Affiliate memberships with government, the private sector, and academia.

To date, there have been a number of COE CST Affiliate Members. Some joined in the early years of COE CST operation, provided and completed their research, and have been inactive in recent years. Some have been active since the program began, and some are just now "knocking on our door," ready to become members in the near future. Below is a brief description of these Affiliate Member organizations.

CARMINATI LAW PLLC (HOSTED BY CU BOULDER)

Carminati Law, PLLC, is a Denver-based law firm whose practice includes space law. Its head, Dr. Maria-Vittoria Carminati, is head of the American Bar Association's space law committee. She obtained her JD from the University of Houston, and her LLM in space, cyber, and telecommunications law from the University of Nebraska-Lincoln. More information can be found on the web at legaltalknetwork.com/guests/dr-maria-vittoria-carminati.

DANISH AEROSPACE COMPANY (HOSTED BY BCM)

Danish Aerospace Company (DAC) is a high-tech company operating in the area of advanced medical instrumentation and other engineering fields primarily within space applications. Their products are based on many years of specialized research and development. These consist of developing, integrating, and applying new as well as established medical technologies to the challenges of functioning and remaining reliable in space. These products and services bring the potential of space research and experience from space operations down to Earth for the benefit of all Mankind. More information can be found on the web at danishaerospace.com/en.

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY (ERAU, HOSTED BY NMSU)

Embry–Riddle Aeronautical University (ERAU) is a private university offering associate through doctoral degrees in arts and sciences, aviation, business, engineering, computer programming, cyber security and security and intelligence. It is the largest, fully accredited university system specializing in aviation and aerospace, with main campuses in Daytona Beach, Florida and Prescott, Arizona. More information can be found on the web at erau.edu.

ETC NASTAR (HOSTED BY UTMB)

Environmental Tectonics Corporation's (ETC) National Aerospace Training and Research (NASTAR) Center (est. 2007) is the premier commercial air and space training, research, and educational facility. It combines state-of-the-art flight simulation with physiology-based courseware to optimize human performance in extreme environments. ETC's NASTAR Center is unique in that it serves as the only non-government (commercial use) facility for the application of acceleration and G force exposure in the world and specializes in replicating high-performance flight environments and characteristics of aerial vehicles. This exclusive capability is ideal for safely modeling nominal and off-nominal (emergency) trajectories and evaluating human performance for military, commercial aviation, and spaceflight clients. The NASTAR Center actively collaborates with numerous agencies including NASA, FAA, JAA, etc. to promote safety in flight. More information can be found on the web at www.etcusa.com and www.nastarcenter.com.

EXOS AEROSPACE SYSTEMS & TECHNOLOGIES (HOSTED BY NMSU)

EXOS Aerospace Systems & Technologies, Inc. has taken the skills from more than a decade of practical lessons learned, and millions of dollars' worth of development and flight experience gained by their team, and moved into the commercial space race, ahead of the game. Over the past decade, the team at EXOS has led the way to some of the most impressive private, commercial, reusable rockets designs and concepts in the world today. They have developed, flown and retrieved for re-use, rockets that are reliable, reusable, better for the environment and easier on your budget. They have successfully designed, built and flown rocket engines used in manned flight. They have fulfilled multiple contracts with NASA. Through all of this, the EXOS team has developed and tested over a hundred rocket engines and dozens of flying vehicles. EXOS is a leading developer and operator of reusable space vehicles. More information can be found on the web at exosaero.com.

IMMORTAL DATA (HOSTED BY NEW MEXICO TECH)

Immortal Data is targeting the aerospace field, where ruggedness, reliability and high data rates for bulk data are more important than fancy GUIs. They are designing the central nervous system of a ship or engines under test or in harsh, real world environments containing huge volumes of high rate data. Accomplishing this means that, for the most part, they do not sell software on its own; they sell it as a pre-installed hardware/software appliance, preferably as part of a systems solution. More information can be found on the web at www.immortaldata.net.

MCGILL UNIVERSITY (HOSTED BY FLORIDA TECH)

McGill University's Institute of Air and Space Law (IASL) is the world's premier academic setting for teaching and research in the dual disciplines of international air law and space law. Having celebrated its 65th year of continuous existence in 2016, the Institute is now on course to consolidate and enhance its record of achievement in the five years leading to its 70th anniversary in 2021, the same year that McGill University itself will turn 200. More information can be found on the web at www.mcgill.ca/iasl/.

THE OHIO STATE UNIVERSITY - BATTELLE CENTER FOR SCIENCE, ENGINEERING, AND PUBLIC POLICY (HOSTED BY FLORIDA TECH)

The Battelle Center was established at the John Glenn College of Public Affairs in 2006 through the generosity of Battelle, the world's largest non-profit research and development organization and long-time neighbor to The Ohio State University. Originally the Battelle Center focused on improving education in science, technology, engineering, and mathematics disciplines. In 2011, it pivoted toward the challenges of encouraging innovation and economic development. In 2016, the partnership between Battelle and the Glenn College was strengthened with the inclusion of Ohio State's College of Engineering in the center. Today, these organizations and Ohio State's Government Affairs Office provide advice and support to the center's director. More information can be found on the web at: www.battellecenter.org.

PRINCETON SATELLITE SYSTEMS (HOSTED BY NMT)

Princeton Satellite Systems, Inc. is a small company developing advanced technology for the aerospace and energy sectors. Their agility and focus enable them to rapidly develop innovative solutions to a wide range of aerospace and energy problems. Their commercial hardware and software products enable their customers to pursue the same types of demanding, state-of-the-art applications. Their core values include a dedication to learning and an emphasis on innovation. More information can be found on the web at www.psatellite.com.

PROJECT POSSUM (HOSTED BY FLORIDA TECH)

Project PoSSUM (Polar Suborbital Science in the Upper Mesosphere) is a 501(c)(3) astronautics research and education program studying our upper-atmosphere and its role in our changing global climate. More information can be found on the web at projectpossum.org.

SOLSTAR (HOSTED BY NMSU)

Solstar is the leading commercial satellite communications company pioneering technology to create a 'Space Wide Web'. Our space communicators and commercial internet/phone service connect space researchers with convenient, real-time interaction with their WiFi-enabled payloads and flight participants on-board spacecraft during flight. More information can be found on the web at www.solstarspace.com.

SOVARIS AEROSPACE (HOSTED BY CU BOULDER)

Sovaris Aerospace is among those leading the advancement of personalized medicine in human spaceflight, with a focus on suborbital, LEO, Lunar, and Mars. As a clinical support organization, Sovaris applies the tools of complex molecular analytics to develop personalized countermeasures that are tailored to each individual entering any spaceflight environment. Our team has refined these methods via deployment with NASA, military Special Forces, S.W.A.T., wilderness medicine, high altitude ascent, Olympic training environments, and others. As a clinical research organization, the Sovaris team incorporates genomics, epigenomics, transcriptomics, proteomics, metabolomics, and microbiomics into the study of humans in space. This includes pharmacogenomics applied to improving the safety of drugs used in space. For instance, Sovaris has been active in translating the NASA Twins Study data into active countermeasures for astronauts and flight surgeons. Sovaris has also been active in advancing a systems engineering approach to personalized medicine focused on the developing suborbital and Lunar missions. More information can be found on the web at www.sovarisaerospace.com.

UNIVERSITY OF NORTH FLORIDA (HOSTED BY NMSU)

Established in 1972, the University of North Florida has grown significantly in size and prominence - particularly in recent years. Today, UNF has an annual economic impact of more than $1 billion and works closely with community leaders and officials to continue to enhance the significant role it plays in the region. The UNF campus, which includes a nature preserve, beautiful lakes and nature trails, is located between downtown Jacksonville and the Atlantic Ocean in a bustling section of Jacksonville. It includes award-winning buildings filled with state-of-the-art equipment that support innovation and excellence. The University is home to six colleges, and routinely ranks high for quality and value on national lists published by U.S. News & World Report, Forbes, the Princeton Review, Wall Street Journal and more. UNF holds the prestigious Carnegie Classification for Community Engagement recognizing our commitment to our community and beyond. More information can be found on the web at www.unf.edu.

UNIVERSITY OF TEXAS PERMIAN BASIN (UTPB, PENDING)

As a regional, comprehensive institution, The University of Texas Permian Basin serves a diverse community of students from the region, the state, and beyond. Through excellence in student-centered teaching, learning, research, and public service, the University cultivates engaged citizens and impacts lives while advancing the technology and public interests of West Texas. The University aspires to be a vibrant, student-focused center of excellence for learning, culture, and economic development — preparing students for leadership and success in a complex and changing world. More information can be found on the web at www.utpb.edu.

ASSOCIATE MEMBERS

Associate Members are much more loosely associated with the COE CST, but their contributions can be very significant. During the eighth year of operation, the COE CST was proud to have the following institutions as Associate Members.

ASTM INTERNATIONAL

Committed to serving global societal needs, ASTM International positively impacts public health and safety, consumer confidence, and overall quality of life. They integrate consensus standards, developed with our international membership of volunteer technical experts. Over 12,000 ASTM standards operate globally. Defined and set by

ASTM International, the standards improve the lives of millions every day. More information can be found

expanded uses of technologies to solve our sponsors' problems. More information can be found on the web at www.mitre.org.

NASA AMES RESEARCH CENTER

NASA Ames Research Center, one of ten NASA field enters, is located in the heart of California's Silicon Valley. For more than 75 years, Ames has led NASA in conducting world-class research and development in aeronautics, exploration technology and science aligned with the center's core capabilities. More information can be found on the web at www.nasa.gov and www.nasa.gov/ames.

Map of COE CST Members, Subcontractor Universities, and Affiliate and Associate Members.

Other Supporting Organizations

The following organizations supported the COE CST Member Universities over the lifetime of the center:

- AIAA
- ATK
- Bachner Consultants, Inc.
- Ball Aerospace
- Bryce Space and Technology (formerly The Tauri Group)
- CEAVCO
- Cimmaron Software Services Inc.
- CSSI Inc.
- Digital Solutions
- Dynetics, Inc.
- Futron
- Jacobs Technology Inc.
- Lockheed Martin Space Systems Company
- National Space Grant Foundation
- New Mexico Spaceport Authority
- NMSU Space Development Foundation
- Orbital Sciences Corporation
- Orion America Technologies
- Pennsylvania State University
- Qinetiq
- SATWEST
- Scitor Corporation
- Secor Strategies
- Simpson College
- Space Florida
- Space News
- Space Systems/Loral
- Space Works Enterprises
- Spaceport America Consultants
- Spaceport Sweden
- Spaceworks
- The Boeing Company
- United Launch Alliance
- Webster University
- Wyle Integrated Science and Engineering Group
- XCOR Aerospace, Inc.

COE CST RESEARCH AREAS AND TASKS

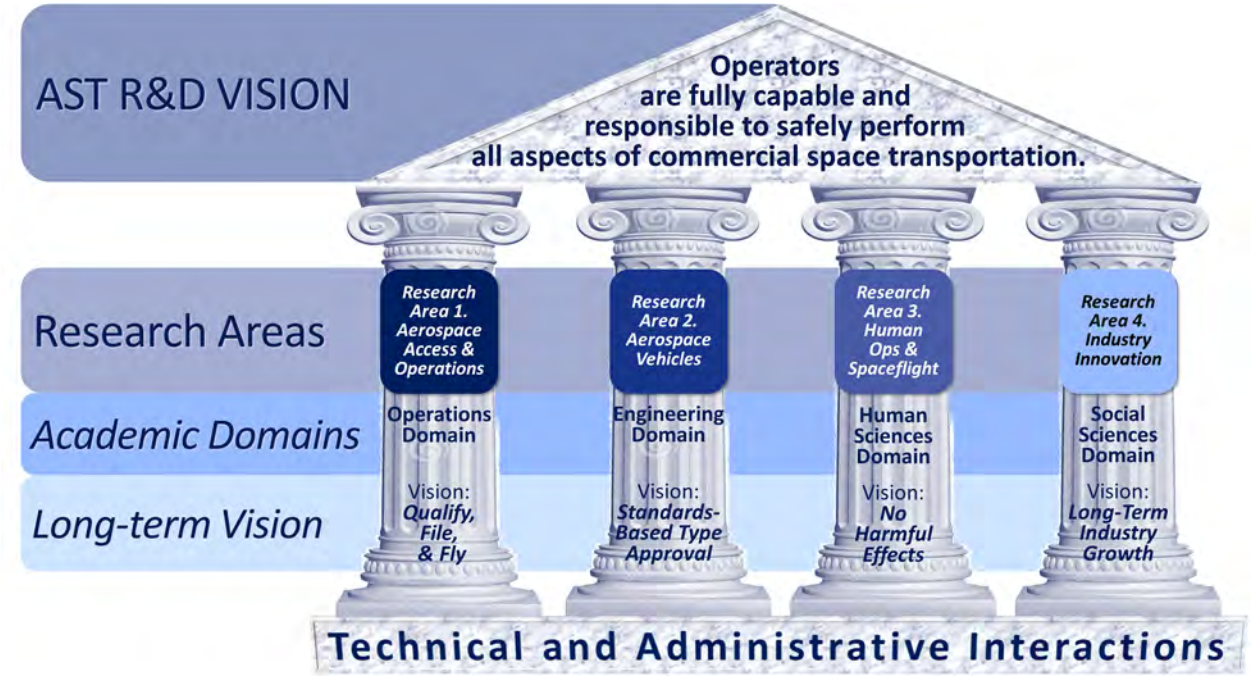
All research activity sponsored by the FAA Office of Commercial Space Transportation is directed by the following goal statement: “Operators are fully capable and responsible to safely perform all aspects of commercial space transportation.” To achieve this goal, COE CST activity is defined by a framework defining different academic areas for every research task. Generally speaking, the four research areas encompass four distinct research domains: operational activities, the physical and engineering sciences, the biological and medical sciences, and the social sciences. A Commercial Space Transportation Research Road Map, last updated in 2015, is available on the web at www.coe-cst.org, and was created to provide a detailed framework within each of these discipline areas. This section provides a brief introduction to the four research areas, identifies the goals associated with each, and then lists the tasks that were conducted in each research area during the eighth year of COE CST operation.

COE CST RESEARCH AREAS

As mentioned above, the research conducted within FAA AST is broken into four major disciplines. Each discipline is identified by a distinct research theme: Aerospace Access & Operations, Aerospace Vehicles, Human Operations & Spaceflight, and Industry Innovation). Each of these research areas is divided into programs, and these are further divided into projects, topics, and tasks. The number of tasks conducted in a given program can vary from year to year, and research is not necessarily conducted in all programs every year. Some research projects may have some number of tasks every year, and other projects may have never had a research task funded over the entire life of the COE CST. FAA AST priorities are considered prior to making funding decisions.

COE CST RESEARCH GOALS

Each research area has multiple goals, and these have been revisited recently. In FY17, research goals have been identified for each research area that correspond to each of the two AST mission goals (i.e., public safety, or industry promotion).



1. AEROSPACE ACCESS & OPERATIONS

- **Public Safety Goals:** (1) Improved analytical and computational methods to evaluate safety of uninvolved public and property. (2) Situational awareness and understanding of risk posed by resident space objects.
- **Industry Promotion Goals:** (1) Safe and equitable sharing of the NAS by air and space transportation operators, with minimal disruption caused by commercial space traffic (outbound and inbound). (2) Improved spaceport interoperability and development of necessary spaceport industry infrastructure resources.

2. AEROSPACE VEHICLES

- **Public Safety Goal**: Improve vehicle safety and risk analyses and management, including knowledge of all safety-critical components and systems of the space vehicles and their operations.
- **Industry Promotion Goal**: Improve the manufacturability, assembly, and operational efficiencies of space transportation vehicles, systems, and subsystems.

3. HUMAN OPERATIONS & SPACEFLIGHT

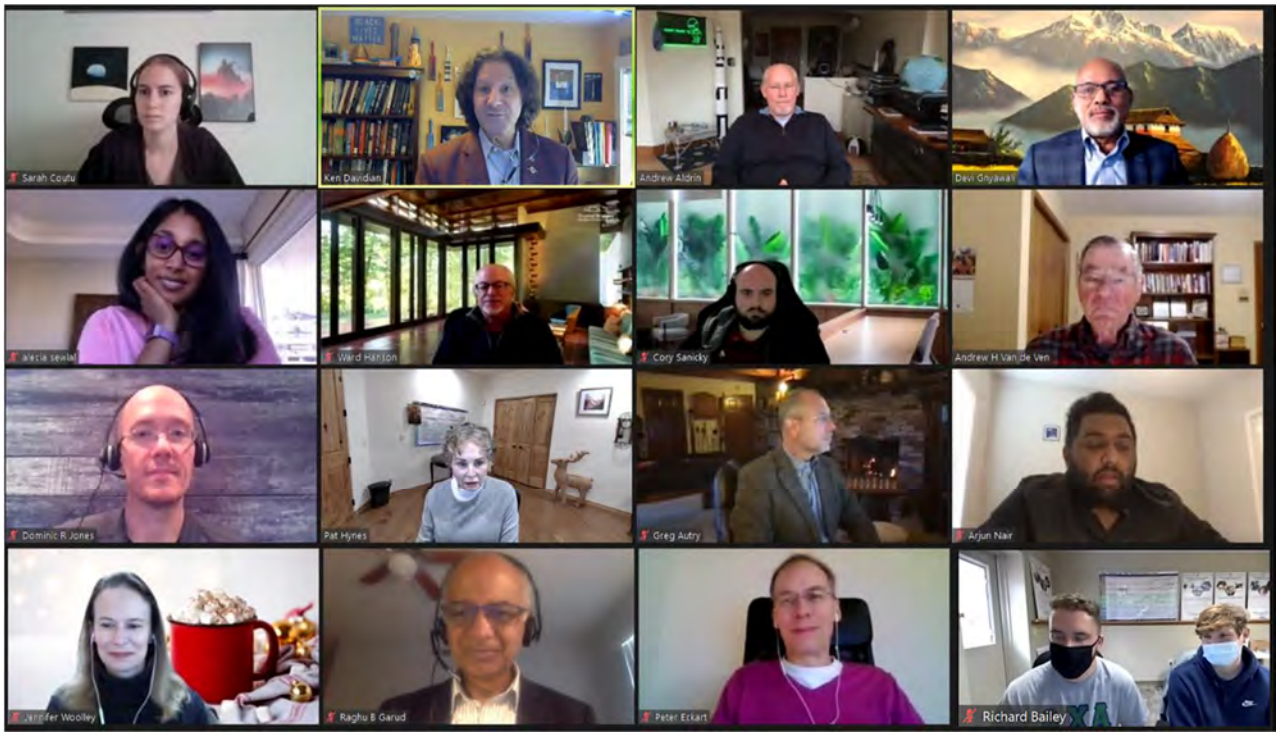
- **Public Safety Goal**: Identification and reduction of avoidable risks of human spaceflight.
- **Industry Promotion Goal**: Facilitate the continuous improvement of the operational safety of human-carrying vehicles (during both launch and reentry) and spaceports.

4. INDUSTRY INNOVATION

- **Public Safety Goal**: Develop improved criteria for evaluating public safety, such as performance-based requirements for the protection of public property and critical assets.
- Industry Promotion Goals: (1) Encourage the growth of evolving space industry sectors through relevant economic, legal, legislative, regulatory, and market analyses & modeling. (2) Support effective policy decision-making in the accomplishment of the dual regulatory and promotional missions of FAA AST. (3) Provide a better understanding of the relationship of governmental policy, innovation adoption, and industry growth.

Process Research Workshop Brings Leading Management Scholars to COE CST

Below is a screenshot of participants at the December 10, 2020 process research methods workshop.



YEAR 10 RESEARCH TASKS

As has been the case in every Annual Report Executive Summary since 2010, COE CST research tasks are listed below in all four research areas, active during the current calendar year (in this case, 2020), conducted by member universities, Affiliate, and Associate members. Unlike previous reports, however, this list includes three research tasks that were conducted by AST via contract, and not through the COE CST. AST has contracted out research tasks in situations where the purpose is to help AST fulfill its safety mission, and when the needs are urgent, requiring firm deadlines and schedules of deliverables. These are contractual conditions that do not apply to research grants of any kind. The inclusion of contractor research for the first time is AST's attempt to provide a more comprehensive picture of the research conducted.

Details of each research task are shown in quad charts that follow. Please note that research tasks are frequently referred to by their task number, because the titles listed below and the titles given on the summary quad charts may differ slightly. Three administrative tasks, active in 2020, are not listed below.

1. Aerospace Access & Operations

- **186-SU**. Space Environment Meteoroid and Orbital Debris Modeling & Prediction, Dr. Sigrid Close
- **367-CU.** CubeSat Cluster Deployment Tracking, Dr. Penina Axelrad
- **371-UTA**. Ontology-based Space Object Database, Dr. Moriba Jah (Hosted by NMSU)
- **372-CU**. Resident Space Objects, Dr. Dan Scheeres
- **375-DLR.** Interoperable Air and Space Traffic Management, Mr. Sven Kaltehäuser (Associate Member)
- **397-FIT.** Measurements of Thunderstorm Electrical Parameters, Dr. Amitabh Nag
- **399-UCF.** Efficient Computation of Space Object Probability of Collision, Dr. Tarek Elgohary

2. Aerospace Vehicles

- **241-FSU.** High Temperature, Optical Sapphire Pressure Sensors, Dr. Billy Oates
- **253-UCF.** Ultra-high Temperature Composites Thermal Protection Systems, Drs. Jan Gou & Jay Kapat
- **311-UCF.** Advancement of LED-Based Hazardous Gas Sensors for Space Applications, Dr. Subith Vasu
- **323-NMT.** Structural Health Monitoring Framework, Dr. Andei Zagrai, Mr. Dale Amon
- **325-FSU.** Optical Measurements of Rocket Nozzle Thrust and Noise, Drs. Rajan Kumar, Farrukh Alvi, Jonas Gustavsson, Michael Sheehan
- **377-NMT.** Nitrous Oxide Composite Case Testing, Drs. Bin Lim & Andrei Zagrai
- **406-ARCTOS.** Aircraft Vulnerability Testing and Modeling, Mr. Ryan Schnalzer (AST Contractor)
- **407-ARCTOS.** Conditional Risk Investigation, Dr. Wije Wathugala (AST Contractor)
- **410-ARCTOS.** Improved Population Clustering Follow-up, Dr. Wije Wathugala (AST Contractor)

3. Human Operations & Spaceflight

- **396-CU.** Mapping Life Support System Functions and Technologies, Dr. David Klaus
- **398-FIT.** Human Input Systems, Dr. Tom Eskridge
- **400-UTMB.** Support of Commercial Space Occupational Medicine Health Standards, Dr. Ed Powers

4. Industry Innovation

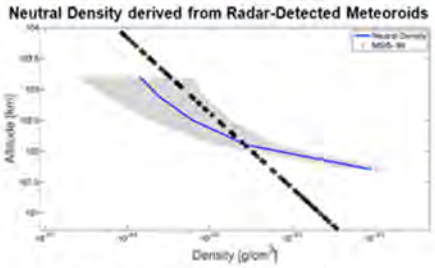
- **358-FIT.** Workshops on Industry Viability and Research, Dr. Andy Aldrin
- **378-USC.** Commercial Space Research Center Initiative, Dr. Greg Autry (Hosted by FIT)
- **380-NMSU.** Spaceport Operations Online Reference Guide, Dr. Patricia Hynes
- **395-FIT.** Emerging Industry Dynamics: Small Satellite Launch Vehicle, Dr. Andy Aldrin
  402-FIT. Emerging Industry Dynamics: Satellite Constellations, Dr. Andy Aldrin (combined with quad chart for 395-FIT)

186. Space Environment Meteoroid And Orbital Debris Modeling & Prediction

PROJECT AT-A-GLANCE
- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR: Dr. Sigrid Close
- CO-INVESTIGATOR: Dr. Nicolas Lee
- STUDENT(S): Lorenzo Limonta

RELEVANCE TO COMMERCIAL SPACE
- LEO spacecraft are routinely struck by human-made (space debris) and natural (meteoroids) impactors
- Characterizing impactor population can help predict threats to launch and operations of LEO spacecraft

STATEMENT OF WORK
- Improve probability estimates of space debris and meteoroids threats by characterizing their populations
- Determine the meteoroid bulk density function, identify scattering patterns based on models, and determine neutral densities using meteoroids
- Filtering methods for larger satellite constellations, determine debris propagation using near real time density data
- Combine above into a new threat assessment model



STATUS
- Developed neutral density determination algorithm
- Improved ablation models to determine ionization efficiency
- Correlated ionization probability with luminous efficiency
- Refined FDTD scattering model

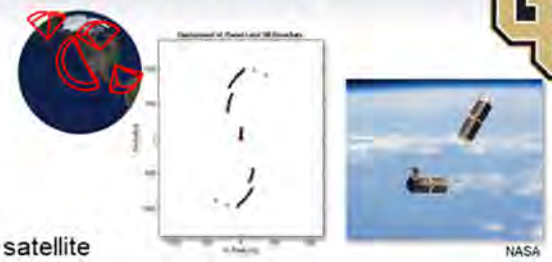
FUTURE WORK
- Improve fragmentation and ablation models
- Orbit determination algorithms
- Develop probabilistic models for risk assessment

367. Cubesat Cluster Deployment Tracking

PROJECT AT-A-GLANCE
- UNIVERSITY: University of Colorado Boulder
- PRINCIPAL INVESTIGATOR: Dr. Penina Axelrad
- STUDENT RESEARCHERS: Ms. Laura Davies
  Dr. John Gaebler (PhD 2020)

RELEVANCE TO COMMERCIAL SPACE
- Accelerates and improves orbit determination and satellite identification in large-scale CubeSat deployments
- Supports decision-makers engaged in regulatory reform by quantifying performance impacts of different tracking strategies

STATEMENT OF WORK
- Create realistic deployment scenarios including anomalies
- Establish baseline filter performance and quantify aspects of deployment strategy that delay or prevent successful tracking
- Model and integrate enhanced ground tracking measurements, and on-orbit measurements from deployer
- Develop concept for CubeSat flight experiment
- Recommend practical CubeSat cluster deployment and observation strategies for improved tracking



STATUS
- Work by J. Gaebler established effective estimation filters and identify management approach (3 journal articles)
- Undergraduate project teams designed and partially built system for in-situ measurements on deployer
- Current work focused on identifying characteristics of objects that limit performance of cluster tracking

FUTURE WORK
- Introduce anomalies and new measurement types
- Develop deployment and tracking recommendations

371. Ontology-based Space Object Database

PROJECT AT-A-GLANCE

- UNIVERSITY: University of Texas at Austin
- PRINCIPAL INVESTIGATOR(S): Dr. Moriba Jah, Maria Esteva, Amit Gupta
- STUDENT(S): Shiva Iyer, Nevan Simone. Kartik Nagpal

RELEVANCE TO COMMERCIAL SPACE

- Big data science and analytics solution to space traffic management (STM)
- Provide a global open and accessible orbital safety service so commercial space activities can thrive

STATEMENT OF WORK

- Develop, implement a STM/orbital safety data lake
- Create an online searchable digital document collection
- Motivate "citizen science" for sensor/telescope data
- Leverage blockchain technology for authentication/identification, and transparent transaction records
- Collect open source software (e.g., GMAT, Orekit, Tensor Flow) to support and enable STM and orbital safety analyses and products

Space Object and Event Behavior

STATUS

- Autonomous retrieval and processing of multiple information sources.
- Knowledge graph database accessible at http://astria.tacc.utexas.edu/AstriaGraph
- Developed queries for monitoring anthropogenic space object behaviors

FUTURE WORK

- Incorporating behavioral and social sciences for cultural context
- More realistic uncertainty quantification
- Expand query use cases (e.g. anthropogenic space object registry

372. Resident Space Object System Mechanics

PROJECT AT-A-GLANCE

- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. Dan Scheeres
- STUDENT RESEARCHERS: Yashica Khatri

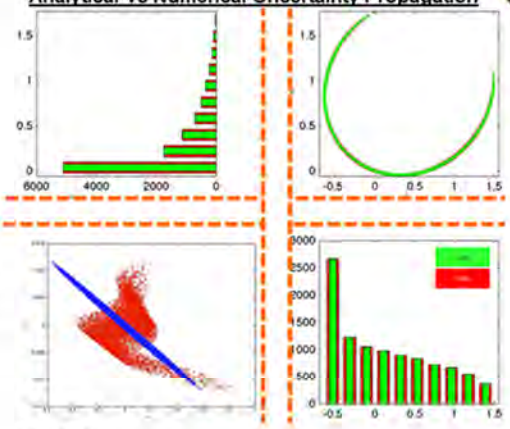
RELEVANCE TO COMMERCIAL SPACE

- Orbit debris is a fundamental issue for space utilization
- The population of debris is relatively well understood, but challenges remain in long-term forecasting for specific pieces of debris
- Challenges include combining observations from disparate sensors and sources, developing efficient dynamic propagation schemes for orbits and uncertainty distributions, and formulating accurate estimation methods for space-based activities

STATEMENT OF WORK

- Maximize the information extracted from usual sources of SSA data (minimize uncertainty)
- Identify how data should be collected to maximize information content (maximize efficiency)
- Recover and predict the space domain with more accuracy
- Timely estimation of the space-based environment to create actionable information

Analytical vs Numerical Uncertainty Propagation



STATUS

- Focusing on predicting space object orbits accounting for uncertainty, improving models for characterizing the effect of non-linearities in uncertainty propagation and computing improved encounter statistics using rapid semi-analytical methods

375. Interoperable Air and Space Traffic Management

DLR

PROJECT AT-A-GLANCE

- DLR German Aerospace Center, Institute of Flight Guidance
- PRINCIPAL INVESTIGATOR: Sven Kaltenhaeuser
- Team: Dr. Dirk-Roger Schmitt, Frank Morlang
- STUDENT: Carmo Kluenker

RELEVANCE TO COMMERCIAL SPACE

- The global growth of commercial space increases the demand for space vehicle operations (SVO) in and over Europe. Air Traffic Management is a key role to address this challenge
- Goal: Preparing the European ATM system for sustainable, efficient and safe integration of SVO, considering interoperability to enable global operations

STATEMENT OF WORK

- Categorization of space flight operations and impact assessment on European airspace
- Optimization of airspace usage for space flight operations with minimized airspace segregation
- Development of concepts & prototypes for seamless, safe and secure implementation of space flight into ATM using SWIM

Enhanced Controller Working Position for integrating Space Flight into Air Traffic Management (ATM)

STATUS

- Collaboration between DLR and FAA-AST on improved inter-operable solutions integrating space flight operations into ATM
- Development and validation of a concept visualizing information at the controller working position (CWP) to enable controllers to initiate appropriate measures to protect aircraft from falling debris

FUTURE WORK

- Procedures for SVO in a Pan-European aviation system
- Enhanced functions for space flight SWIM services

397. Measurements of Thunderstorm Electrical Parameters

FLORIDA TECH

PROJECT AT-A-GLANCE

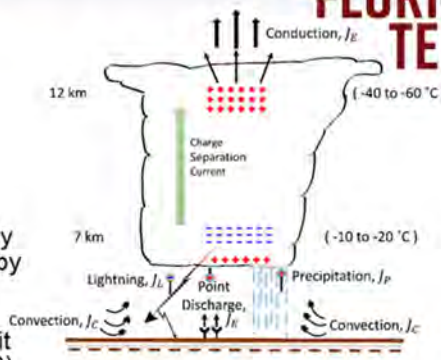
- UNIVERSITY: Florida Institute of Technology
- PRINCIPAL INVESTIGATOR: Dr. Amitabh Nag
- STUDENT RESEARCHER: Mr. Mathieu Plaisir

RELEVANCE TO COMMERCIAL SPACE

- One way to minimize launch costs is to reduce the uncertainty associated with the cloud rules that protect a launch vehicle by preventing its interaction with natural lightning or a lightning strike triggered by the vehicle during a launch
- These cloud rules are known as the Lightning Launch Commit Criteria (LLCC) or the Lightning Flight Commit Criteria (LFCC).
- The goal is to lessen the percentage of launch delays and scrubs associated with the LLCC/LFCC, without compromising safety, thus promoting the commercial launch sector

STATEMENT OF WORK

- Measure Maxwell currents and electric field changes associated with initial cloud electrification
- Examine and identify signatures of inception of separation of cloud charges
- Make suggestions on possible ways to refine cloud rules in the Lightning Flight Commit Criteria



STATUS

- Instrumentation development and testing underway for measurements of thunderstorm parameters

FUTURE WORK

- Data collection, analysis, correlation with weather radar and lightning locating system data, followed by inferences regarding refinement of cloud rules

399. Efficient Computation of Space Object Probability of Collision

PROJECT AT-A-GLANCE
- UNIVERSITY: University of Central Florida
- PRINCIPAL INVESTIGATOR: Dr. Tarek A. Elgohary
- STUDENT RESEARCHER: Mr. Tahsinul Haque Tasif

RELEVANCE TO COMMERCIAL SPACE
- Developing robust efficient methods for uncertainty quantification provides industry with necessary tools for SSA
- Providing a tool for benchmarking for academia, government and industry to evaluate and compare results, results in more transparency for a sustainable space environment for all

STATEMENT OF WORK
- Uncertainty quantification via higher order state transition tensors
- Probability density function approximation using function approximation and Louisville's theorems
- Computation of accurate prediction of probability of collision.
- Benchmarking framework with other tools from academia and industry
- Disseminate information about SSA and its relevance to commercial space flight

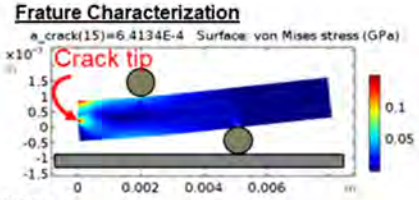
STATUS
- Perturbed first order state transition tensor (journal publication)
- Second order J2 perturbed state transition tensor (conference publication)

FUTURE WORK
- Fully perturbed, arbitrary order state transition tensors
- Function approximation (adaptive collocation) for probability density function description
- Benchmarking and comparison tools

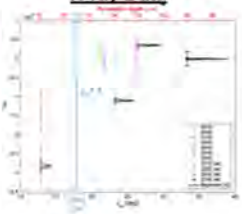
241. High Temperature, Optical Sapphire Pressure Sensors

PROJECT AT-A-GLANCE
- UNIVERSITY: Florida State University
- PRINCIPAL INVESTIGATOR(S): William S. Oates, Rajan Kumar
- STUDENT: Jakob Consoliver-Zack

Frature Characterization



High-Res Multi-axial X-ray Data



RELEVANCE TO COMMERCIAL SPACE
- Structural health monitoring and control of space vehicles
- Better knowledge of aerodynamics for re-launching space vehicles
- Enhanced rocket engine control, better fuel efficiency
- Better understanding of hypersonic turbulence and aeropropulsion

STATEMENT OF WORK
- Research is focused on advancing high temperature pressure sensor technology for sensors that can sustain elevated temperatures (T >1300°C) and high pressures
- Research developed fundamental understanding of laser machined sapphire mechanics
- Facilitated technology transition to sensor structures
- Fracture and fatigue resistance studied through high temperature material characterization

STATUS
- Multi-axial x-ray data of sapphire has been taken and analyzed
- Developed methodology to infer fracture at temperatures >1000°C

FUTURE WORK
- Infer 3D mechanics problem via UQ and x-ray data
- Re-start high temperature strength and fracture experiments to support sensor development

253. Ultra-high Temperature Composites Thermal Protection Systems

UCF

PROJECT AT-A-GLANCE
- UNIVERSITY: University of Central Florida
- PRINCIPAL INVESTIGATOR: Drs. Jan Gou & Jay Kapat
- STUDENT RESEARCHER: Derek Saltzman, Haonan Song, Shengheng Gu

RELEVANCE TO COMMERCIAL SPACE
- Ultra-high temperature ceramic matrix composites could be used for re-entry vehicles, launch vehicles, hypersonic, combustors, gas turbine blades, and heat exchangers

STATEMENT OF WORK
- Development and synthesis of polymer derived ceramic (PDC) precursor, and modification with nanomaterials
- Advanced manufacturing and polymer infiltration and pyrolysis (PIP) processes
- Ground testing with oxyacetylene torch/shock tube/rocket plume/arc jet test
- Development of thermal-mechanical models to uncover thermal damage mechanism

STATUS
- Development of photo-curable PDC precursor
- Additive manufacturing of monolithic PDC ceramic (PDCC) structures
- Ground-based testing PDCC thermal protection systems manufactured from the PIP process

FUTURE WORK
- Formulation optimization of PDC precursor
- Additive manufacturing of fiber reinforced PDCC
- PIP manufacturing of three dimensional PDCC thermal protection systems against the delamination

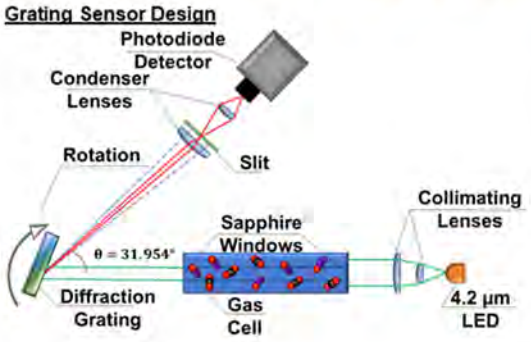
311. Advancement of LED-based Hazardous Gas Sensors

UCF

PROJECT AT-A-GLANCE
- UNIVERSITY: University of Central Florida
- PRINCIPAL INVESTIGATOR(S): Dr. Subith Vasu
- POST DOC(S): Anthony C. Terracciano, Ph.D.
- STUDENT(S): Akshita Parupalli, Zachary Loparo, Justin Urso

RELEVANCE TO COMMERCIAL SPACE
- CO_2 and N_2O measurements are relevant to the health and safety of the crew
- Time-resolved measurements of these gases could help quickly detect electrical shorts or fuel leaks
- Expensive lasers can be replaced with cheaper and more robust LEDs

STATEMENT OF WORK
- Conduct balloon tests to validate sensors over broad range of temperatures and pressures and improve the optical and electrical design
- A rotating diffraction grating used in conjunction with a single LED scans multiple frequencies (4.1 to 4.6 μm)
- Lab tests for different CO_2 and N_2O mixtures balanced in Argon, show ability to detect multiple gases with a single LED



STATUS
- System tested to increase the wavelength range and sensitivity
- Published papers in *New Space* journal

FUTURE WORK
- Increase sensor system precision
- Increase range of applicable gases
- Test in more hazardous environments and conduct suborbital flight

323. Structural Health Monitoring Framework

NEW MEXICO TECH
SCIENCE · ENGINEERING · RESEARCH · UNIVERSITY

PROJECT AT-A-GLANCE

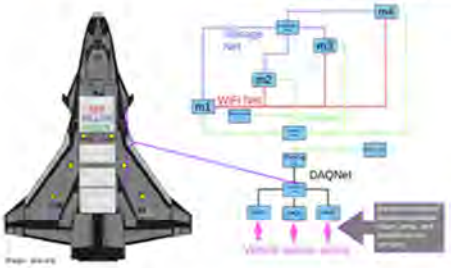
- UNIVERSITY: New Mexico Institute of Mining and Technology
- PRINCIPAL INVESTIGATOR: Dr. Andrei Zagrai, Mr. Dale Amon
- COMPANY: Immortal Data, LLC

RELEVANCE TO COMMERCIAL SPACE

- The project intends to improve safety of space vehicles by developing a distributed blackbox system that will improve key data survivability and analysis of flight events growth
- The economic benefit includes avoiding costly catastrophic events by analyzing survivable blackbox data

STATEMENT OF WORK

- Our team develops a distributed blackbox system to enabled data survivability during catastrophic event
- Design portable multi-channel electro-mechanical impedance structural health monitoring (SHM) hardware
- Demonstrate results of development in tests flight(s) on commercial space vehicle(s)



STATUS

- Establishing specifications and the practical realization of spacecraft's distributed data acquisition system is in progress
- Immortal Data is progressing in development of hardware and software for the proposed system

FUTURE WORK

- NMT will assemble several single-channel impedance measurement units for suborbital test flight
- Immortal Data in cooperation with NMT will complete a first generation of a distributed blackbox for suborbital test flight

325. Optical Measurements of Rocket Nozzle Thrust and Noise

PROJECT AT-A-GLANCE

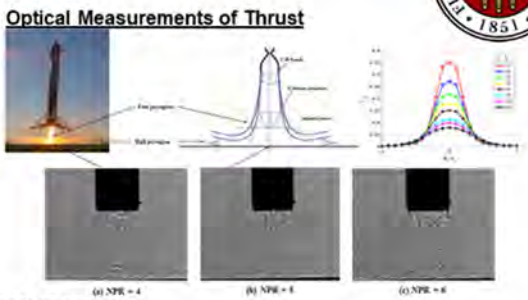
- UNIVERSITY: Florida State University
- PRINCIPAL INVESTIGATOR(S): Drs. Rajan Kumar, Farrukh Alvi, Jonas Gustavsson, Michael Sheehan
- STUDENT(S): Rohit Vemula, Nikhil Khobragade, Vikas Bhargav, Timothy Willms, Yogesh Mehta (Post-doc)

RELEVANCE TO COMMERCIAL SPACE

- Measurement of nozzle thrust and noise is necessary for the design of future launch and reentry space systems and hypersonic vehicles
- Improved propulsion system performance will increase payload capacity and safety for many commercial space transportation programs

STATEMENT OF WORK

- State-of-art thrust and noise measurement techniques to characterize performance at conditions simulating jet impingement on launch/landing surface
- Scaled rocket nozzle simulates realistic temperature and pressure conditions of jet exhaust
- Refine and test measurement techniques and flow control system over wide range of test conditions



STATUS

- Thrust measurements using optical methods
- Testing (velocity, pressure, acoustic surveys and load cell measurements) completed
- Implementation of microjet-based flow control to delay flow separation
- Noise measurements in the hot jet facility
- Single impinging jet to simulate take-off and landing (unsteady loading and noise)

FUTURE WORK

- Jet flow and acoustics of dual impinging jet
- Noise reduction during launch operations

377. Nitrous Oxide Composite Case Testing

NEW MEXICO TECH
SCIENCE · ENGINEERING · RESEARCH · UNIVERSITY

PROJECT AT-A-GLANCE

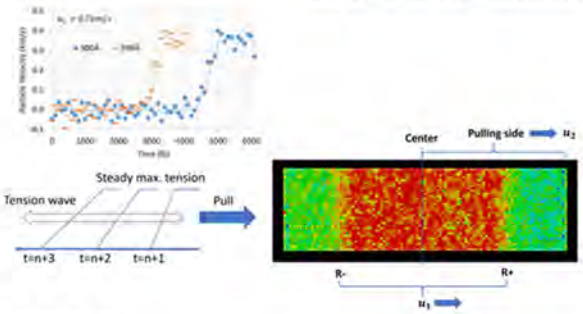
- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR(S): Dr. Seokbin (Bin) Lim, Dr. Andrei Zagrai
- STUDENT(S): Matthew Hirsh, Chris Rood, Angel Chavira, Steven Palmer
- TECHNICAL MONITORS: Dr. Ken Davidian

RELEVANCE TO COMMERCIAL SPACE

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

STATEMENT OF WORK

- Develop methods/hypothesis to predict crack formation behavior
- Construction of analytical approach to predict such behaviors (1D extreme tension theory)
- Molecular Dynamics (MD) code simulation of the extreme tension event for further validation
- Expansion of the theory from 1D to 2D to explain the necking/crack formation



STATUS

- Completion of 1D theory and related MD code simulation
- Identification of the typical extreme tension wave propagation profile followed by the plotting of EoS curves

FUTURE WORK

- Expansion to 2D theory targeting to understand the crack formation or patterns
- More MD code simulations in order to validate the theory

406. Composite Aircraft Vulnerability Modeling

ARCTOS

PROJECT AT-A-GLANCE

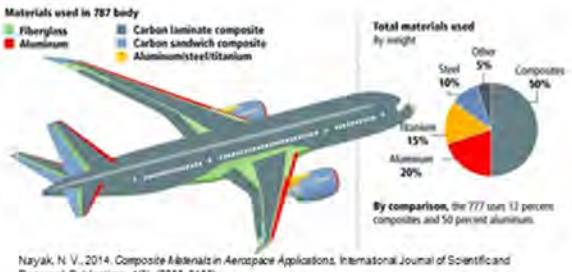
- COMPANY: ARCTOS
- PRINCIPAL INVESTIGATOR(S): Ryan Schnalzer, Jerry Haber
- TECHNICAL MONITORS: Dr. Paul Wilde

RELEVANCE TO COMMERCIAL SPACE

- Addresses vulnerability of composite-based aircraft
- Improves upon existing Aircraft Hazard modeling approach
- Analysis may result in adjusted hazard area requirements which would impact the commercial aircraft industry fuel costs

STATEMENT OF WORK

- Perform Experimental Validation of Penetration Model
- Finalize an Updated Penetration Model
- Develop PAVM Model for Commercial Jet Transports with significant composite material makeup and assess lessons learned for aluminum skinned aircraft
- Evaluate of level of conservatism in Aluminum Aircraft Vulnerability Models for Jumbo Commercial Transport, Commercial Transport, and Business Jet classes



Nayak, N. V., 2014. *Composite Materials in Aerospace Applications*. International Journal of Scientific and Research Publications, 4(9), (2250-3153).

STATUS

- Identified composite aircraft geometries/thicknesses and composite material characteristics for penetration characterization

FUTURE WORK

- Execute material testing and evaluate results
- Update models to account for composite structures and update event tree

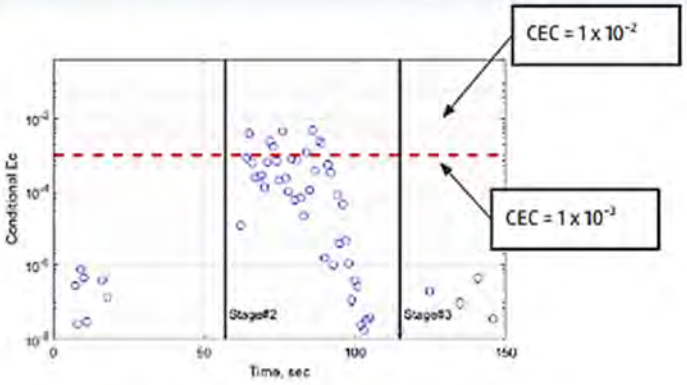
407. Conditional Risk Investigation

ARCTOS

PROJECT AT-A-GLANCE
- COMPANY: ARCTOS
- PRINCIPAL INVESTIGATOR(S): Dr Wije Wathugala, Dr Steve Carbon, Dr. Erik Larson
- TECHNICAL MONITORS: Dr Paul Wilde

RELEVANCE TO COMMERCIAL SPACE
- Techniques will be developed to help compute risk of multiple casualties to the public in the event of a launch or reentry mishap
- More accurate determination of FSS requirements
- Savings for stages where FSS are not needed.

STATEMENT OF WORK
- Assess the sensitivity of the conditional risk metric to input data, failure mode definition and simulation parameters
- Develop a guidance document on the computation of conditional risk including assumptions, guidelines and processes



STATUS
- Completed analysis of over 160 mission segments to study the effect of uncertainties in fragment catalogue, local winds, population models, and Q-alpha threshold

FUTURE WORK
- Complete analyses and develop guidance document in support of Part 450

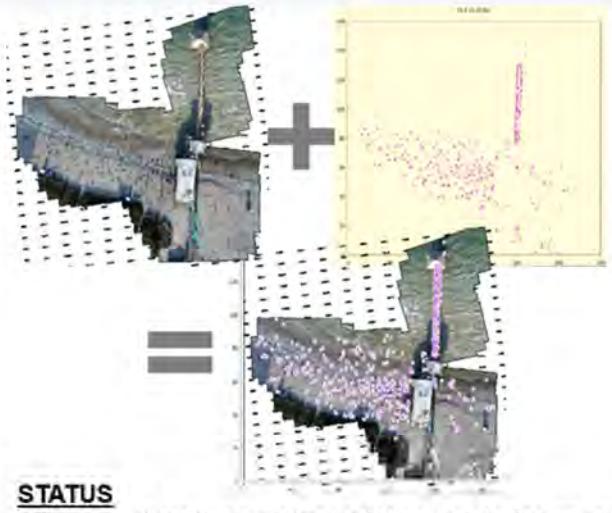
410. Improved Population Clustering

ARCTOS

PROJECT AT-A-GLANCE
- COMPANY: ARCTOS
- PRINCIPAL INVESTIGATOR: Dr. Wenshui Gan, Dr. Wije Wathugala, Dr. Erik Larson
- TECHNICAL MONITORS: Dr Paul Wilde

RELEVANCE TO COMMERCIAL SPACE
- Improved population modeling to provide better estimate of Maximum Probable Loss which affects availability and insurance requirements in space launch industry
- May result in reduced insurance requirements for launch providers and increased launch availability

STATEMENT OF WORK
- Gather imagery data on unsheltered populations in recreation, spectator and transportation areas
- Develop a mathematical model based on the data that estimates the clustering of people
- Implement model into the CRTF/RRAT software
- Develop a fast-running version to improve speed
- Evaluate effects of new model in MPL estimation by comparing old and new models using past missions



STATUS
- Developed an improved population clustering model
- Implemented the new model in CRTF/RRAT
- Complete FRM implementation

FUTURE WORK
- Perform model validation and evaluation

396. Mapping Life Support System Functions and Technologies

PROJECT AT-A-GLANCE

- UNIVERSITY: University of Colorado Boulder
- PRINCIPAL INVESTIGATOR: Dr. David Klaus
- STUDENTS: Kaitlyn Hauber and Hunter Hatchell

RELEVANCE TO COMMERCIAL SPACE

- Augments the FAA's Environmental Control and Life Support Systems (ECLSS) for Flight Crew and Space Flight Participants in Suborbital Space Flight document (April 2010)
- Compile ECLSS information to inform a compliance matrix for requirements and serve as a guide for designers
- Builds upon prior COE CST Tasks addressing human-rating (184), risk analysis (320) and occupant safety (353)

STATEMENT OF WORK

- AIM 1: Functional requirements for ECLSS will be defined and characterized with representative model systems established for different flight profiles ranging from suborbital to short and long term orbital durations
- AIM 2: A foundation will be laid for future ECLSS trade studies by providing a detailed set of operational parameters needed to evaluate the use and integration of each technology option

STATUS

- Task 396 just getting underway as of September 2020

FUTURE WORK

- Ongoing, planned completion by December 31, 2021

398. Human Input Systems

PROJECT AT-A-GLANCE

- UNIVERSITY: Florida Institute of Technology
- PRINCIPAL INVESTIGATOR: Dr. Thomas C Eskridge, Dr. Daniel Kirk (Co-PI), Dr. Don Platt (Co-PI)
- STUDENT RESEARCHER: Kazuhiko Momose, Anna Wojdecka

RELEVANCE TO COMMERCIAL SPACE

- Each new spacecraft has a new control system
- There are currently no standards/guidelines for control systems
- This work will produce guidelines for human input systems to ensure control systems can be used by astronauts and space tourists with precision and minimum effort

STATEMENT OF WORK

- Identify best control logic and mechanisms
- Identify feedback usable in hyperbaric environment
- Determine if a homing capability is useful and necessary
- Identify the key personal physical and cognitive ergonomic features of vehicle occupants
- Determine optimal performance of the mission and safety of astronauts in interactions with adaptive automation

STATUS

- Initial work tested 14 participants with two input devices (Doule, 2018)
- Currently collecting information on input systems and perceptual/sensory ambiguities in variable gravity

FUTURE WORK

- Analysis of input system strengths and weaknesses
- Rapid prototyping control systems and feedback mechanisms
- Testing participants with and without suit

380. Spaceport Operations Online Reference & Spaceport Emergence Data Base

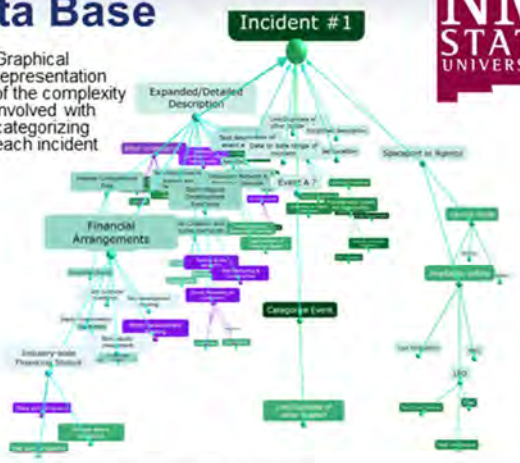
PROJECT AT-A-GLANCE
- UNIVERSITY: New Mexico State University
- PRINCIPAL INVESTIGATOR: Dr. Pat Hynes
- STUDENT RESEARCHERS: Richard Bailey, Miles Stapleton

RELEVANCE TO COMMERCIAL SPACE
- Update and maintain the online Spaceport Body of Knowledge that is available for public use: http://contentdm.nmsu.edu
- Develop a searchable database of spaceport emergence incidents and events for ongoing FAA research and public use

STATEMENT OF WORK
- Task 1 – Develop a searchable, usable database of incidents and events related to Spaceport Emergence
- Task 2 – Update and maintain the online Spaceport Body of Knowledge data base

STATUS
- Spaceport emergence incidents database structure completed. Data gathering and categorization is in progress
- Body of Knowledge screening for updates and repair is ongoing. Average 3,000 document opens monthly

Graphical representation of the complexity involved with categorizing each incident



FUTURE WORK
- Continue with interviews of key spaceport personnel and documentation reviews to populate the database with incidents
- Continue characterizing incidents
- Ongoing updates of the Body of Knowledge

378. Innovation Initiative Policy Research

PROJECT AT-A-GLANCE
- UNIVERSITY: University of Southern California
- PRINCIPAL INVESTIGATOR(S): Dr. Greg Autry, Dr. Andy Aldrin
- TECHNICAL MONITORS: Dr. Ken Davidian

RELEVANCE TO COMMERCIAL SPACE
- Engage industry leaders in case development, engages management scholars in commercial space, finds management lessons with universal application beyond space context, engages students in commercial space
- Management research attracts management scholars to commercial space context
- Establish connections facilitating commercial space research and innovation

STATEMENT OF WORK
- Case studies: Develop and publish case studies in the context of commercial space, for use in management education courses
- Economic value: Research value of physical objects after having flown in space
- Workshops: Conduct workshops annually

STATUS
- Case studies: Two published (Mojave and Relativity Space), two in work (Owens, Masten)
- Economic value: Stamp sheets flown, data collected through auction
- Workshops: Two held in Oct 2018 and Nov 2019

FUTURE WORK
- Case studies: Complete outstanding business cases
- Economic value: Finish data analysis and publication

400. Support of Commercial Space Occupational Medicine Health Standards

utmb Health

PROJECT AT-A-GLANCE
- UNIVERSITY: University of Texas Medical Branch (UTMB)
- PRINCIPAL INVESTIGATOR: Dr. Ed Powers
- STUDENT RESEARCHER: Pending

RELEVANCE TO COMMERCIAL SPACE
- Provide the commercial space industry with guidelines for the evaluation of space workers and reduce the risk of flying those individuals who would have previously been disqualified for flight.

STATEMENT OF WORK
- Review current literature regarding medical standards for populations in extreme environments (analogous to space workers)
- Define the human factors that would jeopardize participant health or mission completion and perform a review of appropriate monitoring and testing hardware and software
- Develop or determine appropriate tests and monitoring technologies (such as wearable monitors) for the medical conditions that have been previously disqualifying
- Support the establishment of Occupational Health Standards for space workers

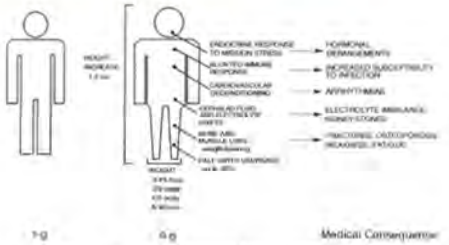


Fig A-1 Interaction between human systems in space flight
(Adapted from Space Biology and Medicine 3rd Ed Vol. III, Book 2, 1993)

STATUS
- Currently in Phase 1: Reviewing current literature regarding medical standards

FUTURE WORK
- Future work includes applying wearable technologies to astronauts or commercial space travelers when they embark on a space journey in order to further evaluate medical monitoring capability in the space environment

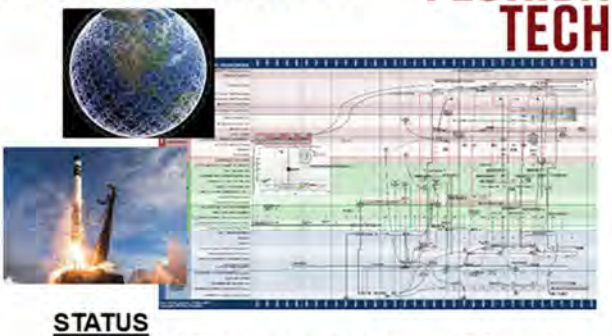
395. Emerging Industries: SmallSat Launchers
402. Emerging Industries: Sat Constellations

FLORIDA TECH

PROJECT AT-A-GLANCE
- UNIVERSITY: Florid Institute of Technology
- PRINCIPAL INVESTIGATOR: Dr. Andy Aldrin
- STUDENT RESEARCHER: Mr. Cory Sanicky

RELEVANCE TO COMMERCIAL SPACE
- This project will develop early indicators regarding the future shape and viability of the largest and most volatile sectors of the space industry
- The database developed through the course of this project will provide valuable source of future industry research

STATEMENT OF WORK
- Develop event databases comparable and consistent with relevant process research in other industries
- Convene methodological and market specific workshops to refine methodology and develop hypotheses/assumptions
- Develop economic/business analyses to support hypothesis/assumption development
- Develop analyses regarding critical assumptions
- Author and submit manuscripts for journal publications



STATUS
- Held practitioner workshop on small launch vehicles
- Produced presentation on small launch vehicle market
- Recruited participants for first methodology workshop

FUTURE WORK
- Additional workshops to be organized on market specific topics
- Development of manuscripts examining key determinative factors in industry development

COE CST STUDENTS, PUBLICATIONS, PATENTS AND AWARDS

In total, there were 43 students and 16 publications generated by the COE CST in 2020. Below is a listing of each 2020 COE CST task, the name(s) of the student(s) supporting each task, and any recent publications, patents, and awards associated with the task.

186-SU. Space Environment Meteoroid and Orbital Debris Modeling & Prediction

Students

- Lorenzo Limonta

- Glenn Sugar

2019-2020 Publications

- Sugar, G. (2019), "Meteoroid Mass from Head Echoes Using Particle-in-cell and Finite-difference Time-domain Simulations", PhD. Thesis, Stanford University, purl.stanford.edu/nz604gp3764.
- Sugar, G., M. M. Oppenheim, Y. S. Dimant and S. Close (2019), "Formation of plasma around a small meteoroid: Electrostatic simulations", JGR Space Physics, Vol. 124(5), pp. 3810–3826, https://doi.org/10.1029/2018JA026434.
- Limonta, L., Close, S., and Marshall, R.A. (2020), A technique for inferring lower thermospheric neutral density from meteoroid ablation, Planetary and Space Science, Vol. 180, 104735, https://doi.org/10.1016/j.pss.2019.104735.

241-FSU. High Temperature, Optical Sapphire Pressure Sensors

Students

- Jakob Consoliver-Zack

2019-2020 Publications

- Bal Singh, H., Consoliver-Zack, J., Oates, W. S., "High-Temperature Mechanical Characterization of Laser-Machined Sapphire for High-Temperature Pressure Sensor Applications," New Space, v. 7 (1), 2019.
- Consoliver-Zack, J., Rebar, D., Siegrist, T., Oates W. S., "Bayesian Uncertainty Analysis of the Residual Stress in Laser Machined Sapphire", in preparation, 2020.

253-UCF. Ultra-high Temperature Composites Thermal Protection Systems

Students

- Derek Saltzman

- Haonan Song

- Shengheng Gu

2019-2020 Publications

- S.S. Gu, J. Kapat, J. Gou, "Additive Manufacturing of Silicon Oxycarbide Ceramic Structures," CAMX 2020, Orlando, FL, September 21-24, 2020.

Patents

- J. Kapat, J. Gou, N. Nagaiah, J. Schmitt, Power generation system using closed or semi-closed Brayton cycle recuperator, U.S. Patent, Publication No. US10,598,093 B2, Issue date: 03/24/2020
- J. Kapat, J. Gou, N. Nagaiah, J. Schmitt, Power generation system using closed or semi-closed Brayton cycle recuperator, European Patent, Publication No. EP3 277 939 B1, Issue date: 05/06/2020

311-UCF. Advancement of LED-Based Hazardous Gas Sensors for Space Applications

Students

- Carmine Terracciano
- Akshita Parupalli
- Zachary Loparo
- Justin Urso

2019-2020 Publications

- Akshita Parupalli, Anthony Carmine Terracciano, Zachary Loparo, Justin Urso, S.S. Vasu, "Multi-Species Single-LED Gas Sensor

for Space Habitats and Vehicles", New Space, 8(2), 2020.

323-NMT. Structural Health Monitoring Framework

Students

- No students due to COVID-19 and visa complications

2019-2020 Publications

- Zagrai, A., Campisi, M., Anderson, M., Hunter, D., Sanchez, J.A., Demidovich, N., Kessler, S., (2019) "Structural Diagnostics, Prognostics and Health Management for Future Space Vehicles: Development, Implementation and Testing," Proceedings of 2019 IEEE Aerospace Conference, Big Sky, MT, USA, March 2-9, 2019, pp. 1-11. doi: 10.1109/AERO.2019.8741659.
- Zagrai, A., Misla, A., Sanchez, J., Powell, D (2020) "Electro-Mechanical Impedance Method for Structural Health Monitoring of Space Structures: from Laboratory Experiments to Measurements during Spaceflight," Proceedings of the AIAA Propulsion and Energy 2020 Forum, paper AIAA 2020-3529, August 24-28, 2020, Virtual Event, https://doi.org/10.2514/6.2020-3529.
- Amon, D., (2020) "Design of an Inexpensive Black Box for Commercial Orbital and Suborbital Vehicles," presentation at Commercial and Government Responsive Access to Space Technology Exchange (CRASTE), June 22, 2020, Virtual Conference.

325-FSU. Optical Measurements of Rocket Nozzle Thrust and Noise

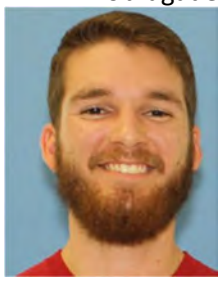
Students

- Jonas Gustavsson

- Michael Sheehan

- Rohit Vemula

- Nikhil Khobragade



- Samuel Lee

- Timothy Willms

- Vikas Bhargav

- Yogesh Mehta

2019-2020 Publications

- Khobragade, N., Wylie, J., Gustavsson, J. & Kumar, R. (2019) Control of Flow Separation in a Rocket Nozzle Using Microjets. New Space Journal, Vol. 7, No. 1, pp31-42, doi: 10.1089/space.2018.0037.
- Mehta, Y., Bhargav, V. N., and Kumer, R. (2020) Experimental Characterization and Control of an Impinging jet Issued from a Rocket Nozzle. Submitted to New Space Journal.

367-CU. CubeSat Deployment Tracking

Students

- Laura Davies

- John Gaebler

2019-2020 Publications

- Gaebler, J., P. Axelrad, P. Schumacher, "CubeSat Cluster Deployment Track Initiation via a Radar Admissible Region Birth Model," Journal of Guidance, Control, and Dynamics, Vol. 43, No. 10, p. 1927-1934, doi.org/10.2514/1.G005139, October 2020.
- Gaebler, J. and P. Axelrad, "Identity Management of Clustered Satellites with a Generalized Labeled Multi-Bernoulli Filter," AIAA Journal of Guidance, Control, and Dynamics, doi.org/10.2514/1.G004725, Online June 2020.

Awards
- 2019 Best Student Paper 2nd Prize: Boylston, A., J.A. Gaebler, and P. Axelrad, "Extracting CubeSat Relative Motion Using In Situ Deployment Imagery," Proc 42nd Annual AAS Guidance & Control Conference, Breckenridge, CO, AAS 19-016, Feb 2019.
- Frank J. Redd Student Competition (2019) 2nd Prize: Aboaf, A., N. Renninger, and L. Lufkin. 2019. "Design of an In-Situ Sensor Package to Track CubeSat Deployments," Proceedings of the Small Satellite Conference, FJR Student Competition (2nd Prize Winner), SSC19-VIII-06, https://digitalcommons.usu.edu/smallsat/2019/all2019/141/

371-UTA. Ontology-based Space Object Database

Students
- Daniel Kucharski, Ph.D. (UT/Oden)
- Shiva Iyer (UT/ASE-EM)
- Nevan Simone (UT/ASE-EM)
- Michael Reinhold (UT/ASE-EM)
- Maria Esteva (UT/TACC)
- Weijia Xu, Ph.D. (UT/TACC)

2019-2020 Publications
- Kucharski, D., Kirchner, G., Otsubo, T., Flegel, S., Kunimori, H., Jah, M., Koidl, F., Bennett, J., Steindorfer, M., Wang, P. (2020). Quanta Photogrammetry of Experimental Geodetic Satellite for remote detection of micrometeoroid and orbital debris impacts, Acta Astronautica, https://doi.org/10.1016/j.actaastro.2020.04.042.
- Le May, S., Carter, B., Gehly, S., Flegel, S., Jah, M. (2020). Representing and Querying Space Object Registration Data Using Graph Databases, Acta Astronautica, https://doi.org/10.1016/j.actaastro.2020.04.056.
- Cai, H., Yang, Y., Gehly, S., He, C., Jah, M. (2020). Sensor tasking for search and catalog maintenance of geosynchronous space objects, Acta Astronautica, Volume 175, October 2020, pp 234-248, https://doi.org/10.1016/j.actaastro.2020.05.063.
- Cai, H., Hussein, I., Jah, M. (2020). Possibilistic Admissible Region Using Outer Probability Measure Theory, Acta Astronautica, Volume 177, December 2020, pp 246-257, https://doi.org/10.1016/j.actaastro.2020.07.041.

372-CU. Resident Space Objects

Students
- Yashica Khatri

2019-2020 Publications
- None

375-DLR. Interoperable Air and Space Traffic Management

Students
- Carmo Kluenkir

2019-2020 Publications
- Kluenker, Carmo (2019), Integration von kommerziellen Raumflügen in das Luftverkehrsmanagement, Master Thesis, Technical University of Berlin / DLR Institute of Flight Guidance.
- Kluenker, Carmo (exp. 2021); Enhanced Controller Working Position for integrating Spaceflight into Air Traffic Management, 12th International Conference on Applied Human Factors and Ergonomics, AHFE.

377-NMT. Nitrous Oxide Composite Case Testing

Students
- Christopher Rood

- Angel Chavira

- Steven Palmer

2019-2020 Publications

Seokbin Lim, et. al., 2020. 'Extreme Dynamic Tension and the Profile of Tension Wave', AIP Advances: in review.

378-USC. Commercial Space Research Center Initiative

Students
- Veronica Perry, USC Marshall
- Kevin Foher, USC Marshall
- Sarah Coutu, Florida Tech

2019-2020 Publications
- Bidushi Bhattacharya, Greg Autry, and Veronica Perry, 2020. Relativity Space: Rocketing into the Future of Manufacturing,

Harvard Business Case Study, SCG575-FDF-ENG.

380-NMSU. Spaceport Operations Online Reference Guide

Students

- Richard (Chase) Bailey
- Miles Stapleton

2019-2020 Publications

- None

395-FIT. Emerging Industries: SmallSat Launchers
402-FIT. Emerging Industries: Satellite Constellations

Students

- Cory Sanicky
- Matt Austin
- Stephen Sullivan
- Victor Bautista

2019-2020 Publications

- None

396-CU. mapping Life Support System Functions and Technologies

Students

- Kaitlyn Hauber
- Hunter Hatchell

2019-2020 Publications

- None

397-FIT. Measurements of Thunderstorm Electrical Parameters

- Matieu Plaisir

2019-2020 Publications

- None

398-FIT. Human Input Systems

Students

- Kazuhiko Momose
- Anna Wojdecka

2019-2020 Publications

- None

399-UCF. Efficient Computation of Space Object Probability of Collision

Students

- Tahsinul Haque Tasif

2019-2020 Publications

- Tasif, T.H., Elgohary, T.A.: A high order analytic continuation technique for the perturbed two-body problem state transition matrix, Advances in Astronautical Sciences: AAS/AIAA Space Flight Mechanics Meeting (2019)
- Tasif, T.H., Elgohary, T.A.: An adaptive analytic continuation technique for the computation of the higher order state transition tensors for the perturbed two-body problem, AIAA Scitech 2020 Forum, p. 0958 (2020)
- Tasif, T.H., Elgohary, T.A.: An adaptive analytic continuation method for computing the perturbed two-body problem state transition matrix, The Journal of the Astronautical Sciences (2020), In Press.

400-UTMB. Support of Commercial Space Occupational Medicine Health Standards

Students
- None

2019-2020 Publications
- None

406-ARCTOS. Aircraft Vulnerability Testing and Modeling

Students
- None

2019-2020 Publications
- None

407-ARCTOS. Conditional Risk Investigation

Students
- None

2019-2020 Publications
- None

410-ARCTOS. Improved Population Clustering Follow-up

Students
- None

2019-2020 Publications
- None

Center of Excellence for
Commercial Space Transportation