BCM

Florida Institute of Technology

NM STATE UNIVERSITY

NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH • 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 11-12 Annual Report

Executive Summary
FINAL

May 31, 2022

Rev-M

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LETTER FROM THE EXECUTIVE DIRECTOR

As the saying goes, all good things must come to an end. So it is that we are now winding down the Center of Excellence for Commercial Space Transportation (COE CST) after its planned decade-plus span of productive research accomplishments and educational activities. But we are going out on a high note in 2022, as the past few years have seen unprecedented advances in commercial space flight…

When we got started on this venture back in 2010, the Space Shuttle was still in operation, retiring when *Atlantis* landed for the last time on July 21, 2011. NASA's Commercial Program was getting underway as cargo resupply launches to the International Space Station (ISS) began with *Dragon* in 2012 and *Cygnus* in 2013. Development efforts on commercial crew-carrying vehicles by a number of different companies were also ramping up around this timeframe, and after nearly a decade of relying on Soyuz launches, 2020 saw the first NASA astronauts being delivered to the ISS onboard SpaceX's *Crew Dragon*. Then, just last month, paying customers visited the ISS on the Axiom 1 mission flying aboard that same reusable *Dragon* capsule, coincidentally occurring while our 11th and final COE CST Annual Technical Meeting (ATM11) was taking place at Florida Tech on April 14.

The era of suborbital commercial space flight, however, had even earlier roots with the Ansari XPRIZE, awarded in 2004, when *SpaceShipOne* twice exceeded the Kármán line of 100 km in altitude, the internationally recognized point where space begins. More recently, following a final test flight in 2018 that reached the USAF/NASA/FAA recognized boundary of space at 50 miles (80 km), *SpaceShipTwo*, the VSS *Unity*, launched a crew along with a third employee in the passenger cabin in 2019, and then on July 11, 2021, took its first fully crewed flight up to the edge of space. Just over a week later, on July 20, 2021, the 52nd anniversary of the Apollo 11 lunar landing and a day short of 10 years since the final Space Shuttle landing, Blue Origin's *New Shepard* conducted its first crewed flight carrying four passengers above the Kármán line, with three additional crewed flights having since been completed to date.

The COE CST has played a role in advancing industry practice and in helping the FAA extend its expertise and emphasis on safety from aviation to space. We had a great run that involved nearly 50 faculty PIs and some 150 students, with many more having benefited from peripheral interactions, and also engaged more than 30 Affiliate and Associate members in related research. A special thanks is owed to our FAA colleagues who made it all possible, especially Pat Watts and Ken Davidian, who supported the Center from the beginning. It has been a pleasure and an honor to have participated in this effort. I look forward to seeing where the future of commercial space transportation goes from here.

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 TO THE POSTLOGUE…

Prefaces found in earlier editions of this Annual Report Executive Summary recount a detailed history of the Federal Aviation Administration (FAA) Center of Excellence for Commercial Space Transportation (COE CST). Because this is the final COE CST Annual Report Executive Summary, this Preface addresses the question "What comes next for the COE CST?" The answer is "It depends."

From a structural perspective, the COE CST is a governmental organization built upon multiple cooperative agreements that end in the same way it came into existence twelve years ago, on a legal basis. Other than administrative activities, the COE CST officially ceases to exist after August 19, 2022.

From a functional perspective, the COE CST provides a cohort of government, university, and industry members the opportunity to assemble, discuss and research many topics of interest to the commercial space transportation industry. After the end of the cooperative agreement, this cohort forever shares a common past identity and experience as COE CST alumnae.

From a network perspective, the COE CST is a collection of interconnected organizational nodes and linkages. Each node is a network itself, including principal investigators, students, administrative support or governmental personnel, and affiliate, associate, or industry members. Each linkage includes information exchange (e.g., annual technical and administrative meetings, monthly meetings) and collaborative research tasks. With cessation of FAA funding of the COE CST, the network nodes will not cease to exist, but the linkages between them weaken, making it a "looser" network, decreasing its sense of identity, but increasing its agility to recombine and reform as needed.

From an evolutionary perspective, the COE CST represents a source of variation in the "variation-selection-retention" cycle. Organizations commonly aim to improve their products and processes (including knowledge, technology and administration) through retention/selection processes, exploiting existing knowledge (widely referred to as "best practices"). Research (or "exploration") provides variation by identifying previously unused or unknown products and processes. Cessation of COE CST operations diminishes, but does not extinguish, the overall source of evolutionary variation.

From an institutional perspective, and continuing the tradition of challenging the taken-for-granted logic that "space = NASA," the COE CST challenges the "space research = NASA" assumption by highlighting the FAA as the ONLY government research collective uniquely supporting non-governmental space sector research goals. Through FAA's support, COE CST research results supported, and will continue to support, the commercial space transportation industry directly and indirectly.

Essentially, echoes and ripples of the COE CST's impact will persist for quite some time and in different ways after it legally ceases to exist.

In conclusion, and for the last time as part of the COE CST, I want to thank all the individuals from the dozens of participating organizations and institutions for their patience and long-standing support of this research consortium. In an ideal world, I would like to thank the 46 principal investigators and 143 students each by name, but I cannot do that here. I would also like to thank each of the dozens of organizations in our corps of Affiliate and Associate members, and all other participating and contributing organizations. Again, I appreciate everybody's contributions of time and effort that helped make the COE CST a successful and worthwhile endeavor.

As always, for more information about the COE CST, please visit the website (www.coe-cst.org).

Ken Davidian, PhD
Program Manager
FAA COE CST

Karl Garman, PhD
Deputy Program Manager
FAA COE CST

INTRODUCTION

This executive summary accompanies the FAA COE CST's more detailed annual report. The annual report volume will be available on the COE CST website, 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 began operation 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 COE CST Member Universities, the Affiliate Members, and the FAA support personnel for all 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 final years of operation. Although the COE CST was supposed to cease operations in 2020, the end date was extended to August 2022 to facilitate the orderly closeout of tasks during the COVID pandemic. The report provides summary information about each task in the form of quad charts and concludes with a listing of the COE CST students, the partnering institutions from industry, research organizations, and technical publications delivered during the year.

OVERVIEWS

FAA OFFICE OF COMMERCIAL SPACE TRANSPORTATION

The Code of Federal Regulations, Title 51 US Code Subtitle V, Ch. 509 defines the FAA Office of Commercial Space Transportation (AST) mission as:

- 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 Omnibus Budget Reconciliation Act, PL 101-508, Title IX, Aviation Safety and Capacity Expansion Act established the FAA Air Transportation Centers of Excellence (COE) program in 1990. The text of this legislation is provided on the inside back cover of the Year 8 Annual Report Executive Summary.

COEs are multi-year, multi-disciplinary partnerships of academia, industry, and government partnerships created to combine world-class resources to address current and future critical challenges for the aviation and aerospace communities, including commercial space transportation. The main goals of every COE include focused 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. Recipient universities satisfy the matching requirement through direct or in-kind contributions from any non-federal funding source, including industry, universities, or state and local government organizations. Jointly-supported COE efforts provide the U.S. citizens with a one-to-one return on their tax dollars. To date, the COE members have generated more than $450M in matching contributions to offset the research costs incurred by the government organizations.

The COE CST is one of six active FAA COEs. Previous COE CST Annual Report Executive Summaries provide details of the other COEs.

FAA CENTER OF EXCELLENCE FOR COMMERCIAL SPACE TRANSPORTATION

Below is a quick look at the major highlights and special mentions of COE CST's final year. Updates to the basic COE CST performance metrics reflect the most recent events and activities.

A Tribute to Pat Watts

The FAA COE CST originated with the watchful guidance and advice of Dr. Patricia Watts. Dr. Watts led the FAA COE program from its inception in 1990 until 2020 when it moved organizationally from the grants organization to the acquisitions organization within the FAA. In 2016, Dr. Watts received the Joseph F. Carrabino Award, nominated by COE CST member Florida Tech, and given to federal employees who significantly contributed to research administration through a single project, activity, innovation, or by a lifetime of service.

• Patricia Watts

COE CST Final Year Highlights

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

- **The Eleventh, and Final, Annual Technical Meeting (ATM11)** took place at Florida Tech in Melbourne, FL, on 14 April 2022. Since this was the final COE CST ATM, it featured retrospective comments from panelists representing each of the four major research areas. The agenda, individual technical presentations (in video and presentation chart formats) for all current tasks, and video recordings of the ATM11 panels, are all available from the COE CST ATM11 web page.
- **George Nield Goes to Space!** – In 2010, Dr. George Nield was the Associate Administrator for the FAA Office of Commercial Space Transportation and oversaw the creation of the COE CST. In 2018, he left that position, entered private industry, and became the Executive Director of the Global Spaceport Alliance. In April 2022, Dr. Nield was aboard the Blue Origin New Shepard vehicle for its suborbital flight mission NS-20. COE CST members were fortunate to receive remarks from Dr. Nield as the ATM11 closing keynote speaker. He described his flight in the following way: "Two weeks ago I had the incredible opportunity to be onboard Blue Origin's fourth human space flight on their New Shepard rocket and of course everybody wants to know what was it like and the answer is: It was awesome, it was amazing, it was exhilarating, it was humbling, it was inspiring. It was all those things all put together." His video address is available on the COE CST ATM11 web page.

• George Nield

COE CST Final 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.

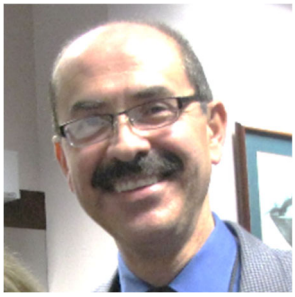
Year 11-12 of COE CST operation accounted for 36 principal investigators (PIs) and Co-PIs, and 55 students conducted 28 research tasks (funded and unfunded), resulting in 40 technical publications and presentations. This Executive Summary presents summary charts (aka "quad charts") for each research task, and provides a complete list of students and the resulting publications.

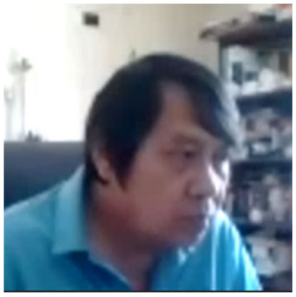
COE CST Year	1	2	3	4	5	6	7	8	9-10	11-12
Fiscal Year(s)	10	11-12	13	14	15	16	17	18	19	20-21
Active Tasks	34	24	28	28	36	22	14	27	20	22
Unfunded Tasks	34	22	22	11	6	5	2	5	14	6
Principal Investigators	27	28	29	25	31	22	21	22	22	36
Students	31	37	55	47	61	28	23	38	34	55
Publications	0	38	28	22	29	19	36	23	16	40
Affiliate Members	0	1	6	6	6	6	8	10	14	16
Associate Members	-	-	-	3	6	3	3	8	8	8
Funding Profile ($M)	2.0	2.4	1.1	1.1	1.0	1.0	1.4	1.6	2.1	0.5

Note: *Count of Principal Investigators (PIs) includes PIs and Co-PIs for current period only. Count of Publications includes Publications and Presentations for current period only.*

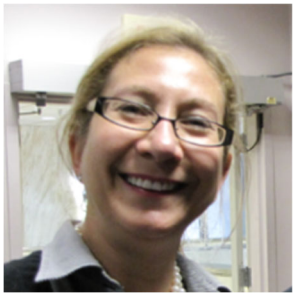
FAA Support Personnel

Personnel across the FAA, past and present, acted as programmatic and technical monitors for AST's research work 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 during the final research period:


• Melchor Antunaño


• Wynn Aung


• Jennifer Bailey


• Laura Bachurski


• Evelina Bern


• Kelvin Coleman


• Anna Cushman


• Dan Czelusniak


• Nick Demidovich


• Steph Earle


• Felistas Githiora


• Henry Lampazzi


• Jose Leal


• Dan Murray


• Randy Repcheck


• Karen Shelton-Mur


• John Sloan


• Gunter Smiley


• Yvonne Tran


• Paul Wilde

Not shown: Nelson del Calvo and Rene Rey.

CONTRACTOR SUPPORT PERSONNEL


• Carol Gregorek, CEO


• Fred Bowen, CIO

FAA acquisition lawyers determined AST could not administer the COE CST directly but could instead issue grants to administer the Center. This task fell to Orion America Technologies (OAT) a company started by Carol Gregorek and Fred Bowen in 1991. Bowen designed a Management Information System (MIS) for the Airworthy Assurance COE to handle the financial and administrative reporting histories of over 80 universities. OAT and the Orion MIS were instrumental to the COE CST's administrative success.

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 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 brings

complementary strengths together to benefit 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)

• Jeff Sutton

Baylor College of Medicine (BCM) is a health sciences university and home to the Center for Space Medicine (CSM). BCM CSM is the lead institution for the NASA-supported Translational Research Institute for Space Health at the forefront of space biomedical research, education and aerospace medicine. Major subcontractors are Caltech and MIT. CSM offers a unique and popular Space Medicine Pathway for medical students and supports graduate and postgraduate training opportunities in space medicine. Find more information on the web at www.bcm.edu. Jeff Sutton served as the COE CST principal investigator for BCM.

FLORIDA INSTITUTE OF TECHNOLOGY (FLORIDA TECH)

Florida Institute of Technology supports doctoral research and undergraduate through postdoctoral graduate education in its four academic colleges 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, and academia for affiliate and associate memberships to the COE CST. Historically known as FIT, Florida Tech's preeminent research centers and institutes include the Center for Advanced Manufacturing & Innovative Design, the FAA Center of Excellence for General Aviation Research, the COE CST, the L3Harris Institute for Assured Information, the Dynamics Systems & Controls Laboratory, the ORION Lab for Orbital Robotic Interaction, On-orbit Servicing & Navigation, etc. Find more information on the web at www.fit.edu. The pictured individuals served as COE CST principal investigators for Florida Tech.

• Andy Aldrin

• Scott Benjamin

• Guy Boy

• Ondrej Doule

• Sam Durrance

• Tom Eskridge

• Tristan Fiedler


• Dan Kirk

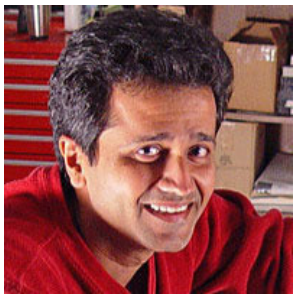

• Amitabh Nag


• Don Platt


• Nathaniel Villaire

FLORIDA STATE UNIVERSITY (FSU)

FSU brings a range of 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. Find more information on the web at www.fsu.edu. The pictured individuals served as COE CST principal investigators for FSU.


• Farrukh Alvi


• Emmanuel Collins


• Rajan Kumar


• William “Billy” Oates

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. Find more information on the web at www.nmt.edu. The pictured individuals were COE CST principal investigators for NMT.


• Seokbin Lim


• Keith Miller


• Warren Ostergren


• Van Romero

• Eileen Ryan

• Dave Westpfahl

• Andrei Zagrai

NEW MEXICO STATE UNIVERSITY (NMSU)

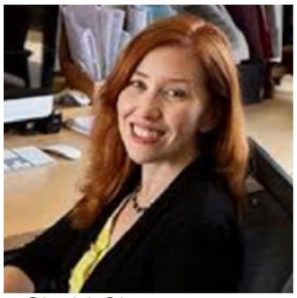
• Patricia Hynes

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 suborbital 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 a related aerospace research focus on annual access to space for student and faculty experiments, uncrewed aerial vehicles, and cube-satellite development. Find more information on the web at www.nmsu.edu. Pat Hynes served as the COE CST principal investigator for NMSU.

STANFORD UNIVERSITY

Stanford University 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. Find more information on the web at www.stanford.edu. The pictured individuals served as COE CST principal investigators for Stanford.

• Juan Alonso



• Sigrid Close

• Ward Hanson

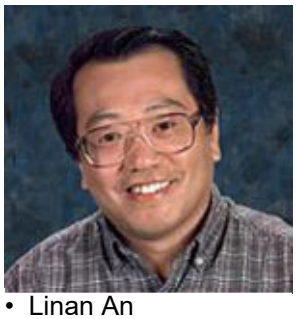
• Scott Hubbard

• Mykel Kochenderffer

• Steve Rock

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 systems, propulsion system components, cryogenic systems and materials, composites, sensors and actuators, and guidance and control. Find more information on the web at www.ucf.edu. The pictured individuals served as COE CST principal investigators for UCF.


• Linan An


• Tarek Elgohary


• Ali Gordon


• Jihua “Jan” Gou


• Jay Kapat


• Subith Vasu

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. Find more information on the web at www.colorado.edu. The pictured individuals served as COE CST principal investigators for UC Boulder.


• Penina Axelrad


• George Born


• Brad Cheetham (PhD Student)


• Tim Fuller-Rowell


• David Klaus


• Dan Scheeres

UNIVERSITY OF FLORIDA (UF)

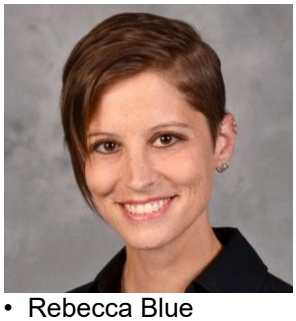
• Norm Fitz-Coy

• Mark Sheplak

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. Find more information on the web at www.ufl.edu. The pictured individuals served as COE CST principal investigators for UF.

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. The pictured individuals served as COE CST principal investigators for UTMB.



• Rebecca Blue

• Tarah Castleberry

• Richard Jennings

• Charles Mathers

• William Powers

• Jim Vanderploeg

COE CST at the 2017 International Symposium for Commercial and Personal Spaceflight, Las Cruces, NM.

COLLABORATING MEMBERS

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

UNIVERSITY OF SOUTHERN CALIFORNIA (USC, COLLABORATOR TO FLORIDA TECH)

- Greg Autry

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. Find more information on the web at www.marshall.usc.edu/departments/lloyd-greif-center-entrepreneurial-studies. Greg Autry served as the COE CST principal investigator for USC.

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

- Moriba Jah

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 world's grand challenges, 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 worldwide by leveraging the school's entrepreneurial ecosystem and partnerships with industry to translate research into practice. Find information on the web at www.engr.utexas.edu/about. Moriba Jah served as the COE CST principal investigator for UT Austin.

AFFILIATE 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 core university members, the COE CST includes two different membership categories to encourage additional members into the COE CST without incurring any additional budget obligations. The two different categories, called Affiliate and Associate Memberships, are described below.

To become a COE CST Affiliate Member, an organization must (a) be conducting self-funded research, 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, and (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 and 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. It serves as the only non-government (commercial use) facility for the application of acceleration and G force exposure in the world. It 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 dollar's 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 human-crewed flight. They have fulfilled multiple contracts with NASA. The EXOS team 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.

INTERNATIONAL INSTITUTE FOR ASTRONAUTICAL SCIENCES (IIAS)

The International Institute for Astronautical Sciences (IIAS) is a citizen-science, research, and education institute specializing in operational space science, human factors, flight test engineering, aeronomy, and bioastronautics. With students from over 50 different countries, IIAS offers professional certifications and sponsors educational outreach programs. IIAS science and research campaigns produce peer-reviewed scientific publications, deployable space technologies, and inspire the next generation of international space professionals. More information on IIAS may be found at astronauticsinstitute.org

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, focusing on suborbital, LEO, Lunar, and Mars. As a clinical support organization, Sovaris applies the tools of complex molecular analytics to develop personalized countermeasures 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 also advances a systems engineering approach to personalized medicine focused on 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 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 supports 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)

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 West Texas' technology and public interests. 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 on the web at www.astm.org.

COMMERCIAL SPACEFLIGHT FEDERATION

The Commercial Spaceflight Federation (CSF) is the leading voice for the commercial spaceflight industry. Founded in 2006, CSF and its 80+ members are laying the foundation for a sustainable space economy and democratizing access to space for scientists, students, civilians, and businesses. CSF members are responsible for creating thousands of high-tech jobs driven by billions of dollars in investment. By promoting technology innovation, CSF is guiding the expansion of Earth's economic sphere, bolstering U.S. leadership in aerospace, and inspiring America's next generation of engineers and explorers. The CSF mission is to promote the development of commercial human spaceflight, pursue ever-higher levels of safety, and share best practices and expertise throughout the industry. More information can be found on the web at www.commercialspaceflight.org.

EMBRY-RIDDLE AERONAUTICAL UNIVERSITY (ERAU)

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.

GERMAN AEROSPACE CENTER (DLR)

The German Aerospace Center (DLR) is the national aeronautics and space research center of the Federal Republic of Germany. Its extensive research and development work in aeronautics, space, energy, transport, digitalization and security is integrated into national and international cooperative ventures. In addition to its research, as Germany's space agency, DLR has been given responsibility by the federal government to plan and implement the German space program. DLR is also the umbrella organization for one of Germany's largest project management agencies. DLR has approximately 8000 employees at 20 locations in Germany. DLR also has offices in Brussels, Paris, Tokyo and Washington D.C. More information can be found on the web at www.dlr.de.

INTERFLIGHT GLOBAL (IFG)

InterFlight Global (IFG) solves complex business problems. They relish a challenge. They help their clients define, structure, produce, execute and profit from effective strategic, feasibility, business, marketing and financial plans. IFG's input and services result in their clients' enterprises, whether public, private or hybrid, to grow profitably and add significant equity growth and market value gains. More information can be found on the web at www.interflightglobal.com.

MITRE CORPORATION

As a not-for-profit organization, MITRE works in the public interest across federal, state and local governments, as well as industry and academia. MITRE operates federally funded research and development centers, FFRDCs, unique organizations that assist the United States government with scientific research and analysis; development and acquisition; and systems engineering and integration. MITRE also has an independent research program that explores new and expanded uses of technologies to solve our sponsors' problems. More information can be found on the web at www.mitre.org.

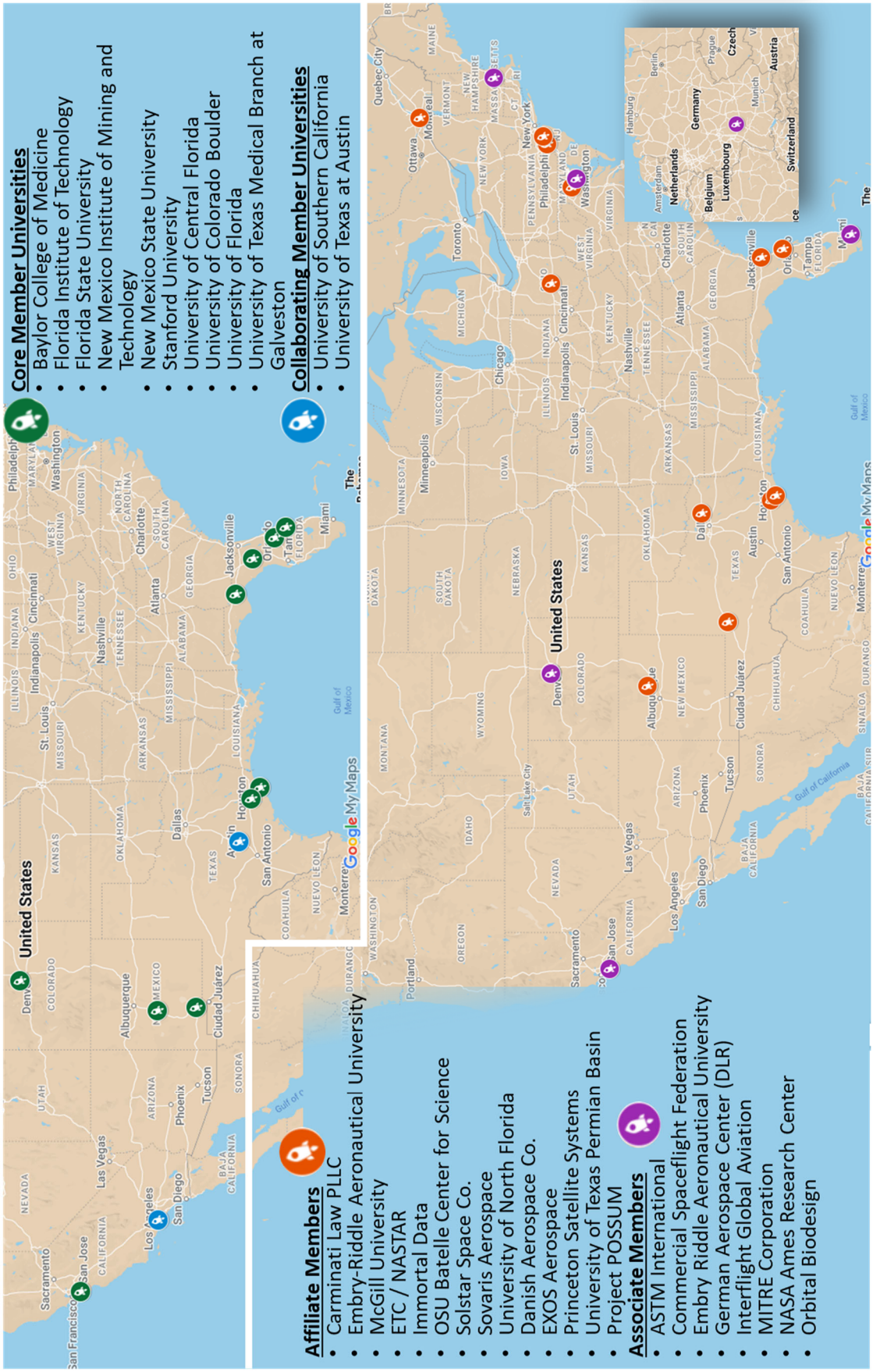
NASA AMES RESEARCH CENTER

NASA Ames Research Center, one of ten NASA field centers, 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.

ORBITAL BIODESIGN

Orbital Biodesign is Ea health technology development and consulting company weaving together years of expertise in medicine, aviation and aerospace/biomedical engineering to support human health both on Earth and in space. Orbital Biodesign is currently based in Boulder, CO, with an experienced advisory team stretching east to Kentucky and west to Southern California. As an organization that grew organically out of a genuine, unmet need to develop creative solutions addressing some of the most persistent problems in space health, Orbital Biodesign is closely engaged with its base of stakeholders and customers.

Top: Map of 2021-2022 COE CST Core and Collaborating Member Universities.
Bottom: Map of 2021-2022 COE CST Affiliate and Associate Members.



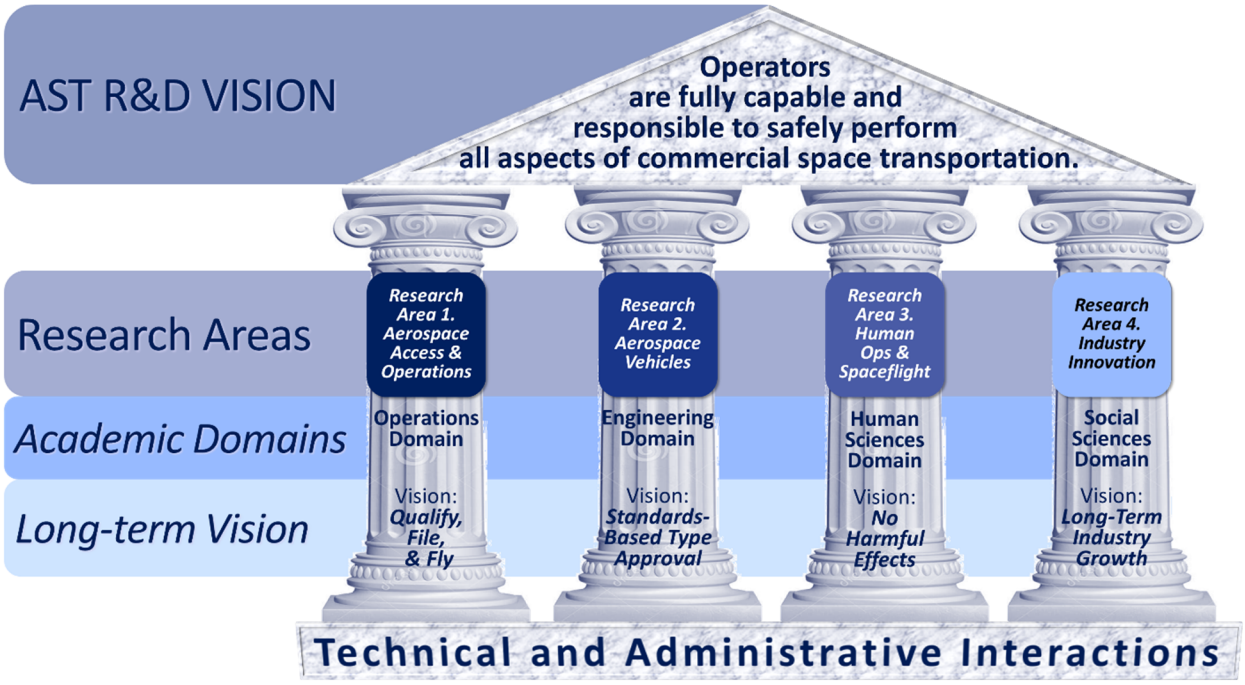
OTHER SUPPORTING ORGANIZATIONS

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
- 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 TASK QUAD CHARTS

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.” 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 offers a brief introduction to the four research areas, identifies the goals associated with each, and then lists the tasks conducted in each research area during the eighth year of COE CST operation.



COE CST Research Areas

As mentioned above, FAA AST categorizes research into four major disciplines, each directly linked to a distinct research theme: Aerospace Access & Operations, Aerospace Vehicles, Human Operations & Spaceflight, and Industry Innovation). Each research area subdivides into subsequently lower levels of programs, projects, topics, and tasks. The number of tasks conducted in a given program can vary from year to year, and AST does not conduct research in all programs every year. FAA AST priorities are considered before making funding decisions.

COE CST Research Goals

Listed below are the AST research goals for each research area relevant to AST's two mission goals (public safety and industry promotion). Collectively, these goals support the overall AST R&D vision that operators safely perform all commercial space transportation operations.

1. Aerospace Access & Operations – Long-Term Vision: Qualify, File & Fly

- **Public Safety Goals:** (1) Improved analytical and computational methods to evaluate the safety of uninvolved public and property. (2) Situational awareness and understanding of the 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 – Long-Term Vision: Standards-Based Type Approval

- **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 – Long-Term Vision: No Harmful Effects

- **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 – Long-Term Vision: Long-Term Industry Growth

- **Public Safety Goal**: Develop improved criteria for evaluating public safety, such as performance-based requirements protecting 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 accomplishing 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.

COE CST Research Tasks

COE CST research tasks conducted by member universities, Affiliate, and Associate members and active during the final research period (2021-22) are listed below in all four research areas. Quad charts presented on the following pages provide details for each research task listed below, excluding active administrative tasks.

1. Aerospace Access & Operations

- 186-SU. Space Environment Meteoroid and Orbital Debris Modeling & Prediction
- 367-CU. CubeSat Cluster Deployment Tracking
- 371-NMSU/UTA. Ontology-based Space Object Database
- 372-CU. Resident Space Objects
- 375-DLR. Interoperable Air and Space Traffic Management

- 397-FIT. Measurements of Thunderstorm Electrical Parameters
- 399-UCF. Efficient Computation of Space Object Probability of Collision
- 430-FIT/POSSUM. Tomographic Imagery of Noctilucent Clouds

2. Aerospace Vehicles

- 241-FSU. High Temperature, Optical Sapphire Pressure Sensors
- 253-UCF. Ultra-high Temperature Composites Thermal Protection Systems
- 311-UCF. Advancement of LED-Based Hazardous Gas Sensors for Space Applications
- 323-NMT. Structural Health Monitoring Framework
- 325-FSU. Optical Measurements of Rocket Nozzle Thrust and Noise
- 377-NMT. Nitrous Oxide Composite Case Testing

3. Human Operations & Spaceflight

- 396-CU. Mapping Life Support System Functions and Technologies
- 398-FIT. Human Input Systems
- 400-UTMB. Support of Commercial Space Occupational Medicine Health Standards
- 431-FIT/IIAS. Bioastronautics Research: Space Suit Test and Evaluation
- 432-FIT/IIAS. Human Factors Research

4. Industry Innovation

- 376-FIT/MU. Legal Issues Concerning Suborbital Flight
- 380-NMSU. Spaceport Operations Online Reference Guide
- 395-FIT. Emerging Industry Dynamics: Small Satellite Launch Vehicle
- 402-FIT. Emerging Industry Dynamics: Satellite Constellations
- 434-FIT/UTPB. Coopetition In Efficient Spaceport Ecosystem Development

Florida Tech hosted the COE CST Eleventh Annual Technical Meeting in-person and virtually. In attendance for the photo were (left to right): Ken Davidian, Rajan Kumar, Anthony Terracciano, Jan Gou, Dave Klaus, Karl Garman, Dale Amon, Andrei Zagrai, Zoom attendees, Laura Davies, Anita Gale, Tom Eskridge, Don Platt, Tristan Fiedler, Anna Wojdecka, Djalma Batista, Nick Demidovich, and Oscar Garcia.

Third Annual Administrative Meeting: (row 1-l to r) Carol Gregorek, Emmanuel Collins; (row 2) Pat Hynes, Scott Hubbard, Dave Westpfahl, Nat Villaire; (row 3) Brad Cheetham, David Klaus, Tristan Fiedler, Warren Ostergren, Jim Vanderploeg, Chuck Mathers; (row 4) Norm Fitz-Coy, Fred Bowen, Pat Watts

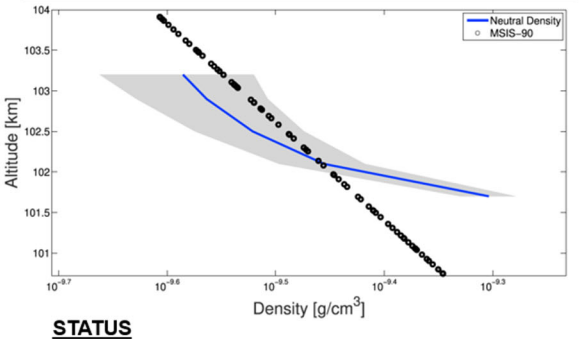
Drs. Tarah Castleberry & Rebecca Blue at the Seventh Annual Technical Meeting.

COE CST RESEARCH TASK QUAD CHARTS

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

Stanford University

Neutral Density derived from Radar-Detected Meteoroids



PROJECT AT-A-GLANCE

- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR(S): Dr. Sigrid Close
- CO-INVESTIGATOR: Dr. Nicolas Lee
- STUDENT(S): Alan Li, Diana Juarez, Lorenzo Limonta, Glenn Sugar

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- LEO spacecraft are routinely struck by impactors, both human-made (space debris) and natural (meteoroids)
- Characterizing the impactor population will help predict threat to the launch and operation of commercial LEO spacecraft

STATEMENT OF WORK

- Improve the probability estimates of the threat of space debris and meteoroids by characterizing their populations.
- Determine the meteoroid bulk density function, identify scattering patterns based on the FDTD 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

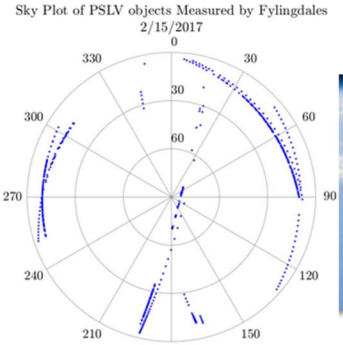
STATUS

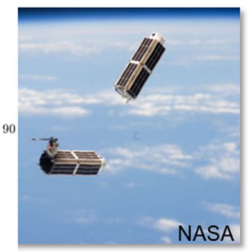
- Developed neutral density determination algorithm
- Improved ablation models to determine ionization efficiency
- Correlated ionization probability with luminous efficiency
- Refined FDTD scattering model

FUTURE WORK

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

367-CU. 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), Ms Shaylah Mutschler

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- 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/prevent successful tracking
- Model and integrate enhanced ground tracking measurements
- Model and integrate on-orbit measurements from deployer
- Develop concept for CubeSat flight experiment
- Recommend practical CubeSat cluster deployment and observation strategies to facilitate tracking success

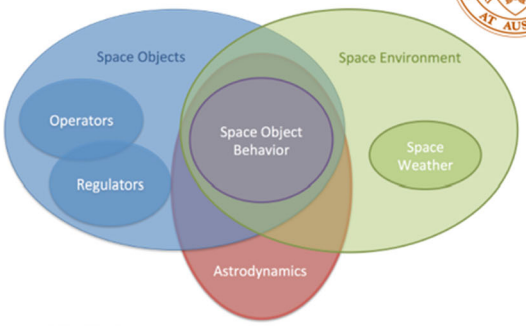
STATUS

- Prior work by J. Gaebler established effective estimation filters and identity management approach (3 journal articles)
- Undergraduate project teams designed/partially built system for in-situ measurements on deployer (2 conference papers)
- Simulations identified characteristics of objects that limit performance of cluster tracking
- Currently analyzing radar data provided by US Space Force

FUTURE WORK

- Complete orbit initialization w/radar data
- Develop deployment and tracking recommendations

371. Ontology-based Space Object Database



PROJECT AT-A-GLANCE

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

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Big Data Science and Analytics Solution to Space Traffic Management.

STATEMENT OF WORK

- Take the initial steps to develop, implement, and federate a Space Domain Digital Twin. Set up an online searchable Digital Collection of these documents that is similar in capability to the Framework for Spaceport Operations.
- Motivate "citizen Science" where people can donate their own sensor/telescope data. Leverage Blockchain technology as a method of STM "cryptocurrency", authentication/identification, and transparent transaction records
- Put together a collection of Open Source Software that can be used to support and enable space traffic management and orbital safety analyses and products. Gather tools like GMAT, Orekit, Tensor Flow, and others that are currently Open Source and leverage those to serve the needs of STM/Orbital Safety

STATUS

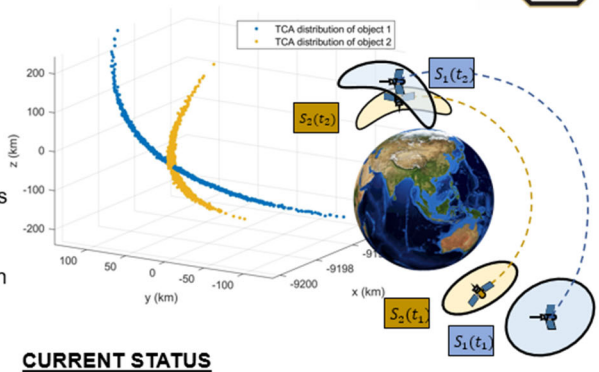
- Autonomously retrieves and processes multiple sources of information and updates a knowledge graph database accessible at http://astria.tacc.utexas.edu/AstriaGraph
- Implemented in NEO4J and successfully commercialized to Privateer Space Inc. (http://www.privateer.com)
- Developed queries for monitoring anthropogenic space object behaviors

FUTURE WORK

- Incorporating Computation Behavioral and Social Science for Cultural Context and Competency
- Implement more realistic uncertainty quantification
- Expand query use cases such as space actor compliance with laws, rules, and regulations. Add ability to "track" liability

327-CU. Resident Space Object System Mechanics

Semi-analytical methods for rapid conjunction analysis for Earth orbiting satellites



PROJECT AT-A-GLANCE

- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. Dan Scheeres
- STUDENT RESEARCHERS: Several PhD students were supported by this task over the last few years, most recently Y. Khatri and J. Greaves.

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Orbit debris remains a fundamental issue for all aspects of space utilization. Specific challenges remain in performing long-term forecasts for specific pieces of orbit debris. While the population of debris is relatively well understood — research advances continue to open new windows on this population.

STATEMENT OF WORK

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

CURRENT STATUS

- Current stage of direct FAA funded research is focusing on predicting space object orbits accounting for uncertainty, improving models for characterizing their dynamics as subject to non-gravitational forces, and investigating optimal evasion maneuvers given a non-zero impact probability.
- Papers presented in 2021 at the IAC in Dubai and AMOS in Maui. Both papers submitted to peer-reviewed journals.
- Paper to be presented at the 2022 IAC in Paris.

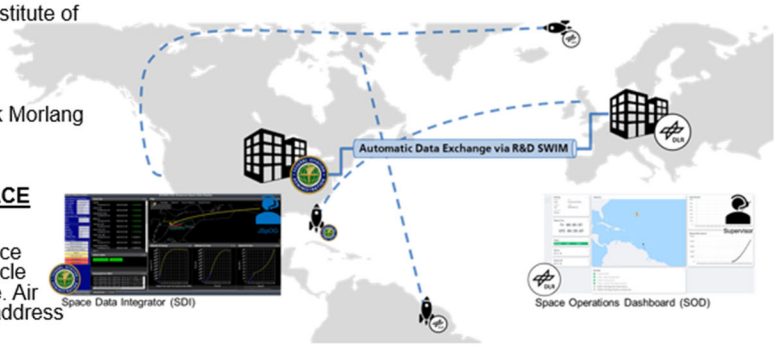
FUTURE WORK

- Project funds are expected to be depleted.
- Research work will on these topics will continue in the future.

375-DLR: Interoperable Air and Space Traffic Management

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 INDUSTRY

- 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.

STATUS

- DLR / FAA-AST Data Exchange Project demonstrated inter-operable solutions integrating space flight operations into ATM.
- Commercial Space Data can be exchanged and utilized for L/R and air traffic management on an international level in realtime.
- The concept is transferrable to other operations (countries).

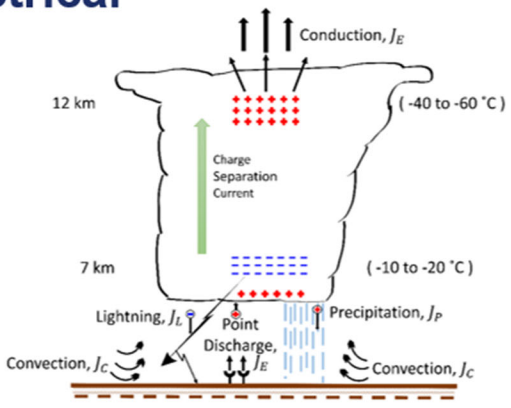
FUTURE WORK

- Work continues within under the DLR/FAA-AST MOC and within the DLR project "Spacetracks" on the development of a Launch Coordination Center for Europe

397-FIT. Measurements of Thunderstorm Electrical Parameters

PROJECT AT-A-GLANCE

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



RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- 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.
- Identify/examine signatures of cloud-charge separation.
- Make suggestions on possible ways to refine cloud rules in the LFCC.

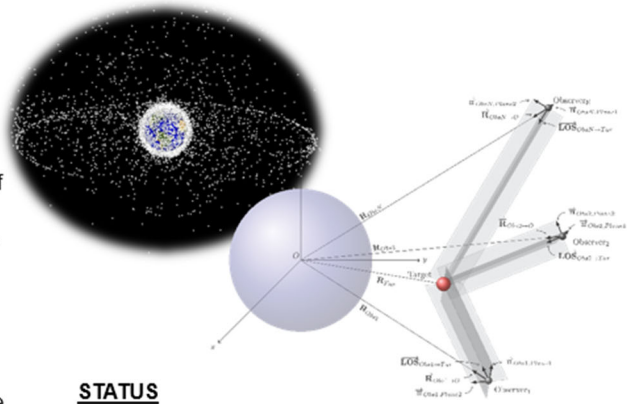
STATUS

- Analyzed Maxwell current, electric field, and lightning datasets.
- Identified thunderstorm conditions in which Maxwell current measurements provided additional information.

FUTURE WORK

- In future projects, more such cases need to be analyzed to determine the statistical consistency of results.

399-UCF. Efficient Uncertainty Quantification, Probability of Collision and Benchmarking



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 INDUSTRY

- **Research:** Developing robust efficient methods for uncertainty quantification provides industry with necessary tools for SSA. .
- **Training:** Next generation of Aerospace Engineers capable of addressing the SSA problem and associated space environment sustainability.
- **Outreach:** Networking with industry (LM Space) to be actively involved in the upcoming CSII

STATEMENT OF WORK

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

STATUS

- Fully perturbed state transition matrix for the orbit problem
- Robust estimation framework in the absence of continuous measurements via accurate propagation of uncertainty.

FUTURE WORK

- Fully perturbed, arbitrary order state transition tensors.
- High order estimation for space-based surveillance and tracking.
- Solution of the multi-revolution Lambert's problem.

430-FIT/PoSSUM: Tomographic Imagery of Noctilucent Clouds

PROJECT AT-A-GLANCE

- UNIVERSITY: International Institute for Astronautical Sciences
- PRINCIPAL INVESTIGATOR: Dr. Jason Reimuller
- STUDENT RESEARCHERS: Adrien Mauduit, Heidi Hammerstein

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- **Research** – Imagery obtained from aircraft and balloon reveal novel processes of turbulence and instability demonstrated through NASA-funded balloon experiment.
- **Training** – operational citizen-science campaigns expose students to systemic planning of research campaigns and foster deeper appreciations of aeronomy.
- **Outreach** - IIAS provides NLC tomography-based courses to over 260 students from over 50 different countries.

STATEMENT OF WORK

- Coordinate imagery of noctilucent clouds (NLCs) from ground observers
- Hold biennial citizen-science aircraft and balloon campaigns to demonstrate and validate that small-scale structures of NLCs observed on the NASA balloon mission may be observed through low-cost, on-demand platforms.

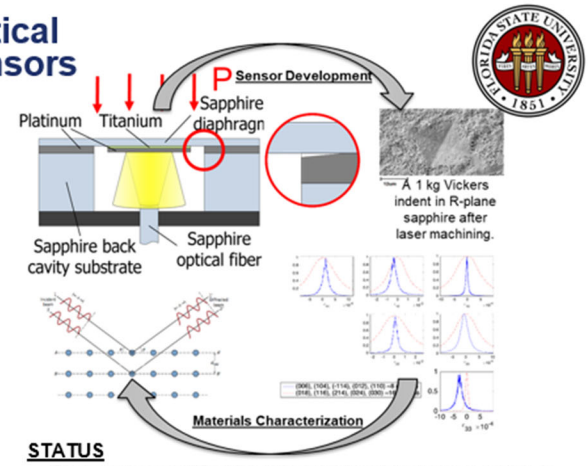
STATUS

- Ongoing ground observations, citizen science app development. Balloon and payload design improvements.
- Presentations at 3 conferences.

FUTURE WORK

- AER 103 course planned for July 2023 with aircraft and balloon deployment to High Level, Alberta.

241-FSU. 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

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Structural health monitoring and control of space vehicles.

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
  - Advantage: Laser machining produces desirable fracture toughness enhancements
  - Disadvantage: Expensive machining process requiring picosecond pulsed, high energy laser
- Approach
  - Use facilities at the National High Magnetic Field laboratory to understand laser induced material changes in sapphire
  - Combine non-destructive x-ray data with advanced Bayesian statistical tools to infer sapphire residual stress
  - Use this information to guide future laser machine manufacturing and sensor packaging to produce reliable high temperature pressure sensors

STATUS

- Rigorously quantified laser induced residual stress states in sapphire
- Developed a new uncertainty quantification method to non-destructively determine residual strain from multi-axial x-ray
- Currently evaluating fracture of sapphire and interface mechanics to support sensor fabrication

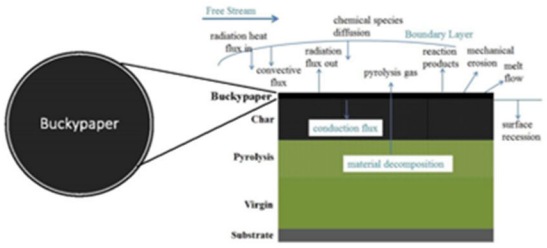
ECONOMIC IMPACT

- Better knowledge of aerodynamics for re-launching space vehicles
- Enhanced rocket engine control enabling better fuel efficiency
- Better understanding of aerodynamics at hypersonic speeds.

FUTURE WORK

- Summarize laser induced residual effects, quantify crack tip toughness, and thermocompression bonding behavior
- Transition results to the manufacturing of pressure sensors for reliable high temperature implementation

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



PROJECT AT-A-GLANCE

- UNIVERSITY: University of Central Florida
- PRINCIPAL INVESTIGATOR: Drs. Jan Gou & Jay Kapat
- STUDENT RESEARCHER: Derek Saltzman and Haonan Song

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Ultra-high temperature ceramic matrix composites (UHTCMC) for planetary entry vehicles, spacecraft launch vehicles, hypersonic vehicles, combustion chambers, gas turbine blades, heat exchangers, etc.

STATEMENT OF WORK

- **Materials Development**: Heat shield material in extreme environments using the buckypaper
- **Process Optimization**: Manufacturing process development of the buckypaper for composite thermal protection systems
- **Testing & Performance Evaluation**: Ground testing with oxyacetylene torch/shock tube/rocket plume/arc jet test
- **Thermal-Mechanical Modelling**: Thermal-mechanical modelling and validation under aerodynamic heating

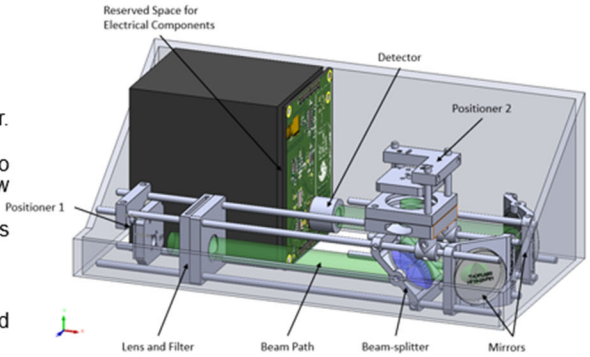
STATUS

- Design, fabrication, and acetylene torch testing of the buckypaper heat shield towards thermal protection
- Computer code development for design of the buckypaper heat shield in extreme environments

FUTURE WORK

- Multi-functional ultra-high temperature ceramic matrix composites by integrating heat shielding and electromagnetic performance, such as radar absorption or penetrating

311-UCF. Robust and Low-Cost LED Absorption Sensor



PROJECT AT-A-GLANCE

- UNIVERSITY: University of Central Florida
- PRINCIPAL INVESTIGATOR(S): Dr. Subith Vasu, Dr. Anthony C. Terracciano
- STUDENT(S): Chelsea Kincaid, Garrett Mastantuono (Veteran), Zachary Rogers, Abbey Havel, Andrew DeRusha, Hamil Patel, Nick Sally, Justin Urso
  - Students 2021-2022 who received internships Giovanni Wancelotti, & Farid Abuid (Veteran)

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- CO_2/CO measurements are relevant to the health and safety of missions, habitats and other structures.
- Time-resolved measurements of CO_2/CO would be able to detect fuming which may lead to fire or explosion.
- Externally placed sensors could detect leaks.

STATEMENT OF WORK

- A sensor is used for the detection of CO_2 and CO.
- An onboard PIC microcontroller will control system functionality and provide data interfacing protocols.
- Use of analog systems and serial LED operation minimizes power draw
- A model of the absorption of the broad-spectrum source characteristic of LEDs are explored for increasing the flexibility and understanding of the sensors response.

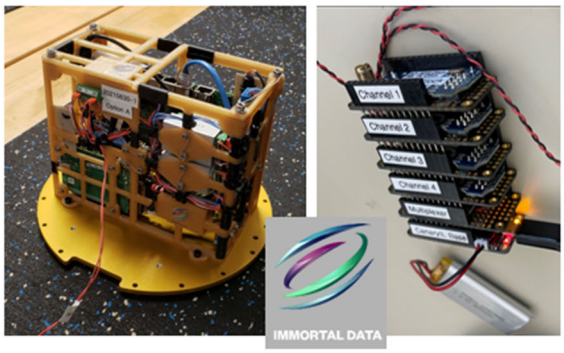
STATUS

- 3 Journal publications, 10 conference publications, over 12 students trained
- Significant expansions of 3D printed components for space applications

FUTURE WORK

- Benchtop testing of structural, electrical, and thermal systems - Shake table, vacuum chamber, various test mixtures
- Sounding rocket, suborbital flight
- Commercial partnering & industry adaptation

323-NMT. Structural Health Monitoring Framework



PROJECT AT-A-GLANCE

- UNIVERSITY: New Mexico Institute of Mining and Technology
- INDUSTRY: Immortal Data, Inc.
- PRINCIPAL INVESTIGATOR: Dr. Andrei Zagrai & Dale Amon
- STUDENT RESEARCHER: Mrs. Funmilola Nwokocha

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- This task is aimed at improving safety and affordability of commercial spaceflights.
- Structural Health Monitoring (SHM) is viewed as enabler of safety inspections for space structures and systems.
- Distributed flight recorder will improve data survivability and assist with accident reporting.

STATEMENT OF WORK

- Develop a portable electro-mechanical impedance SHM unit for integration with commercial space vehicles. This design and development of a multi-channel unit and on-chip data analysis algorithms for the single channel unit for flight testing.
- Design of spacecraft data acquisition system as a precursor of future flight recorder
- Demonstrate SHM integration with the Immortal Data's distributed spaceship's data acquisition system.

STATUS

- Immortal data has developed hardware and software for the distributed flight recorder.
- Multi-channel impedance measurement unit was developed
- Suborbital flight payload demonstrated hardware integration.

FUTURE WORK

- University and industry team will launched a payload with project hardware in November 2022.
- The team intends to collaborate on future implementation of SHM and distributed black box in commercial space vehicles.

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

PROJECT AT-A-GLANCE

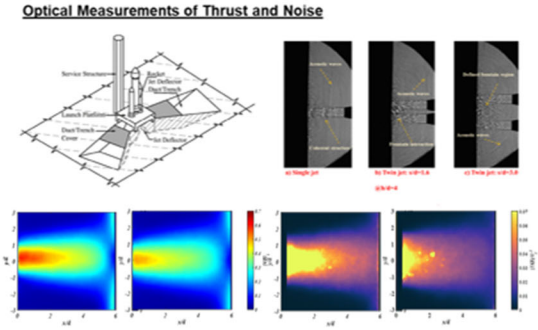
- UNIVERSITY: Florida State University
- PRINCIPAL INVESTIGATOR(S): **Rajan Kumar** & Farrukh Alvi, Jonas Gustavsson, Michael Sheehan
- STUDENT(S): Rohit Vemula, Nikhil Khobragade, Vikas Bhargav, Timothy Willms, Yogesh Mehta (Post-doc)

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Measurement of nozzle thrust, and noise is necessary for the design of future launch and reentry space systems and hypersonic vehicles. The improved aerodynamic performance and propulsion system will help increase payload capacity and safety for many government and commercial space transportation programs.

STATEMENT OF WORK

- Development of a research plan based on state-of-art thrust and noise measurement techniques and discussion with NASA /commercial launch engineers to ensure the transition of technology from lab to full-scale.
- Design of a scaled rocket nozzle to simulate realistic temperature and pressure conditions of the jet exhaust and carry out thrust and noise measurements in the FSU high-speed jet lab.
- Design and develop advanced optical techniques for thrust measurements and characterize its performance at controlled conditions.
- Refine and test the measurement techniques over a wide range of test conditions.
- Flow control system implementation over a wide range of test conditions.
- Simulate take-off and landing conditions of a rocket engine as impinging jet on a launch/landing surface.



STATUS

- Thrust measurements using optical methods
- Extensive testing (velocity, pressure and acoustic surveys as well as load cell measurements) completed
- Implementation of microjet based flow control to delay flow separation
- Noise measurements in the hot jet facility completed
- Cold as well as High-temperature single impinging jet to simulate take-off and landing (unsteady loading and noise).
- Twin jets in different orientations and corresponding pressure, acoustics and flowfield measurements completed.

FUTURE WORK

- Technology transition to industry

377-NMT: Nitrous Oxide Composite Case Testing

PROJECT AT-A-GLANCE

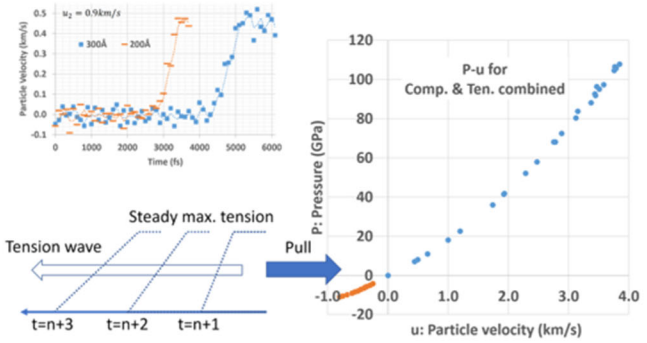
- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR: Dr. Seokbin Lim

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- **Research** – Safety near spacecraft fuel tanks and prediction of fragmentation
- **Training** – Safety of the fuel tank and construction of safe fuel tanks

STATEMENT OF WORK

- Understanding of fragmentation hazards from composite and Al tanks used for fuel/oxidizer storage
- Construction of hypothesis and numerical validation of how cracks form in test samples
- Construction of analytical approach to predict such behaviors (completed)
- 1D Molecular Dynamic code simulation to understand the fundamental mechanism (completed)
- Application of the theory to a series of experiments (in progress)



STATUS

- Two different hypotheses of 1) wave speed based and 2) deformation energy based are built.
- These two hypotheses should be combined together to identify the nature of uniform crack formation.

FUTURE WORK

- Study of the energy consumption per each crack/plastic deformation, and the wave propagation speed depending on the tension load amplitude
- Study of data compatibility between uniaxial strain vs. stress

396-CU: Mapping Life Support System Functions and Technologies to Commercial Spaceflight Applications

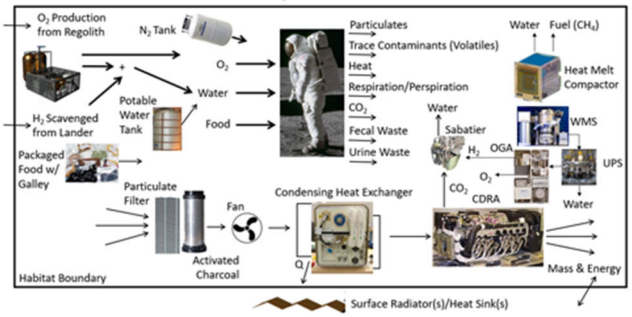
PROJECT AT-A-GLANCE

- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. David Klaus
- STUDENT RESEARCHERS: Kaitlyn Hauber & Hunter Hatchell

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Augments and builds upon *FAA Environmental Control and Life Support Systems (ECLSS) for Flight Crew and Space Flight Participants in Suborbital Space Flight* (Version 1.0, Apr 2010)

Lunar Surface Model ECLSS



STATEMENT OF WORK

- Define basic human physiological needs across a variety of industry standards (FAA, NASA, OSHA, FDA, etc.)
- Characterize corresponding functional ECLSS requirements
- Construct representative ECLSS models for a range of spaceflight profiles (from suborbital to planetary surfaces)
- Identify and characterize candidate ECLSS technologies (including vendors) to inform future trade studies
- Provide considerations for design validation and compliance verification acceptance testing

STATUS

- Klaus, D. and Hauber, K. (2022) *Mapping Life Support System Functions and Technologies to Commercial Spaceflight Applications*. IEEE Aerospace Proceedings (978-1-6654-3760-8/22 paper no. 2531)
- Hauber, K. and Klaus, D. (2021) *Mapping Life Support System Functions and Technologies to Commercial Spaceflight Applications*. (poster) 50th Int'l Conference on Environmental Systems (ICES)
- Final Report submitted to FAA AST on Dec 17, 2021

FUTURE WORK

- Task completed/closed out, potential for CSII follow on activities

398-FIT. 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)
- RESEARCHER: Dr. Troy R Weekes
- STUDENT RESEARCHERS: Kazuhiko Momose, Andrew Biron

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- 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

- Tested 27 participants in two conditions and four input devices, collecting speed, accuracy, and EEG data
- Moving to hyperbaric testing
- Data relates size, distance, accuracy, and mental effort

FUTURE WORK

- Standards for CST instrumentation
- Extension of Fitt's Law to include accuracy
- Relating mental effort to interface construction

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

utmb Health
Working together to work wonders.™

PROJECT AT-A-GLANCE

- UNIVERSITY: University of Texas Medical Branch - Galveston
- PRINCIPAL INVESTIGATORS: Dr. William (Ed) Powers and Dr. Rebecca Blue
- STUDENT RESEARCHERS: 9 Aerospace Medicine Residents

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Provide the commercial space industry with evidence for reducing the risk of flying individuals who would have previously been disqualified medically for space flight.

- **STATEMENT OF WORK**
- Review current literature regarding medical standards for populations working in places analogous to spaceflight.
- Determine the most common medical issues that current commercial spaceflight companies encounter.
- Perform a review of appropriate hardware used for medical monitoring.
- Select a cohort of individuals who have medical conditions that are currently disqualifying for spaceflight and test them under extreme conditions analogous to spaceflight using the selected monitoring equipment.

STATUS

- Abstract presented at 2021 Aerospace Medical Association
- Human centrifuge data collection completed March 2022
- Case studies and other publications currently in work

FUTURE WORK

- Future work includes applying wearable technologies to commercial astronauts in order to further evaluate medical monitoring capability in the space environment.
- Results of these studies will result in revision of current medical standards established for spaceflight.

431-FIT/IIAS: Bioastronautics Research – Space Suit Test and Evaluation

IIAS
International Institute for Astronautical Sciences

PROJECT AT-A-GLANCE

- UNIVERSITY: International Institute for Astronautical Sciences
- PRINCIPAL INVESTIGATOR: Dr. Aaron Persad
- STUDENT RESEARCHERS: Heidi Hammerstein, Brien Posey

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- **Research** – Space suit tech maturation to TRL 7
- **Training** – Immersive education for STEM professionals and students. Evaluations integral to professional courses licensed in State of Connecticut.
- **Outreach –** Participation from members of 53 different countries with outreach programs (PoSSUM13, Out Astronaut, Space for all Nations) serving under-represented populations.

STATEMENT OF WORK

- Evaluate Intravehicular Activity (IVA) space suits in microgravity and high-G environments to quantify comfort, mobility, CO_2 washout, effectiveness of biomonitoring and cooling systems, ad fine motor skills.
- Evaluate IVA space suits in post-landing egress and parachute scenarios, stability in water, functionality of post-landing survivability gear, and raft ingress situations.
- Evaluate Extravehicular Activity (EVA) space suits in gravity-offset and neutral buoyancy conditions.

STATUS

- Annual IVA suit microgravity evaluations from 2015-2019.
- Annual IVA suit postlanding tests held in 2018, 2019, and 2021
- Gravity offset EVA suit campaign held in 2019; initial NBL EVA suit preparatory campaign held in 2021.
- 260 total participants and 2 publications presented.

FUTURE WORK

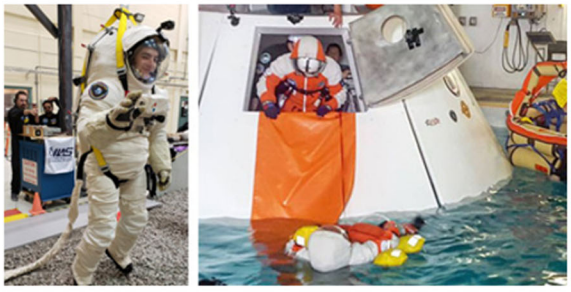
- Annual microgravity, post-landing, and gravity-offset campaigns

432-FIT/IIAS: Human Factors Research

PROJECT AT-A-GLANCE
- UNIVERSITY: International Institute for Astronautical Sciences
- PRINCIPAL INVESTIGATOR: Mr. Ken Trujillo
- STUDENT RESEARCHERS: Brien Posey, Joey Corso

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- **Research** – Human performance studies in space suits of varying pressure levels, cockpit design,
- **Training** – Immersive education for STEM professionals and students. Evaluations integral to professional courses licensed in State of Connecticut.
- **Outreach –** Participation from members of 53 different countries with outreach programs (PoSSUM13, Out Astronaut, Space for all Nations) serving under-represented populations.

STATEMENT OF WORK
- Over 50 experiments conducted in microgravity environments.
- Evaluate human performance in Intravehicular Activity (IVA) and Extravehicular Activity (EVA) space suits in varying pressure settings in microgravity, high-altitude, post-landing, gravity-offset, neutral buoyant, and high-G environments to quantify comfort, mobility, CO2 washout, effectiveness of biomonitoring and cooling systems, ad fine motor skills.



STATUS
- Annual IVA suit microgravity evaluations from 2015-2019.
- Annual IVA suit postlanding tests held in 2018, 2019, and 2021
- Gravity offset EVA suit campaign held in 2019; initial NBL EVA suit preparatory campaign held in 2021.
- 260 total participants and 2 publications presented.

FUTURE WORK
- Annual microgravity, post-landing, and gravity-offset campaigns

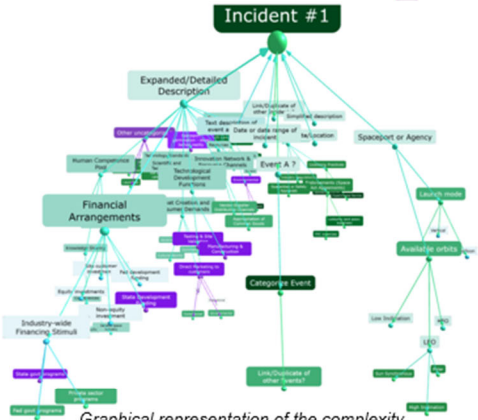
380-NMSU. Spaceports Online Reference Guide

PROJECT AT-A-GLANCE
- University: New Mexico State
- Principal Investigator: Patricia Hynes, Ph.D.
- Student(s): Richard Bailey, Miles Stapleton
- Mark Greby, Research Partner

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- Maintain an updated U.S. Spaceports Online Reference Guide for use by anyone 24/7/365.

STATEMENT OF WORK
- Task 1 – Develop a relational database for researchers to find incidents and events related to Spaceport Emergence. Database allows for efficient searching among data elements related to spaceport activities.
- Task 2 – Update and Maintain the existing U.S. Spaceports Online Reference Guide.

STATUS
- Spaceport Emergence database completed and all in-hand data has been incorporated. Developing submittal product for the FAA
- U.S. Spaceports Online Reference Guide, formerly The Body of Knowledge for Spaceport Operations, updates and repairs are complete



Graphical representation of the complexity involved with categorizing each incident. Incidents are activities, events, or actions.

FUTURE WORK
- Develop submittal package for the Spaceport Emergence Database to the FAA
- Final reports and lessons-learned developed
- Contract closeout

395 & 402-FIT. Emerging Industry Dynamics: Small Satellite Launch Vehicles & Satellite Constellations

FLORIDA TECH

PROJECT AT-A-GLANCE

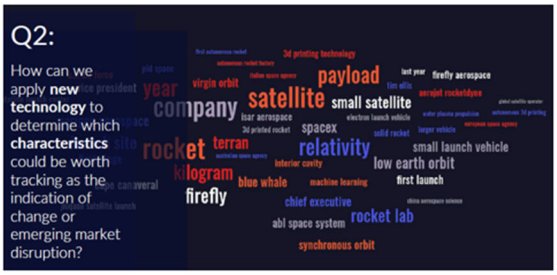
- University: Florida Institute of Technology
- Principal Investigator: Don Platt, Ph.D.
- Student(s): Anna Wojdecka, Djalma Batista

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Provides detailed, time-ordered documentation of major innovation and industry emergence events and relationships for specific industry segments.
- Provides basis for innovation forecasting, for AST to make changes to regulation and regulatory practices to minimize the burden on commercial space transportation industry.

STATEMENT OF WORK

- Develope an event database using the process research data collection methodology, permitting interchangeability of data across similar research projects.
- Develop models of key industry emergerce parameters to possibly identify relationships between independent and dependent variables of interest.
- Participate in collaborative process research workshops.



STATUS

- Approach includes: gather and inspect the data, clean the data, querying the data, classification, industry emergence characteristics, visualization opportunities, and visual storytelling.
- Selected Satellite Applications Catapult as one of the main resources related to Small Satellite Market Intelligence.
- Generated preliminary findings through keyword searches form smallsat launch vehicles and satellite constellations.
- Investigating variety of visualization options to enable analysis insights.

434-FIT/UTPB. Coopetition In Efficient Spaceport Ecosystem Development

THE UNIVERSITY OF TEXAS PERMIAN BASIN
COLLEGE OF BUSINESS

Midland International Air & Space Port

PROJECT AT-A-GLANCE

- UNIVERSITY: University of Texas Permian Basin
- PRINCIPAL INVESTIGATOR: Dr. Steven L. Beach
- STUDENT RESEARCHER: Roshan KC

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- **Research** – analysis of Midland Spaceport role in the Spaceport ecosystem in coopetition framework
- **Outreach** - networking opportunities are provided to participants to build networks that grow the industry

STATEMENT OF WORK

- Investigate cooperative behavior's commercial and development benefits among the competing Spaceport sites.
- A complete analysis of the Commercial Space Transportation industry in terms of a competitive market and cooperative opportunity has not been conducted, nor has there been a focused examination of Spaceports. Any progress in this endeavor will benefit the emergence of this industry as a force for advancing the potential for CST to impact society and mankind positively.

STATUS

- Presented "Coopetition as an Industry Analysis Model for the Commercial Space Transportation Industry" at COE CST Executive Committee Telecon, May 10, 2021.
- Presented "Into a Decisive Decade for High-Speed Aerospace Transportation – Point to Point Focus w Coopetition" at High Speed Aerospace Transportation Workshop, Midland, TX, December 9, 2021.

FUTURE WORK

- Further develop framework and apply to HSAT and the role of the Midland Spaceport.

COE CST STUDENTS, PUBLICATIONS, PATENTS AND AWARDS

Below is information about each COE CST task conducted in the COE CST's final period of performance. Each task starts with a colored banner: red for Research Area (RA) 1: Space Access & Operations, blue for RA2: Aerospace Vehicles, green for RA3: Human Operations & Spaceflight, and orange for RA4: Industry Innovation.

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

Students

• Alan Li

• Diana Juarez

• Lorenzo Limonta

• Glenn Sugar

2021-22 Publications

- 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,
- 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.

Collaborating Organizations

- University of Western Ontario
- NASA Marshall Space Flight Center

241-FSU. High Temperature, Optical Sapphire Pressure Sensors

2021-22 Publications

- Consoliver-Zack, Siegrit & Oates, 2022, "A New Bayesian Uncertainty Methodology for Inferring Strain Gradient Residual States via Multi-Axial X-Ray Data in Single Crystal Sapphire", in preparation.

Student

- Jakob Consoliver-Zack

Collaborating Orgs

- Florida Center for Advanced Aero-Propulsion
- FAMU-FSU College of Engineering

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

Past Student

• Shengheng Gu

Current Students

• Derek Saltzman

2021-22 Publications

- Song, Saltzman, Kapat & Gou, 2021, "Processing and characterization of Continuous Carbon Fiber Reinforced Silicon Oxycarbide Ceramic Matrix Composites," ASME 2021 Intern'l Mech Engineering Congress and Expo

• Haonan Song

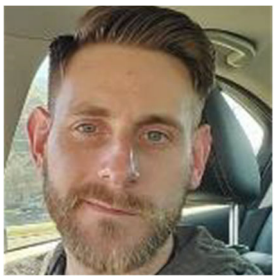
Recognitions

- Inducted as a Fellow of the International Association of Advanced Materials, Jan Gou

311-UCF. Advancement of LED-Based Hazardous Gas Sensors

Students

• Chelsea Kincaid



• Garrett Mastantuono

• Zachary Rogers

• Abbey Havel

• Andrew DeRusha

• Hamil Patel

• Nick Sally

• Justin Urso

Students with Internships

• Giovanni Wancelotti • Farid Abuid

2021-22 Presentations

- Abbey Havel, Andrew DeRusha, Hamil Patel, Chelsea Kincaid, Giovanni Wancelotti , Zachary Rogers, Nickolas Demidovich, Anthony C. Terracciano, Subith S. Vasu, 2022, "Gaseous Absorption Detection for Space Applications (GADSA): An LED Based Early Fire Warning System", SPIE 2022 Defense + Commercial Sensing.
- Hamil Patel, Andrew M. DeRusha, Abbey Havel, Giovanni D. Wancelotti , Zachary L. Rogers, Chelsea M. Kincaid, Justin J. Urso , Nickolas Demidovich, Anthony C. Terracciano, and Subith S. Vasu, 2022, "Rapid Indexable Positioning System (RIPS) for 3D printed aerospace electro optics", SPIE 2022 Defense + Commercial Sensing.
- Zachary L. Rogers, Chelsea M. Kincaid, Hamil Patel, Andrew M. DeRusha, Abbey Havel, Giovanni D. Wancelotti , Garrett T. Mastantuono, Justin J. Urso , James Wilson, Nickolas Demidovich, Anthony C. Terracciano, Subith S. Vasu, 2022, "High efficiency thermoelectric optoelectronic component temperature regulation", SPIE 2022 Defense + Commercial Sensing.
- Chelsea Kincaid, Giovanni Wancelotti , Abbey Havel, Andrew DeRusha, Hamil Patel, Zachary Rogers, Nicholas A. Sally, Nickolas Demidovich, Justin Urso , Anthony C. Terracciano, Subith S. Vasu, 2022, "Embedded systems development for spacecraft MIR hazardous gas detector ",SPIE 2022 Defense + Commercial Sensing.
- Andrew DeRusha, Hamil Patel, Abbey Havel, Giovanni Wancelotti , Zachary Rogers, Chelsea Kincaid, Nickolas Demidovich, Justin Urso , Anthony C. Terracciano, Subith S. Vasu, 2022, "3D Printed Optomechanical Positioners for Aerospace Metrological Instruments", SPIE 2022 Defense + Commercial Sensing.

Collaborating Organizations

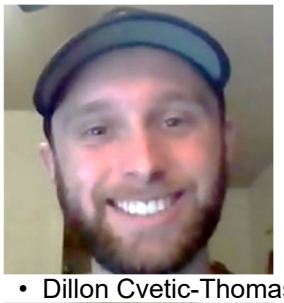
- Oak Ridge National Laboratory
- CATER
- Space Florida
- Florida Space Institute

323-NMT. Structural Health Monitoring Framework

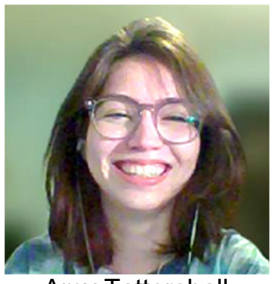
Students

• Funmilola Nwokocha

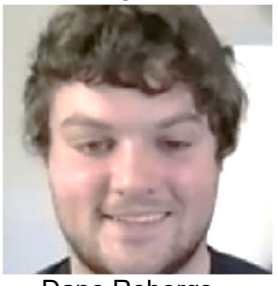
• David Hunter



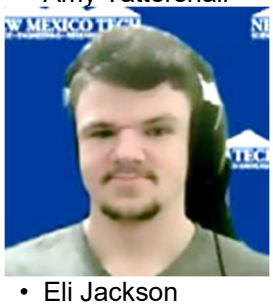
• Dillon Cvetic-Thomas



• Amy Tattershall



• Dane Robergs



• Eli Jackson

2021-22 Publications and Presentations

- Nwokocha, F., Zagrai, A., Hunter, D., 2022, "Multichannel Electromechanical Impedance Structural Diagnostics in Plate Specimens," Proceedings of the ASME 2022 International Mechanical Engineering Congress and Exposition, October 30 – November 3, 2022, Columbus, OH, upcoming.
- Nwokocha, F., Zagrai, A., Amon, D., Hunter,

D., and Demidovich, N., 2022, “Suborbital Test of the Electro-Mechanical Impedance Structural Health Monitoring System,” presentation at Commercial and Government Responsive Access to Space Technology Exchange (CRASTE), 27 - 30 June 2022, Madison, WI, upcoming.
- Nwokocha, F., Hunter, D., Zagrai, A., Amon, D., Cvetic-Thomas, D., Weathers, D., Tattershall, A., Robergs, D., and Jackson, E., 2022, “Electro-mechanical Impedance Structural Health Monitoring as an Integral Component of a Flight Recorder for Space Vehicles,” Proceedings of SPIE Smart Structures + Nondestructive Evaluation, 6-9 March 2022, Long Beach, CA.
- Cvetic-Thomas, D., Tattershall, A., Jackson, E., Robergs, D., Nwokocha, F., and Zagrai, A., 2021, “Mechanical Design and Development of a Suborbital Payload for Real-Time Data Acquisition and Structural Health Monitoring,” Proceedings of the ASME 2021 International Mechanical Engineering Congress and Exposition, paper IMECE2021-71881, November 1-5, 2021, Virtual.
- Amon, D., Zagrai, A., Nwokocha, F., Hunter, D., and Demidovich, N., 2021, “Structural Health Monitoring as a Part of Spaceship’s Data Acquisition System,” presentation at Commercial and Government Responsive Access to Space Technology Exchange (CRASTE), June 21 - 24, 2021, Virtual.
- Zagrai, A., 2021, “Structural Health Monitoring of Spacecrafts: from Assembly to Deployment and Operation,” presentation at the virtual International Conference on Condition Monitoring, Jharkhand, India, 21–22, January 2021.

Collaborating Organizations

- Immortal Data, Inc

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

2021-22 Publications

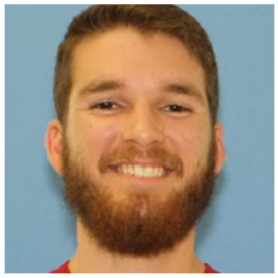
- Mehta, Bhargav, and Kumar.,”Control of High Temperature Impinging Jet Issued from Overexpanded Rocket Nozzle”, Journal of Spacecraft and Rockets (to be submitted).
- Mehta, Y., Bhargav, V., and Kumar, R., “Characterization and Control of High Temperature Impinging Jet Issued from a Mach 4 Rocket Nozzle,” AIAA SCITECH Forum, January 2022.
- Mehta, Y., Natarajan, K., Sellappan P., Gustavsson, J., and Kumar, R.,”Effect of Nozzle Spacing in Supersonic Twin Impinging Jets,” AIAA Journal, Vol 60 No 4 pp 2423-2440.
- Mehta Y., Natarajan K., Gustavsson J., Kumar R., 2021 An experimental investigation into the effect of nozzle spacing in supersonic twin jets AIAA Scitech 2021 Forum.
- Mehta, Y., Bhargav, V., Natarajan K., and Kumar, R., “Experimental Characterization and Control of an Impinging Jet Issued from a Rocket Nozzle,” New Space, Vol 9 No 3 2021 pp 187- 201.

Students


- Jonas Gustavsson


- Michael Sheehan


- Rohit Vemula


- Nikhil Khobragade


- Samuel Lee


- Timothy Willms


- Vikas Bhargav


- Yogesh Mehta

Collaborating Organizations

- Florida Center for Advanced Aero-Propulsion
- Space Florida
- SpaceX

367-CU. CubeSat Deployment Tracking

Students

• Laura Davies

• Shaylah Mutschler

2021-22 Publications

• Axelrad, P., "Tracking Clustered CubeSat Deployments," Invited Talk Stanford Center for Position, Navigation & Time (SCPNT) Symposium, October 27, 2021.

• John Gaebler

Awards

• Vantage Senior Project Team (2020) Department Award for Best Technical Understanding.

371-UTA. Ontology-based Space Object Database

Students

• Shiva Iyer • Nevan Simone • Kartik Nagpal

372-CU. Resident Space Objects

Students

• Yashica Khatri

• Jesse Greaves

2021-22 Publications

• J. A. Greaves and D. J. Scheeres. 2021, "Observation and Maneuver Detection for Cislunar Vehicles," Journal of the Astronautical Sciences 68: 826 854.
• Jesse Greaves, D.J. Scheeres, 2021. "Relative Estimation in the Cislunar Regime using Optical Sensors." AMOS Conference, September 15 17, 2021. To be submitted to JGCD.
• Y. Khatri, D.J. Scheeres, 2021, !Nonlinear Semi Analytical Uncertainty Propagation for Conjunction Analysis.! IAC Conference, October 25 29, 2021. Submitted to Acta Astronautica.

Awards

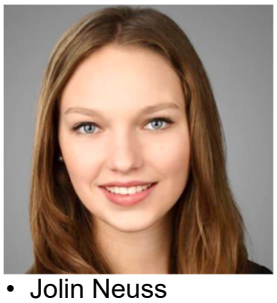
• 2021, Amelia Earhart Fellowship, Y. Khatri
• 2022, Tau Beta Pi Fellowship, Y. Khatri

Collaborating Organizations

• AGI

375-DLR. Interoperable Air and Space Traffic Management

Student



• Jolin Neuss

2021-22 Publications

• Klünker, Carmo Sonja und Kaltenhäuser, Sven und Schmitt, Dirk-Roger, 2021, "Grenzüberschreitender Austausch von Raumfahrzeugdaten zur sicheren und effizienten Durchführung von Weltraum-aktivitäten." Deutscher Luft-und Raumfahrt Kongress (DLRK), 31 Aug - 02 Sep 2021, Bremen.
• Klünker, Carmo Sonja und Neuß, Jolin, 2021, "Data Exchange Project (DEP) Eine Kooperation des Deutschen Zentrums für Luft- und Raumfahrt (DLR) und der Federal Aviation Administration (FAA)." Deutscher Luft- und Raumfahrt Kongress (DLRK), 31 Aug - 02 Sep 2021, Bremen.
• Kaltenhäuser, Sven und Klünker, Carmo Sonja, 2021, "Cross-border exchange of spacecraft data for the safe and efficient execution of space activities." FAA Quick Look, 30 November 2021.
• Kaltenhaeuser, S., Morlang, F., Schmitt, D.-R., 2022 (planned), "Interoperable data exchange for safe and efficient launch and re-entry operations in an international environment", IAC 2022, Paris, upcoming.

376-MU/FIT. Legal Issues Concerning Suborbital Flight

Student

• Mr. Bayar Goswami

377-NMT. Composite Case Testing

Students

- Christopher Rood
- Matthew Hirsch

- Angel Chavira
- Don Ryu

2021-22 Publications and Presentations

- Seokbin (Bin) Lim PhD, Christopher Rood, Angel Chavira, Matthew Hirsch, Don Ryu, "Extreme Tension Wave Profile in Aluminium", APS March Meeting 2021.
- Seokbin (Bin) Lim PhD, Christopher Rood, Angel Chavira, Don Ryu, "Characteristics of Extreme Tension Wave and Necking in Al6061", SEM Annual conference 2021.
- Seokbin (Bin) Lim PhD, "Explosively Driven Fracture & Fragmentation Patterning in Cylinder – Extreme Tension Physics: Preliminary Study", NSMMS & CRASTE 2022, abstract submitted and accepted.

380-NMSU. Spaceport Operations Online Reference Guide / Spaceport Industry Emergence Research

Students

- Chase Bailey

- Miles Stapleton

Research Partner

- Mark Greby, PE

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

Students

- Anna Wojdecka

- Djalma Batista

396-CU. Mapping Life Support System Functions and Technologies

Students

- Kaitlyn Hauber

- Hunter Hatchell

2021-22 Publications and Presentations

- Klaus, D. and Hauber, K., 2022, "Mapping Life Support System Functions and Technologies to Commercial Spaceflight Applications". IEEE Aerospace Proceedings (978-1-6654-3760-8/22 paper no. 2531).
- Klaus, D. "FAA AST Senior Management and Staff Briefing, COE CST Research Area 3: Human Spaceflight Tasks," virtual event, December 2020.
- Hauber, K., "Mapping Life Support System Functions and Technologies to Commercial Spaceflight Applications". (student poster) 50th Int'l Conference on Environmental Systems (ICES), July 2021.
- Klaus, D., "Mapping Life Support System Functions and Technologies to Commercial Spaceflight Applications". IEEE Aerospace Conference, Big Sky, MT, April 2022.

Awards

- 1st place for "Characterizing Non-invasive Biometric Sensors For Use In Task Performance Prediction And Operational Design", NASA Human Research Program (HRP) Investigators' Workshop Annual (Virtual) Meeting, Feb 2022, Kaitlyn Hauber.
- 2021 CU College of Engineering & Applied Science Dean's Faculty Performance Award, Dave Klaus.
- 2021 CU Aerospace Department Distinguished Performance Award, Dave Klaus.

397-FIT. Measurements of Thunderstorm Electrical Parameters

Student

- Mathieu Plaisir

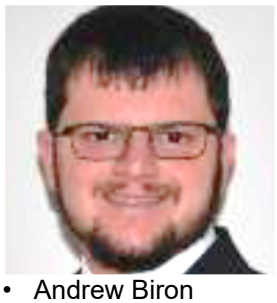
Collaborating Orgs

- Florida Institute of Technology
- Vaisala Inc.
- NASA Kennedy Space Center

398-FIT. Human Input Systems

Students

- Kazuhiko Momose



- Andrew Biron

2021-22 Publications

- Momose, K., Weekes, T.R., and Eskridge, T.C., 2021, "Human Centered Design for Spaceflight Participant Safety and Experience: A Case Study of Blue Origin Suborbital Flight". New Space Journal , online 11 Nov 2021.

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

2021-22 Publications

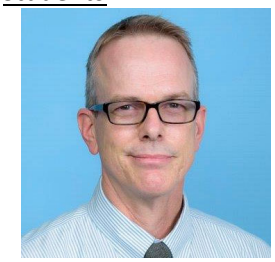
- Tasif, Tahasinul H.; Hippelheuser, James; and Elgohary, Tarek A., "Analytic Continuation Extended Kalman Filter Framework for Space-Based Inertial Orbit Estimation via a Network of Observers", IAA Space Traffic Management Conference, January 26 – 27, 2021.
- Tasif, Tahsinul Haque; and Elgohary, Tarek A., "A Computation Process for the Higher Order State Transition Tensors of the Gravity and Drag Perturbed Two-Body Problem using Adaptive Analytic Continuation Technique", The International Conference on Computational and Experimental Engineering and Sciences (ICCES 2022), January 2022.
- Tasif, Tahsinul H.; Hippelheuser, James; and Elgohary, Tarek A., "An Analytic Continuation Extended Kalman Filter Framework for Perturbed Orbit Estimation Using a Network of Space-Based Observers with Angles-Only Measurements", Astrodynamics (2022). In Press.

Student

- Tahsinul Haque Tasif

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

Students



- Michael Rhode

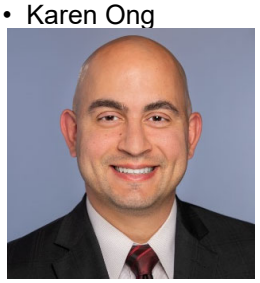
- William Fernandez

- John Marshall

- Quinn Dufurrena

- Karen Ong

- Kristy Ray



- Bashir El-Khoury

- Brian Hanshaw

Collaborating Orgs

- Center for Polar Medical Operations at UTMB
- Environmental Tectonics Corp (ETC) - National Aerospace Training and Research (NASTAR)

- Isaiah Reeves

2021-22 Presentations

- "Development of Commercial Space Occupational Medicine Health Standards" Abstract presented at the 2021 Aerospace Medical Association Annual Meeting.

Center of Excellence for
Commercial Space Transportation