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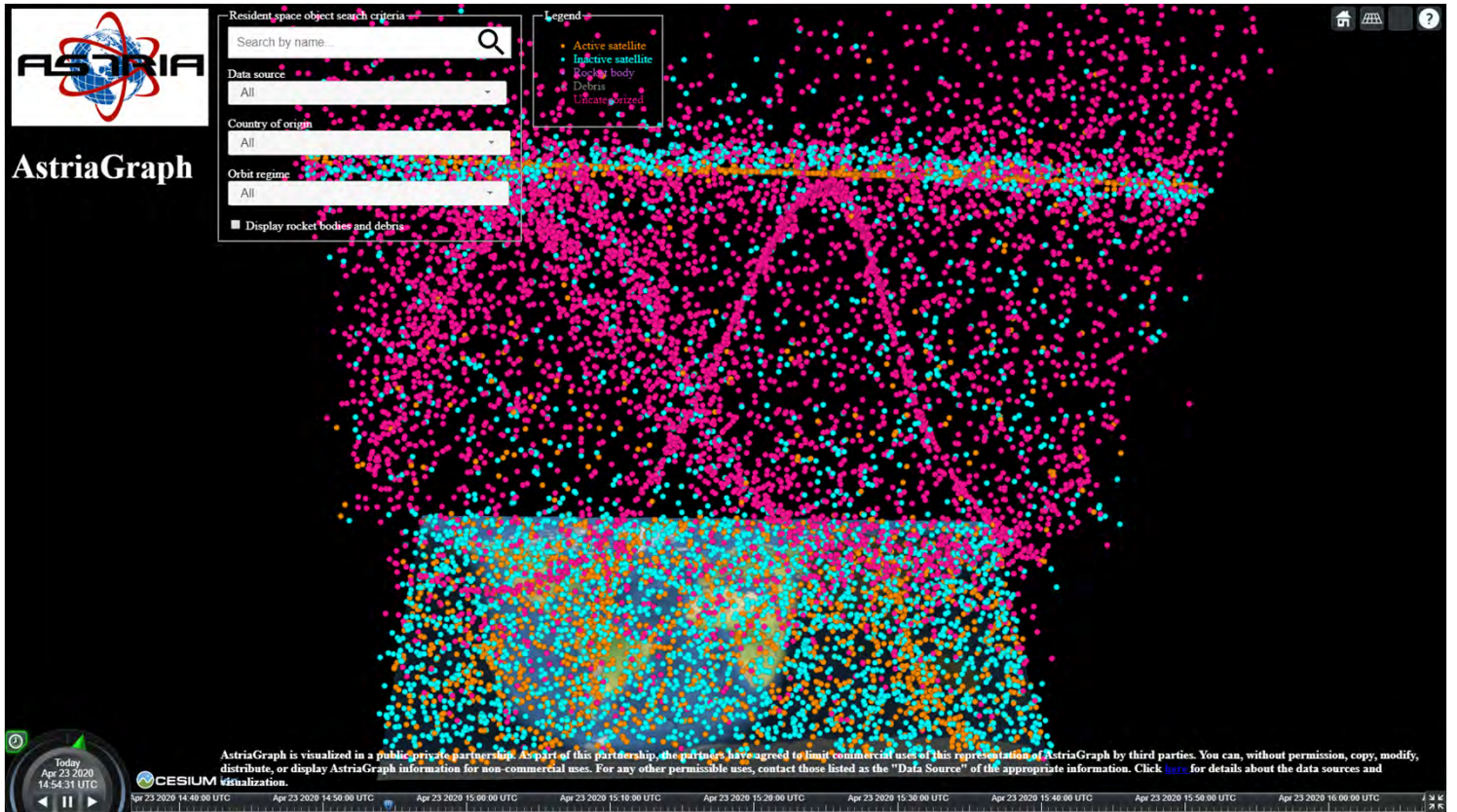
Center of Excellence for
Commercial Space Transportation

**Federal Aviation Administration
Center of Excellence for
Commercial Space Transportation**

Year 9 Annual Report

Executive Summary

April 30, 2020



ASTRIAGraph (URL: <http://astria.tacc.utexas.edu/AstriaGraph>), an “open, transparent, and crowdsourced space traffic and environment monitoring and awareness system,” is the work of **Dr. Moriba Jah** at the University of Texas Austin, funded by the COE CST. As part of the ASTRIAGraph public-private partnership, the partners have agreed to limit commercial uses of any representations of by third parties. On this page, two planar ASTRIAGraph displays show active and inactive satellites, not including rocket bodies and debris. A screen capture of the spherical display can be seen on page 21 of this report.

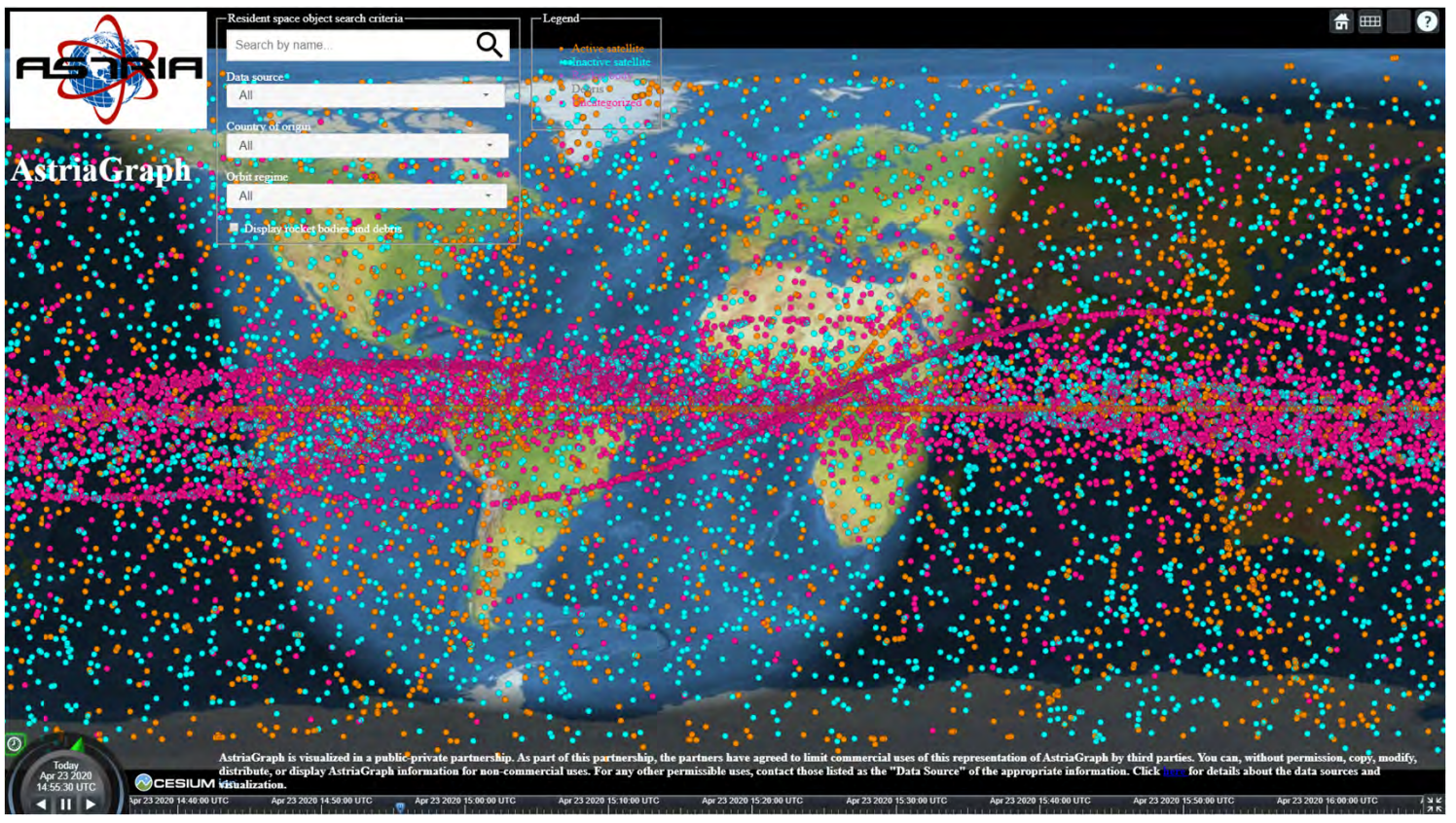




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LETTER FROM THE EXECUTIVE DIRECTOR



During our 9th year of operations, in addition to continuing the ongoing research tasks, we have worked to solidify our relationships with the Affiliate and Associate Members, begun focusing on the ultimate close out process to ensure all reporting obligations are fulfilled, updated the web page, and initiated discussions for potential post-COE CST era research opportunities. These and other topics were addressed at our Ninth Annual Administrative Meeting (AAM9), held in April at the Florida Institute of Technology in Melbourne. At the time, we had intended to conduct the Ninth Annual Technical Meeting (ATM9) in conjunction with the International Symposium for Personal and Commercial Spaceflight (ISPCS) in October 2019 and discussed plans for doing so.

The past year was not without challenges, however, namely with research and meeting plans being significantly impacted by uncertainties in funding. As prior tasks ended, the anticipated June 1 start date for the next round came and went with no clear decision target indicated on the horizon. Consequently, given the lead times associated with integrating sessions into a conference agenda and allowing sufficient advance notice for making travel plans to attend, we were forced to forgo participation with ISPCS in October and began looking for a later venue to host ATM9. After much discussion on several viable alternatives, we found an excellent fit with the Next-Generation Suborbital Researchers Conference (NSRC) in March 2020, organized by the Southwest Research Institute (SwRI) and the Commercial Spaceflight Federation (CSF), and arranged a tentative agreement for the COE CST to participate in this meeting with a series of dedicated sessions. Unfortunately, as the agenda was being finalized and the time to commit to attending arrived with still no definitive expectation of funding availability, we had to withdraw and decided to cancel the ATM9 altogether.

February 2020 finally brought some good news with the final round of COE CST funding fully released and the principal investigators now able to resume their research plans, just in time for the COVID-19 pandemic to wreak its havoc across the globe and force schools into remote operations, presenting an unprecedented impact to our education and research missions. At the time of this writing, it is looking hopeful that we may be on the verge of reopening facilities and I anticipate fully engaging the COE CST again as we move into the final phase of center operations, with research tasks getting underway and plans for AAM10 and ATM10 being formulated. We are looking forward to a strong finish and exploring new beginnings!

David Klaus, PhD
Professor, Aerospace Engineering Sciences
Executive Director, COE CST





PREFACE

The Federal Aviation Administration (FAA) Office of Commercial Space Transportation (AST) is pleased to release this FAA Center of Excellence for Commercial Space Transportation (COE CST) Year 9 Annual Report Executive Summary.

The COE CST is now a collection of ten incredible universities, supplemented by affiliate and associate members, and complemented by numerous private organizations and research institutions. The collective effort of these organizations and individuals, including the principal investigators (PIs), students, financial officers, contractors, business women (and men), executives, and administrators, makes the COE CST research possible. They provide matching cash and in-kind contributions, post the extensive technical and financial data for government-required reports, and fundamentally make the overall system function efficiently.

The first years of COE CST operation focused on building the many required relationships (e.g., research, administrative, financial, personal, etc.) between university and government individuals. Although the budget of the Center may be relatively small, the complexity of the network makes its smooth operation more challenging than what may be encountered at COEs with more universities and larger budgets. Despite this complexity, the COE CST has successfully emerged as a fully functional, cohesive unit.

Year 6 began the second half of the ten-year program. The FAA emphasized raising the COE CST profile with industry, to better familiarize universities with needs of the evolving commercial space marketplace, and to be better understood by the major marketplace actors.

2018-19 were tumultuous times for all COEs. Increased oversight on the award of grant funding, and leadership changes in and above the COE Program Office, interrupted the cadence of COE CST funding, research, and technical meetings. The repercussions and delays caused by these changes were deeply felt throughout the COE CST membership and management. Only recently, with the start of 2020, has the sense of stability and operational normalcy returned to our Center, and the PIs and government officials directly involved are all glad to get back to work.

With the culmination of Year 9, however, the COE CST is entering its final planned year of operation. Due to the delays of the recent years, the Center period of performance has been extended through August 2022 to ensure the universities' ability to spend all the recently-awarded grant funding. I want to thank all the COE CST individuals, representing the dozens of participating organizations and institutions, for their patience and continuing support of this research consortium. I cannot thank them enough for their contributions of time and effort.

For more information about the content of this report, please visit the COE CST web site at www.coe-cst.org. Please address any questions or corrections to Dr. Ken Davidian (202-267-7214, ken.davidian@faa.gov) or Dr. Karl Garman (202-267-0614, karl.e.garman@faa.gov).

INTRODUCTION

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

The Executive Summary begins with overviews of the FAA Office of Commercial Space Transportation (the sponsoring organization), the FAA COE Program and the COE CST. The COE CST became operational on August 18, 2010, with nine members. It has subsequently added an additional core university, as well as numerous Affiliate and Associate organizations, representing both academia and industry. Brief introductions and general descriptions are provided for each of the COE CST Member



Universities, the Affiliate Members, and the FAA Technical Monitors for the COE CST research tasks. Next, this document describes the overall scope of COE CST research areas, and lists each of the research tasks initiated, conducted and concluded by the COE CST during the ninth year of operation. The report provides summary information about each task in the form of quad charts. The Executive Summary concludes with a listing of the COE CST students, the partnering institutions from industry, the research organizations, and the technical publications delivered during the year.

OVERVIEWS

FAA OFFICE OF COMMERCIAL SPACE TRANSPORTATION

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

- Regulate the U.S. commercial space transportation industry, to ensure compliance with international obligations of the United States, and to protect the public health and safety, safety of property, and national security and foreign policy interests of the United States;
- Encourage, facilitate, and promote commercial space launches and reentries by the private sector;
- Recommend appropriate changes in Federal statutes, treaties, regulations, policies, plans, and procedures; and
- Facilitate the strengthening and expansion of the United States space transportation infrastructure.

FAA CENTER OF EXCELLENCE PROGRAM

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

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

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

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

- **The Center of Excellence for Technical Training and Human Performance (TTHP)** (on the web at coetthp.org), was established in 2016. The core focus of the COE for TTHP includes curriculum architecture, content management and delivery, simulation and part task training, human factors, analytics, safety, and program management. Core members include Auburn University, Drexel University, Embry-Riddle Aeronautical University (technical co-lead), Inter American University, Oklahoma State University, Purdue University, Tennessee State University, the Ohio State University, the University of Akron, the University of Oklahoma (technical co-lead), Tulsa Community College, University of Nebraska-Omaha, University North Dakota, University of Wisconsin – Madison, Western Michigan University, and Wichita State University (administrative lead).



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

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

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



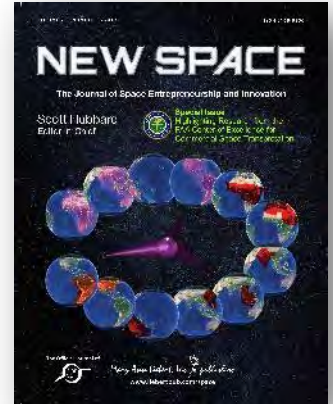
FAA CENTER OF EXCELLENCE FOR COMMERCIAL SPACE TRANSPORTATION

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

COE CST YEAR 9 HIGHLIGHTS

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

- **The Ninth Annual Administrative Meeting (AAM9)** was held at the Florida Tech (FIT) Center for Aeronautics and Innovation on April 1, 2019. During this meeting, many administrative topics were discussed, the most important being the lengthy concurrence process that had been implemented to allocate research grant funding. COE CST Executive Director, Dr. Dave Klaus (from the University of Colorado Boulder), led the discussions about bylaws and Affiliate/Associate membership.
- **New Space** (the official journal of the COE CST) completed its seventh year, featuring a wide range of topics pertaining to non-governmental aspects of space activities. *New Space* volume 7, issue 1 consisted entirely of COE CST research publications (cover shown in figure right).
- **Research Area Workshop** – Dr. Andy Aldrin (FIT) conducted a workshop focusing on the Industry Innovation research area. The focus topics of this workshop included the small launch vehicle sector, regulatory initiatives, and public-private partnerships. Guest lecturers and speakers included Dr. Greg Autry (University of Southern California), Mr. Chad Anderson (Space Angels), Mr. Jim Cantrell (Vector), Mr. Rich Dabello (Virgin Orbit), Dr. Alex MacDonald (NASA HQ).



COE CST YEAR 9 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.

In Year 9 of COE CST operation, 22 principal investigators (PIs) and 34 students conducted 20 research tasks, resulting in 24 technical publications. This Executive Summary presents summary charts (aka "quad charts") for each task, and provides a complete list of students and the resulting publications.

COE CST Metrics	Year 1 (FY10)	Year 2 (FY11-12)	Year 3 (FY13)	Year 4 (FY14)	Year 5 (FY15)	Year 6 (FY16)	Year 7 (FY17)	Year 8 (FY18)	Year 9 (FY19)
Active Tasks	34	24	28	28	36	22	14	27	20
Unfunded Tasks	34	22	22	11	6	5	2	5	14
Principal Investigators	27	28	29	25	31	22	21	22	22
Students	31	37	55	47	61	28	23	38	34
Publications	0	38	28	22	29	19	36	23	24
Affiliate Members	0	1	6	6	6	6	8	10	14
Associate Members	-	-	-	3	6	3	3	8	8
Funding Profile (\$M)	2.0	2.4	1.1	1.1	1.0	1.0	1.4	1.6	2.1



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

FAA AST TECHNICAL MONITORS

FAA AST Technical Monitors (TMs) are the links between FAA’s research requirements and the work being performed by COE CST member universities. Below is a listing of the FAA COE CST TMs who contributed to the research efforts of the COE CST in year 9:

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

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 in 2019 include the Baylor College of Medicine (BCM), Florida Institute of Technology (Florida Tech), Florida State University (FSU), New Mexico Institute of Mining and Technology (NMT, or New Mexico Tech), New Mexico State University (NMSU), Stanford University (SU), University of Central Florida (UCF), University of Colorado at Boulder (CU), University of Florida (UF), and the University of Texas Medical Branch at Galveston (UTMB). Collaborating Members are those universities conducting research under sub-grant to a Core Member university.

CORE AND COLLABORATING MEMBERS

COE CST member universities provide a comprehensive distribution of geographical coverage representing the entire commercial space transportation industry, including the top four civil space states (California, Colorado, Texas, and Florida) and New Mexico, the state leading the suborbital industry as well as having a significant level of military space activity. As a single entity, the COE CST bring complementary strengths together for the benefit of the overall COE. FAA finds that each team member provides highly respected and accomplished experiences that directly address the research and study needs of the commercial space industry. Combined, the universities bring a large number of organizations (government, industry, and academic) into the COE CST network as research partners.

BAYLOR COLLEGE OF MEDICINE (BCM)

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



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



FLORIDA INSTITUTE OF TECHNOLOGY (FLORIDA TECH)

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



FLORIDA STATE UNIVERSITY (FSU)

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



NEW MEXICO INSTITUTE OF MINING AND TECHNOLOGY (NMT)

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



NEW MEXICO STATE UNIVERSITY (NMSU)

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



STANFORD UNIVERSITY (SU)

SU brings a 50-year history of aerospace research excellence and a broad scope of expertise to the COE CST, including the optimization and autonomous operation of complex systems, strategic research planning, organizational integration and distributed administration experience. More information can be found on the web at www.stanford.edu.





UNIVERSITY OF CENTRAL FLORIDA (UCF)

UCF, as partners of Florida Center for Advanced Aero-Propulsion (FCAAP) and the Center for Advanced Turbines & Energy Research (CATER), offers its experience and expertise in thermal protection system, propulsion system components, cryogenic systems and materials, composites, sensors and actuators, and guidance and control. More information can be found on the web at www.ucf.edu.



UNIVERSITY OF COLORADO AT BOULDER (CU BOULDER)

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



UNIVERSITY OF FLORIDA (UF)

UF has been performing aeronautical and aerospace research since 1941, with current emphasis in the Department of Mechanical and Aerospace Engineering on research in space systems, MEMS, computational sciences, structural dynamics, controls, gas dynamics, and propulsion. More information can be found on the web at www.ufl.edu.



UNIVERSITY OF TEXAS MEDICAL BRANCH (UTMB)

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



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

UNIVERSITY OF SOUTHERN CALIFORNIA (COLLABORATOR TO FLORIDA TECH)

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



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

The Cockrell School of Engineering at The University of Texas at Austin is a top-ranked epicenter of engineering education, and knowledge creation and distribution. Comprised of renowned educators, researchers and thought leaders, the Cockrell School addresses the grand challenges of the world, drives economic progress and improves quality of life. The Cockrell





School educates future engineering leaders who think creatively, work collaboratively, and push technological boundaries; develops innovative solutions through groundbreaking research; and improves lives throughout the world by leveraging the school's entrepreneurial ecosystem and partnerships with industry to translate research into practice. More information can be found on the web at www.engr.utexas.edu/about.

Affiliate & Associate Members

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

AFFILIATE MEMBERS

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

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

CARMINATI LAW PLLC (HOSTED BY CU BOULDER)

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

DANISH AEROSPACE COMPANY (HOSTED BY BCM)

Danish Aerospace Company (DAC) is a high-tech company operating in the area of advanced medical instrumentation and other engineering fields primarily within space applications. Their products are based on many years of specialized research and development. These consist of developing, integrating, and applying new as well as established medical technologies to the challenges of functioning and remaining reliable in space. These products and services bring the potential of space





research and experience from space operations down to Earth for the benefit of all Mankind. More information can be found on the web at danishaerospace.com/en.

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



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

ETC NASTAR (HOSTED BY UTMB)



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

EXOS AEROSPACE SYSTEMS & TECHNOLOGIES (HOSTED BY NMSU)



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

IMMORTAL DATA (HOSTED BY NEW MEXICO TECH)



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

MCGILL UNIVERSITY (HOSTED BY FLORIDA TECH)



McGill University's Institute of Air and Space Law (IASL) is the world's premier academic setting for teaching and research in the dual disciplines of international air law and space law. Having celebrated its 65th year of continuous existence in 2016, the Institute is now on course to consolidate and enhance its record of achievement in the five years leading to its 70th



anniversary in 2021, the same year that McGill University itself will turn 200. More information can be found on the web at www.mcgill.ca/iasl/.

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

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



PRINCETON SATELLITE SYSTEMS (HOSTED BY NMT)

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



PROJECT POSSUM (HOSTED BY FLORIDA TECH)

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



SOLSTAR (HOSTED BY NMSU)

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



SOVARIS AEROSPACE (HOSTED BY CU BOULDER)

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





UNIVERSITY OF NORTH FLORIDA (HOSTED BY NMSU)

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



UNIVERSITY OF TEXAS PERMIAN BASIN (UTPB, PENDING)

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



ASSOCIATE MEMBERS

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

ASTM INTERNATIONAL

Committed to serving global societal needs, ASTM International positively impacts public health and safety, consumer confidence, and overall quality of life. They integrate consensus standards, developed with our international membership of volunteer technical experts. Over 12,000 ASTM standards operate globally. Defined and set by ASTM International, the standards improve the lives of millions every day. More information can be found 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 the creation of thousands of high-tech jobs driven by billions of dollars in investment. Through the promotion of 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 mission of the Commercial Spaceflight Federation (CSF) 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 own research, as Germany's space agency, DLR has been given responsibility by the federal government for the planning and implementation of 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.





Professor David Klaus received the 2019 International Conference on Environmental Systems (ICES) Award for Technical Excellence

At the 49th ICES meeting held in Boston in July 2019, it was announced that Dr. Klaus was selected as the recipient of the Conference's *Award for Technical Excellence* in recognition for his multi-decade effort in establishing an academic focus in Bioastronautics and mentoring hundreds of students in this field. ICES was started in 1971 with a focus on the dissemination of technical and scientific information on topics related to humans living in space and working in extreme environments.



Smithsonian Solstar Space

In 2019, the Smithsonian Air and Space Museum added hardware developed by COE CST Affiliate Member, Solstar Space Company, that was flown into space in 2018. In a November 2019 website post,² Solstar CEO Brian Barnett wrote "Solstar Space Company's Schmitt Space Communicator has been accessioned into the Smithsonian's National Air and Space Museum's collection. Dr. Martin Collins, curator of the museum's civilian application satellites collection, presented Solstar Space Company CEO M. Brian Barnett the official deed of gift accepting the donation in Washington, D.C. last week.

"Solstar's Schmitt Space Communicator SC-1x prototype first flew to space onboard Blue Origin's rocket 'New Shepard' on April 29th, 2018. Solstar Space Company achieved the first commercial Wi-fi hotspot and commercial internet service, sending the first commercial tweet from space. The Schmitt Space Communicator demonstrated the Wi-Fi hot spot service inside and outside the spacecraft, for second time on July 18, 2018."

Dr. Moriba Jah Selected as 2019 TED Fellow

Dr. Moriba Jah was selected as a 2019 TED Fellow, and gave a TED talk in April, 2019 in Vancouver, Canada. His profile and presentation can be viewed on the web.³ Dr. Jah monitors orbital debris with ASTRIAGraph, a crowd-sourced, citizen-science, visually searchable database platform.⁴ ASTRIAGraph makes information about space traffic openly available with the goal of making space safe, secure, and sustainable.



Solstar Space Receives Mobile Satellite Users Association Award

As announced in a March 11, 2020 news release,⁵ Solstar received another award associated with flights of their Schmitt Space Communicator in 2018. Solstar received the Chairman's Award for Outstanding Innovation for User Community Development," which celebrates the engagement of "new and expanding user communities to aid in the adoption of and use cases for satellite connectivity." Solstar's technology provides data communications services using MSS satellites and ground infrastructure, enabling Wi-Fi access to astronauts, future human spaceflight participants, and Wi-Fi enabled space experiments.

² On the web at <https://solstarspace.com/solstar-space-companys-schmitt-space-communicator-accepted-into-smithsonians-national-air-and-space-museum-collection/>

³ URL: https://www.ted.com/speakers/moriba_jah?language=en

⁴ URL: <http://astria.tacc.utexas.edu/AstriaGraph/>

⁵ On the web at <http://www.satnews.com/story.php?number=1385171024>



Solstar Co-Founder, Dr. Mark Matossian, and CEO, Mr. Brian Barnett, receive the MSUA Chairman's Award for Outstanding Innovation for User Community Development from MSUA president, Catherine Melquist, at the 2020 MSUA Conference.

COE CST RESEARCH AREAS AND TASKS

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

COE CST RESEARCH AREAS

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



COE CST RESEARCH GOALS

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

1. AEROSPACE ACCESS & OPERATIONS

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

2. AEROSPACE VEHICLES

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

3. HUMAN OPERATIONS & SPACEFLIGHT

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

4. INDUSTRY INNOVATION

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



COE CST YEAR 9 RESEARCH TASKS

COE CST research tasks in all four research areas, conducted in calendar year 2019, are listed below, and shown in the quad charts that follow. Most of the tasks were funded by the FAA AST to COE CST member universities, but also listed are research tasks conducted during this period by COE CST Affiliate and Associate members. (NB: Research tasks are frequently referred to by their task number, because the titles listed below and the titles given on the summary quad charts may differ slightly. Tasks denoted with a single asterisk have quad charts that are nearly identical to the previous year's submission. Three administrative tasks active in 2019 are not listed below. Some tasks were compromised due to a discontinuous funding stream, inability to hire students in a timely fashion, subsequently limiting research results and publications.)

1. Aerospace Access & Operations

- 186-CU, Mitigating Threats Through Space Environment Modeling & Prediction, Dr. Timothy Fuller-Rowell*
- 186-SU, Space Environment Meteoroid and Orbital Debris Modeling & Prediction, Dr. Sigrid Close*
- 331-SU, Advanced 4D Special Use Airspace, Dr. Mykel Kochenderfer
- 367-CU, CubeSat Deployment Tracking, Dr. Penina Axelrad*
- 371-NMSU-UTA, Ontology-based Space Object Database, Dr. Moriba Jah*
- 372-CU, Resident Space Objects, Dr. Dan Scheeres
- 375-DLR (Associate), Interoperable Air and Space Traffic Management, Mr. Sven Kaltehäuser
- 380-NMSU, Spaceport Operations Online Reference Guide, Dr. Patricia Hynes

2. Aerospace Vehicles

- 241-FSU, High Temperature, Optical Sapphire Pressure Sensors, Dr. Billy Oates

- 253-UCF, Ultra-high Temperature Composites Thermal Protection Systems, Drs. Jan Gou & Jay Kapat
- 311-UCF, Advancement of LED-Based Hazardous Gas Sensors for Space Applications, Dr. Subith Vasu*
- 325-FSU, Optical Measurements of Rocket Nozzle Thrust and Noise, Drs. Rajan Kumar, Farrukh Alvi, & Jonas Gustavsson
- 377-NMT, Nitrous Oxide Composite Case Testing, Drs. Bin Lim & Andrei Zagrai

3. Human Operations & Spaceflight

- 309-UTMB, Suborbital Pilot Training Assessment, Dr. Tarah Castleberry*
- 353-UTMB, Design & Operational Considerations for Occupant Safety, Dr. Jeff Sutton (Quad chart not included)

4. Industry Innovation

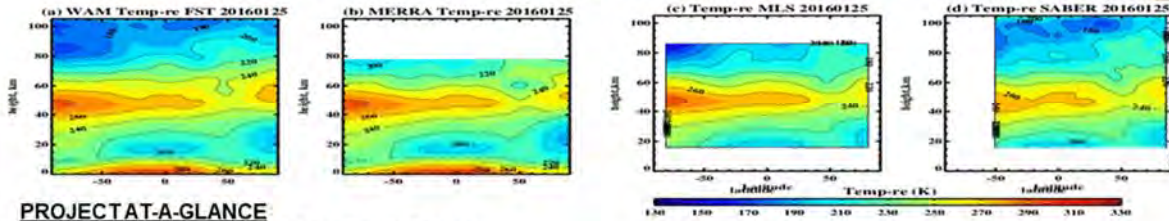
- 358-FIT, Workshops on Industry Viability and Research, Dr. Andy Aldrin
- 378-FIT-USC, Commercial Space Research Center Initiative, Dr. Greg Autry*

Attendees at the COE CST Ninth Annual Administrative Meeting (AAM9), held at the Florida Tech Center for Aeronautics and Innovation Building in Melbourne, Florida, on April 1, 2019. From left to right: Dr. Andy Aldrin (FIT), Dr. Karl Garman (FAA), Dr. David Klaus (CU), Dr. Tristan Fiedler (FIT), Dr. Jim Vanderploeg (UTMB), Dr. Andrei Zagrai (NMT), Dr. Subith Vasu (UCF), Dr. Rajan Kumar (FSU), Mr. Fred Bowen (Orion America), and Dr. Ken Davidian (FAA).





Task 186. Mitigating Threats Through Space Environment Modeling & Prediction



PROJECT AT-A-GLANCE

- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. Tim Fuller-Rowell
- AST RDAB POC: Karen Shelton-Mur

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- An integrated air and space traffic management system requires real-time knowledge of environmental conditions and their impact on flight conditions from the ground to 600 km altitude, including:
 1. Neutral density variability and structure for on-orbit collision avoidance, spacecraft drag, and atmospheric re-entry, and forecast of near-surface and space weather conditions
 2. Plasma density, D-region absorption, total electron content, ionospheric structure and irregularities, for impact on communications, navigation, and safety in flight

STATEMENT OF WORK

- Develop a seamless atmosphere-space model from the ground to 600 km altitude to fill gap between conventional weather and space weather conditions
- Develop terrestrial and space weather products tailored to suborbital and commercial space transportation needs
- Integrate terrestrial and space weather forecasts from one coordinated source

STATUS

- Past year's goal was to improve gravity wave parameterization and extend GSI data assimilation to 50-120 km altitude, to provide realistic winds, temperature, and density fields to predict the track of debris at sub-orbital and re-entry altitudes
- Gravity Wave (GW) physics and dynamics were tuned to bring seasonal/latitude thermal budget and temperature structure in agreement with observations
- NWS Gridpoint Statistical Interpolation (GSI) data assimilation scheme was extended to 100 km altitude with AURA MLS and SABER observations of temperature and composition to constrain WAM above the stratopause

FUTURE WORK

- Update real-time system, 2-way WAM-IPE coupling, optimize IPE and remove dependence on SMS, validate self-consistent electrodynamics, and use WAM/IPE fields to support CST.



Task 186. Space Environment Meteoroid and Orbital Debris Modeling & Prediction



PROJECT AT-A-GLANCE

- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR(S): Dr. Sigrid Close
- Co-I: Dr. Nicolas Lee
- STUDENT(S): Lorenzo Limonta

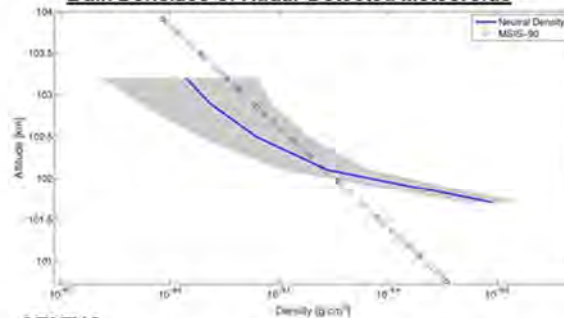
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- An integrated air and space traffic management system requires knowledge of the threat to objects in and entering Low Earth Orbit (LEO). LEO spacecraft are routinely struck by impactors, both human-made (space debris, posing a mechanical threat) and natural (meteoroids, posing a mechanical and electrical threat). Characterizing the impactor population through data analysis and modeling will help predict meteoroid and orbital debris (MOD) threat to the launch and operation of commercial LEO spacecraft.

STATEMENT OF WORK

- The research improves the current probability density functions that estimate the human-made and natural space debris and meteoroid environment by characterizing the meteoroid and orbital debris population. Research is conducted to determine the meteoroid bulk density function, identify scattering patterns based on the FDTD models, and determine neutral densities using meteoroids. Research on orbital debris includes filtering methods for larger satellite constellations, and the determination of debris propagation using near real time density data. Results from these activities are combined into a new threat assessment model.

Bulk Densities of Radar-Detected Meteoroids



STATUS

- Developed neutral density determination algorithm
- Developed improved ablation models to determine ionization efficiency
- Correlated ionization probability with luminous efficiency for improved meteoroid mass estimates
- Refined FDTD scattering model

FUTURE WORK

- Continue to improve fragmentation and ablation models to determine ionization and luminous efficiency
- Continue to develop orbit determination algorithms to correlate bulk density with source
- Develop probabilistic models for risk assessment

Task 331. Advanced 4D Special Use Airspace



PROJECT AT-A-GLANCE

- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR(S): Mykel J. Kochenderfer
- STUDENT(S): Rachael E. Tompa

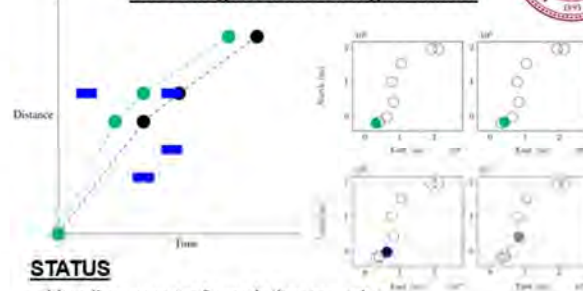
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- During launches, a large segment of the airspace must be cleared to minimize safety risk, which has a significant impact on efficiency of commercial flights in the region, especially as launches become more frequent. One important challenge is minimizing the impact on commercial air traffic.

STATEMENT OF WORK

- Use a Markov decision process to create optimal rerouting policies for an aircraft during a commercial space launch.
- Use an inclusive and representative debris model to capture the inherent uncertainty of launch anomalies and provides encompassing rerouting regions.
- Simulation studies across diverse scenarios for various operational and safety metrics
- Introduce metering aircraft "in time" to avoid the launch hazard.
- Measure success against past aircraft rerouting and nominal aircraft trajectories using NASA's FACET.

Rerouting Aircraft During a Launch



STATUS

- Heading reroute formulation complete
- Metering reroute formulation complete
- Combined heading and metering reroute formulation ongoing

ECONOMIC IMPACT

- During a Feb. 6, 2018 rerouted 563 flights and estimated to cost airlines over \$308,000.
- Each rerouted flight is estimated to result in a few thousand dollars of additional expenses in fuel, labor, and missed connections.

FUTURE WORK

- Enhancing metering formulation to include ground holding
- Combining heading and metering rerouting

Task 367. CubeSat Deployment Tracking



Estimation of 88 clustered CubeSats

PROJECT AT-A-GLANCE

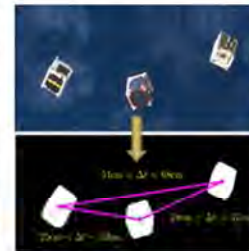
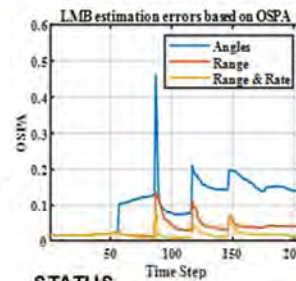
- UNIVERSITY: University of Colorado Boulder
- PRINCIPAL INVESTIGATOR(S): Penina Axelrad
- STUDENT(S): John Gaebler

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Clustered CubeSat deployments, where multiple CubeSats are released over a short time span will become more common as primary launch opportunities
- Rapid detection, tracking, and identification of individual CubeSats within the cluster presents new challenges
- Prompt establishment of accurate orbit estimates reduces the number of conjunction notices generated and provides longer mission life for the satellites.

STATEMENT OF WORK

- Focus on overall tracking and detection methodology including filtering algorithms, sensor scheduling, data fusion, navigation aids, and deployment strategies
- Preliminary simulations modeled after Indian PSLV-C37 mission launched in Feb 2017
- Various sensor configurations to be studied: sensor distribution, measurement types, quality and quantity
- Probabilistic multi-target filtering algorithms including the Cardinalized Probability Hypothesis Density (CPHD) and the Labeled Multi-Bernoulli (LMB) will be assessed



STATUS

- Enhanced simulations created using actual pre-launch and ground tracking data.
- LMB filter implemented and tested on this scenario.
- Work in progress for rigorous incorporation of observations with satellite identifiers and on-orbit imaging from deployer

ECONOMIC IMPACT

- Reducing the time to establish orbits/TLE's for CubeSats allows operators to more quickly begin their missions.
- In LEO, where lifetimes are measured in months, additional weeks/days contribute meaningfully to overall utility
- Better orbit predictions, after closely spaced deployments, allow for more informed conjunction assessments, reducing unnecessary maneuvers and expenditure of limited fuel.

FUTURE WORK

- Demonstrate integrated filter w/ ambiguous & tagged meas.
- Demonstrate improvement expected with observations from deployer



371-NMSU/UT Austin Ontology-based Space Object Database

PROJECT AT-A-GLANCE

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

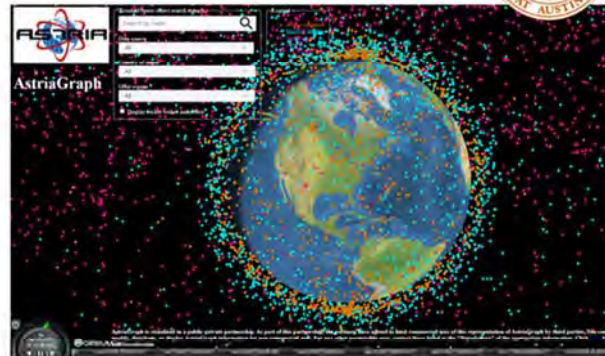
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

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

STATEMENT OF WORK

- Take the initial steps to develop, implement, and federate a Space Traffic Management/Orbital Safety Data Lake. 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

ASTRIAGraph Website



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
- Developed open-source orbit determination capability within OREKIT

Economic Impact

- Strive to provide an open and accessible layer of orbital safety service to the global community (like GNSS) upon which space activities and commerce can thrive.

FUTURE WORK

- Incorporating Computation Behavioral and Social Science for Cultural Context and Competency
- Implement more realistic uncertainty quantification
 - Difference between parameter knowledge driven by randomness versus ignorance

TASK 327. RSO System Mechanics

PROJECT AT-A-GLANCE

- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. Dan Scheeres
- STUDENT RESEARCHERS: Several PhD students have been supported by this task over the last few years, most recently CK Venigalla, M. Pellegrino and J. Greaves.

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

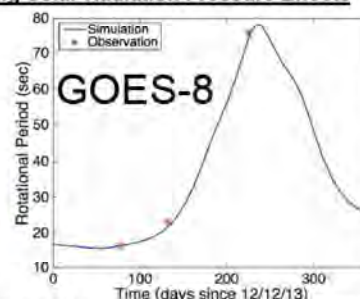
- Orbit debris remains a fundamental issue for all aspects of space utilization. Specific challenges remain in performing long term forecasts for specific pieces of orbit debris. While the population of debris is relatively well understood — research advances continue to open new windows on this population.

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.



Large Fluctuations of Spin Period in Defunct GOES-8 Satellite can be accurately fit by modeling Solar Radiation Pressure Effects



PREVIOUS TASK 187: Space Situational Awareness

- Graduated two FAA-funded PhD students: Kohei Fujimoto, May 2013 & In-Kwan Park Fall 2015, started work with others
- Have a large combined student team focused on relevant SSA research topics of direct interest to the COE
- Presented over 34 distinct papers at 20 conferences
- Over 13 papers published with more in peer review

CURRENT WORK: Task 327 — RSO System Mechanics

- 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.



Task 375. 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: Lisa Zetsche

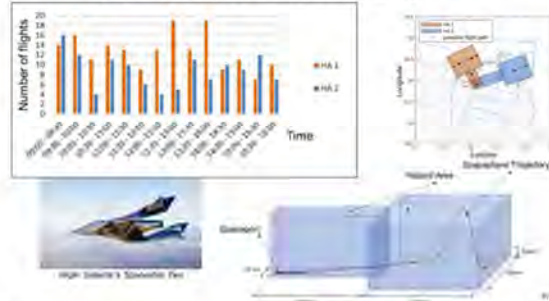
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- With global growth of the commercial space industry there is a developing demand for space flight operations in and over Europe. Air Traffic Management (ATM) is playing a key role to address this challenge.
- The goal is to prepare the European ATM system to enable a safe integration of space vehicle operations (SVO) in a sustainable and efficient way. To enable global operations, interoperability of implemented technologies and procedures is an essential requirement and a specific focus of the DLR work program..

STATEMENT OF WORK

- Categorization of relevant space flight operations and assessing their impact on European airspace using the DLR Space and Air Traffic Management (SATM) testbed.
- Development of measures and procedures for enabling efficient ways to optimize airspace usage for space flight operations while minimizing airspace segregation.
- Development of concepts and prototypes for a seamless, safe and secure implementation of space flight operations into the ATM flight planning and control processes using System Wide Information Management (SWIM) and related open and standard mainstream technologies.

Traffic Impact Modelling for suborbital flight profiles over Northern Germany



STATUS

- Collaborative work between DLR and FAA-AST on interoperable solutions for improved integration of space flight operations into ATM.
- Secure SWIM application enhancing security of SWIM data consuming client for ATM integration of commercial space
- Use case analysis, modeling and simulating suborbital flight profiles and determining related airspace restrictions for an application scenario in Europe

ECONOMIC IMPACT

- Provision of concepts and technical solutions enabling sustainable and interoperable space flight operations in EU& US.

FUTURE WORK

- Identifying optimization potential of operational mechanisms and procedures for SVO in a Pan-European aviation system
- Applying advanced ATM concepts such as Flexible Use of Airspace, Flight Centric ATC and Dynamic Sectorization
- Enhanced functions for space flight SWIM services including all ATM planning and execution levels.

Task 380. Spaceport Operations Online Reference Guide



PROJECT AT-A-GLANCE

- UNIVERSITY: New Mexico State University
- PRINCIPAL INVESTIGATOR(S): Patricia C. Hynes, Ph.D.
- STUDENT(S): Isaac Garza

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Provide a starting point and ready references to industry and government groups interested in conducting Spaceport Operations.

STATEMENT OF WORK

- Complete an end-to-end review of the Spaceport Operation Body of Knowledge to identify missing or broken links
- Establish a workflow to allow for regular and efficient updates to the Body of Knowledge
- Preliminary identification of gaps and weaknesses in the Body of Knowledge resulting from industry advancements since inception of the BoK

STATUS

- Completed the end-to-end review of the BoK, identifying all "broken" or missing reference links
- Established the workflow for BoK updates through this minor update and for future updates
- Graduate student staff to perform bulk of the work

Body of Knowledge for Spaceport Operations



About this collection

Today's space access systems do not imply standard systems allowing operators, targets, and launch providers to interoperate in the seamless manner needed to stimulate a vibrant commercial space industry. This poses a challenge to the only firm development of a commercial space transportation system. The development of a Framework for Spaceport Operations has shown that space launch sites, i.e. spaceports, provide their own set of operational activities, but not all are similar to those of other spaceports.

Funded by the FAA Center of Excellence for Commercial Space Transportation, the Body of Knowledge for Spaceport Operations is an evolving collection of documents and information that will define the Framework and support the development of space launch site interoperability. This information has been selected by members of the Body of Knowledge for Spaceport Operations research team, and the database is constructed and managed by the New Mexico State University library.

Framework for Spaceport Operations

The information in this database is organized according to the Framework for Spaceport Operations. The Framework is composed of 14 top-level categories, each with multiple subcategories. The top-level categories are:

ECONOMIC IMPACT

- Minimize the cost of research by any group or entity researching spaceport operations. This database is especially effective for new spaceports, as well as spaceports looking towards upgraded operations.

FUTURE WORK

- Revision of the BoK, including new references and best practices
- Integration of the BoK and Framework with other groups, such as ASTM F47 and FAAAST field work
- Develop and publish, with FAAAST concurrence, a Spaceport "pre-audit" preparation guide
- Develop a project plan for a Spaceport Startup "Roadmap"

Task 241. High Temperature, Optical Sapphire Pressure Sensors

PROJECT AT-A-GLANCE

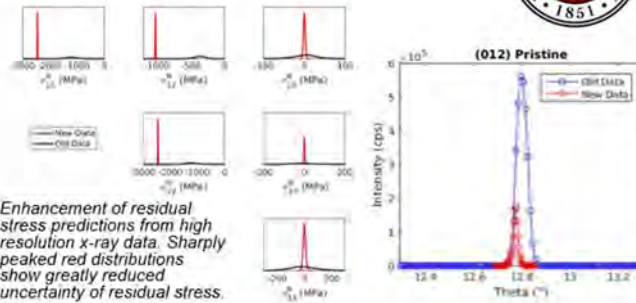
- UNIVERSITY: Florida State University
- PRINCIPAL INVESTIGATOR(S): William S. Oates, Rajan Kumar
- STUDENT: Jakob Consoliver-Zack

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 ($T > 1300^{\circ}\text{C}$) 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

- High resolution x-ray data of sapphire has been taken and analyzed.
- Modifications to the spectra statistical model were made to reduce code redundancies and improve uncertainty quantification

ECONOMIC IMPACT

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

FUTURE WORK

- Update statistical strain model to be higher fidelity.
- Compare cost effectiveness of high and low fidelity models
- Incorporate Maximum Entropy methods to best utilize all available data.

Task 253. Ultra-high Temperature Composites Thermal Protection Systems

PROJECT AT-A-GLANCE

- UNIVERSITY: University of Central Florida
- PRINCIPAL INVESTIGATOR(S): Drs. Jan Gou & Jay Kapat
- STUDENT(S): Derek Saltzman, Daniel Poljak, Haonan Song

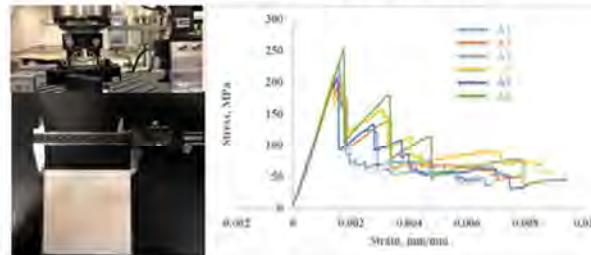
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Ultra-high temperature, light-weight, re-usable and cost-effective composites thermal protection systems (TPS) are enabling technologies for viable commercial spacecraft and launch vehicles.

STATEMENT OF WORK

- Fiber/matrix/coating materials development for thermal protection systems
- Manufacturing techniques of polymer derived ceramic composites (PDCC) using polymer infiltration and pyrolysis (PIP) process
- Ground testing of PDCC thermal protection systems with oxyacetylene exposure testing, rocket plume testing, and shock tube testing at UCF
- Flight testing of PDCC-based solid rocket nozzles and in-situ sensing for structural health monitoring
- Thermo-mechanical modeling of polymer derived ceramics composites (PDCC) thermal protection systems

Four-Point Bending Testing of Polymer Derived Ceramic Matrix Composites



STATUS

- Pre-impregnation techniques of Nextel 610™ ceramic fibers and carbon fibers with PDC resin system
- Polymer infiltration and pyrolysis (PIP) process of PDCC composite structures
- Microstructural characterization and four-point bending testing

FUTURE WORK

- The torch test will be conducted on the fabricated composites to analyze their high temperature performance.
- The panels after the torch test will be analyzed to uncover the thermal degradation mechanism.
- Hypersonic testing of the composites using rocket plume testing.

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

PROJECT AT-A-GLANCE

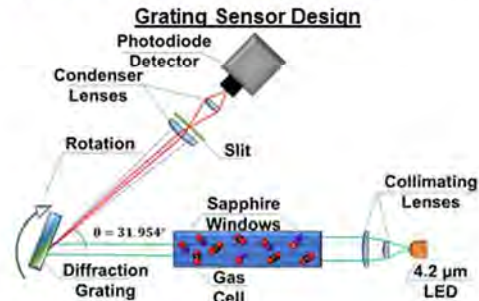
- UNIVERSITY: University of Central Florida
- PRINCIPAL INVESTIGATOR(S): Dr. Subith Vasu
- POST DOC(S): Anthony C. Terracciano, Ph.D.
- STUDENT(S): Akshita Parupalli, Zachary Loparo, Justin Urso

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- CO₂ and N₂O measurements are relevant to the health and safety of the crew.
- Time-resolved measurements of these gases could help quickly detect electrical shorts or fuel leaks

STATEMENT OF WORK

- A sensor is used for the detection of CO₂ and N₂O.
- Balloon tests were conducted to validate sensor responsiveness at micro-gravity conditions across a range of temperatures and pressures.
- The results from the balloon tests are used to improve the optical and electrical design.
- A rotating diffraction grating is used in conjunction with a single LED to scan from 4.1 to 4.6 μm.
- Laboratory tests were performed in a fume hood for different mixtures of CO₂ and N₂O balanced in Argon.
- The results show the capabilities for detecting multiple gases with the use of a single LED.



STATUS

- The system was tested to increase the wavelength range and sensitivity.

ECONOMIC IMPACT

- This project shows the potential for replacing expensive lasers with cheaper and more robust LEDs in space vehicles
- The overall cost for safety devices can decrease as a result

FUTURE WORK

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

Task 325. 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
- STUDENT(S): Rohit Vemula, Nikhil Khobragade, Vikas Bhargav, Timothy Willms, Yogesh Mehta (Post-doc)

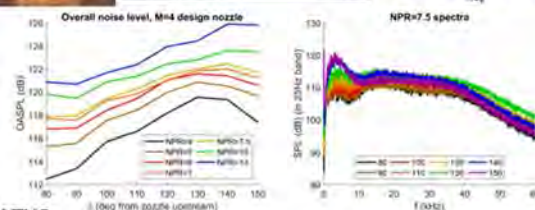
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- 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 free 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.

Optical Measurements of Thrust and Noise



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

FUTURE WORK

- Fluid dynamic and acoustic characteristics of impinging jet
- Noise reduction technique during launch operations



Task 377. Nitrous Oxide Composite Case Testing



PROJECT AT-A-GLANCE

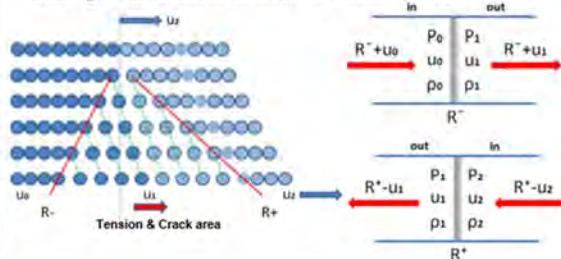
- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR(S): Seokbin (Bin) Lim, Andrei Zagrai
- STUDENT(S): Luis Ortega, Chris Rood, Matt Hirsh, Angel Chavira, Steven Palmer
- TECHNICAL MONITORS: Ken Davidian

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

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

STATEMENT OF WORK

- Develop methods/hypothesis to predict crack formation behavior
- Construction of analytical approach to predict such behaviors (1D extreme tension theory)
- Molecular Dynamics (MD) code simulation of the extreme tension event for further validation
- Building a 1D extreme tension test configuration



1D extreme tension test configuration

STATUS

- Preliminary results from the MD code: Favorable agreement between the analytical models and the MD code results
- In order to realize the extreme tension behavior, an air-gun system (projectile speed ~1km/s) is in the middle of construction. This system will be used to create the 1D-impact driven tension of the sample.

FUTURE WORK

- Detailed MD code analysis to understand the tension wave profile
- Experimental validation of the 1D impact-driven tension condition of the given samples
- Construction of tension isentrope (or Hugoniot) graphs/EoS in a way to provide a material data library to be used in the given applications

Task 309: Assessment of Physiological Screening Requirements & Training Modalities for Repeated Exposures to Sustained High G Acceleration



PROJECT AT-A-GLANCE

- University: The University of Texas Medical Branch
- Principal Investigator: Tarah Castleberry, DO, MPH
- Co-Investigator: James Vanderploeg, MD, MPH
- Residents: James Pavel, MD; Wilfredo Rodriguez-Jimenez, MD

RELEVANCE TO COMMERCIAL SPACEFLIGHT INDUSTRY

- Repeated exposure of the crew to sustained high +G_x and +G_z acceleration in highly demanding spaceflight profiles is a new and untested paradigm. Identifying the unique physiological challenges, screening and training techniques will enable spaceflight operators to ensure safe operations.

STATEMENT OF WORK

- Compare pilot performance and physiological response in aerobatic flights, centrifuge acceleration profiles, and actual spaceflight.
- Develop recommendations for pilot training and medical screening.



STATUS

- Collected data on pilots in centrifuge-simulated suborbital flight, aerobatic flight, and space flight through 2018

FUTURE WORK

- Obtain and analyse physiological data during centrifuge runs, aerobatic flights and spaceflights in 2019

Task 358. Workshops on Industry Viability and Research



PROJECT AT-A-GLANCE

- UNIVERSITY: Florida Institute of Technology
- PRINCIPAL INVESTIGATOR(S): Dr. Andrew Aldrin
- STUDENT(S): Shayan Shirshekar, Alex Coultrup

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Workshop facilitated a discussion of relevant issues to industry viability and research, and informed research projects SOW.

STATEMENT OF WORK

- Organize and produce annual agenda for COE RA-4 (Industry Viability and Research)
- Facilitate sophisticated discussion of key issues facing industry
- Promote development of productive future research agenda

STATUS

- 2020 workshop completed

FUTURE WORK

- Spring 2020 Postponed due to coronavirus
- Spring 2021 To be announced



INDUSTRY INNOVATION WORKSHOP AGENDA



AGENDA

TUESDAY, APRIL 2, 2019	
8:00 am – 8:30 am	Registration at KSC Visitor's Center
9:00 am – 12:00 pm	Bus tour of KSC
12:00 pm – 1:00 pm	Lunch served at the DeBus Conference Center
TOPIC 1: REGULATORY INITIATIVES IN COMMERCIAL SPACE LAUNCH	
1:00 pm – 1:30 pm	Introductory Comments: Ravi Chaudhary
1:30 am – 2:30 pm	Group Discussion: TBD
2:30 pm – 3:00 am	Morning Break
3:00 pm – 4:00 pm	Breakout Groups
4:00 pm – 4:30 pm	Group Presentations & White Paper Synthesis
	<i>Lunch: TBD</i>
WEDNESDAY, APRIL 3, 2019	
Topic 2: SMALL LAUNCH VEHICLE INDUSTRY DYNAMICS	
8:00 am – 8:30 am	Introductory Comments: Ken Davidian
8:30 am – 9:30 am	Group Discussion: Anderson, Aldrin, Dabbeo, Cantrell
9:30 am – 10:00 am	Morning Break
10:00 am – 11:00 am	Breakout Groups
11:30 am – 12:00 pm	Group Presentations & White Paper Synthesis
12:00 pm – 1:00 pm	Lunch
TOPIC 3: PUBLIC-PRIVATE PARTNERSHIPS	
1:00 pm – 1:30 pm	Introductory Comments: Greg Autry
1:30 pm – 2:30 pm	Group Discussion: Mulholland (on.) Autry, Aldrin, MacDonald
2:30 pm – 3:00 pm	Afternoon Break
3:00 pm – 4:00 pm	Breakout Groups
4:00 pm – 4:30 pm	Group Presentations & White Paper Synthesis
4:30 pm – 5:00 pm	Closing remarks: Chaudhary, Davidian
5:00 pm – 6:30 pm	Free time, tour KSC Visitor Complex
6:30 pm – 8:00 pm	Reception, ISU Center for Space Entrepreneurship@FIT

Task 378. Commercial Space Research Center Initiative



Special Guest Speaker at First SCCSI Workshop: Charlie Bolden



PROJECT AT-A-GLANCE

- UNIVERSITY: University of Southern California, Affiliate to Florida Institute of Technology
- PRINCIPAL INVESTIGATOR(S): Dr. Greg Autry (USC), Dr. Andy Aldrin (FIT)

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Southern California has long and deep roots in the space industry and has become the center of the emerging entrepreneurial New Space sector. This vibrant commercial space ecosystem calls for dedicated management research and support from the academic community. Funds from industry donations and in-kind contributions from the University will match the amount received by the Center. The activities supported will include business focused research published in management, entrepreneurship, aerospace and policy journals along with the launch of an annual commercial space conference event.

CURRENT ACTIVITIES

- Initiated a business research experiment to investigate the value add of "flown in space" items. These items should be flown this year. As the flight provider does not wish to be identified, it would be awesome if FAA AST could work with me to certify these items were part of a licensed commercial payload.
- Working with students to form a new organization to connect Latino students with the space industry (along the lines of Brook Owens Fellowship).
- Presented first annual Commercial Space Research Award to Pat Hynes of NMSU for her many years of service hosting ISPCS.

STATUS

- Established Southern California Commercial Spaceflight Initiative and leveraged FAA AST funding into broad support from industry partners.
- First annual SCCSI workshop held on Nov. 4. Attendees included Ken Davidian (FAA), Scott Pace (National Space Council) and many current and former NASA leaders: Dan Rasky, Charlie Bolden, George Whitesides.

FUTURE WORK

- Plan to host Space Foundation & Dept of Commerce "Space Commerce Workshop" for Minority Business Development Agency on January 26, 2019, to connect local minority owned firms and underrepresented students to the commercial space sector.
- Work just started on first annual (2019) report on the economic contribution of commercial spaceflight industry in California.



COE CST STUDENTS AND PUBLICATIONS

In total, there were 34 students and 24 publications generated by the COE CST in 2018-2019. Below is a listing of each 2019 COE CST task, the name(s) of the student(s) supporting each task, and any recent publications associated with the task.

Task 186-CU. Space Environment Modeling/Prediction

- No Students
- No 2019 Publications

Task 186-SU. Probabilistic Debris Model Development

Students

- Lorenzo Limonta, Glenn Sugar

2018-2019 Publications

- Sugar, G., M. Oppenheim, Y. Dimant and S. Close, "Formation of Plasma Around a Small Meteoroid: Simulation and Theory".
- Limonta, L., Sugar, G., Close, S., and Marshall, R.A. (2018), Cross calibration of meteoroid's mass parameters from optical and radar measurements, Journal of Geophysical Research: Space Physics, in review.
- Limonta, L., Close, S., and Marshall, R.A. (2018), A technique for inferring lower thermospheric neutral density from meteoroid ablation, Planetary and Space science, in review.

Task 241-FSU. High Temperature, Optical Sapphire Pressure Sensors for Hypersonic Vehicles

Students

- Jakob Consoliver-Zack

No 2019 Publications

Task 253-UCF. Ultra-High Temperature Composites Thermal Protection Systems

Students

- Derek Saltzman, Daniel Poljak, Haonan Song

No 2019 Publications

Task 309-UTMB. Suborbital Pilot Training Assessment

Residents

- James Pavela, Wilfredo Rodriguez-Jimenez, Ann Tsung
- No 2019 Publications

Task 311-UCF. LED-based Low-Cost Gas Sensor for Crew and Vehicle Safety

Students

- A. Terracciano, A.Parupalli, Z. Loparo, J. Urso

2018-2019 Publications

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

S.S. Vasu, "Multi-Species Single-LED Gas Sensor for Space Habitats and Vehicles", New Space, *In progress*, 2019.

- Anthony Carmine Terracciano, Kyle Thurmond, Michael Villar, Akshita Parupalli, Justin Urso, Erik Ninnemann, S.S. Vasu, "Hazardous Gas Detection Sensor Using Broadband Light-Emitting Diode-Based Absorption Spectroscopy for Space Applications", New Space, 6(1), 28-36, 2018.

Task 325-FSU. Optical Rocket Nozzle Noise Measurements

Students

- Rohit Vemula, Nikhil Khobragade, Vikas Bhargav, Timothy Willms, Yogesh Mehta

No 2019 Publications

Task 331-SU. Advanced 4D Special Use Airspace Research

Student

- Rachel Tompa

2018-2019 Publications

- R. E. Tompa and M. J. Kochenderfer, "Optimal aircraft rerouting during space launches using adaptive spatial discretization," in Digital Avionics Systems Conference (DASC), 2018
- R. E. Tompa, "Optimal aircraft rerouting during space launches," PhD Thesis, 2019.
- R. E. Tompa and M. J. Kochenderfer, "Efficient aircraft rerouting during commercial space launches," New Space, vol. 7, no. 1, pp. 12-18, 2019.
- R. E. Tompa and M. J. Kochenderfer, "Optimal aircraft metering during space launches," in Digital Avionics Systems Conference (DASC), 2019.

Task 353-UTMB. Human Factors - Physiological Focus

- No Residents
- No 2019 Publications

Task 358-FIT. RA4 Workshop - Industry Viability Research

Students

- Shayan Shirshekar, Alex Coultrup

No 2019 Publications

**Task 367-CU. Cubesat Cluster Deployment Trackings***Student*

- John Gaebler

2018-2019 Publications

- Gaebler, J.A., Axelrad, P., “CubeSat Cluster Deployment Tracking with a CPHD Filter”, 9th International Workshop on Satellite Constellations and Formation Flying. June 19-21 2017. Boulder, CO.

Task 371-NMSU/UT. Space Object Database

- No Students
- No 2019 Publications

Task 372-CU. Resident Space Object (RSO) System Mechanics*Students*

- Daniel Kucharski, Shiva Iyer, Nevan Simone, Michael Reinhold, Maria Esteve, Weijia Xu

2018-2019 Publications

- Kelecyc, T., Lambert, E., Sunderland, B., Stauch, J., Mallik, V., Jah, M., (2019). Automated near real-time validation and exploitation of optical sensor data for improved orbital safety, Acta Astronautica.
- Do, H., Chin, T., Moretti, N. Jah, M., & Tetlow, M. (2019). Robust Computer Vision Algorithms for GEO Object Detection, Elsevier Advances in Space Research, Vol. 64, Issue 3, pp 733-746.
- Delande, E., Houssineau, J., Franco, J., Frueh, C., Clark, D., Jah, M. (2019). A New Multi-Target Tracking Algorithm for a Large Number of Orbiting Objects. Elsevier Advances in Space Research, Vol. 64, Issue 3, pp 645-667.
- Kucharski, D., Kirchner, G., Otsubo, T., Kunimori, H., Jah, M., Koidi, F., Bennett, J., Lim, H-C., Wang, P., Steindorfer, MN., Sosnica, K. (2019). Hypertemporal Photometric Measurement of Spaceborne Mirrors Specular Reflectivity for Laser Time Transfer Link Model, Elsevier Advances in Space Research.
- Skinner, M., Jah, M., McKnight, D., Howard, D., Mukrami, D., Kai-Uwe, S. (2019). Results of the International Association for the Advancement of Space Safety Space Traffic Management Working Group, Elsevier Journal of Space Safety Engineering.
- Iyer, S., Jah, M., Hussein, I., McNeely, D., (2019). “Context-Based Non-Compliance for GEO Satellite Reorbiting” AAS 19-433, 29th AAS/AIAA Space Flight Mechanics Meeting, Maui, HI, January.
- Bever, M., Delande, E., Jah, M. (2019). “Outer Probability Measures for First and Second

Order Uncertainty in the Space Domain” IAA-AAS SciTech-040, Moscow, Russia June.

Task 375-DLR. Interoperable Air and Space Traffic Management*Student*

- Lisa Zetsche

2018-2019 Publications

- Zetsche, Lisa (2019) Modellierung und Simulation suborbitaler Flugprofile am Beispiel des Virgin Spaceship 2 und Ermittlung zugehöriger Luftraumbeschränkungen für ein Anwendungsszenario in Europa, Master Thesis, Sept. 2020, Technical University Braunschweig / DLR German Aerospace Center, Braunschweig, Germany
- Zetsche, Lisa und Kaltenhäuser, Sven (2020) Modelling and Simulation of Suborbital Flight Profiles & Determination of Related Airspace Restrictions for an Application Scenario in Europe. 6th Annual Space Traffic Management Conference, 19-20 Feb. 2020, Austin, Texas
- Kaltenhäuser, Sven und Luchkova, Tanja und Klay, Niklas und Ang, Rui Bin Randy (2019) Assessment of the Impact of Air Launch Operations on Air Traffic in Europe. 5th Annual Space Traffic Management Conference, 26.-27. Feb. 2019, Austin, USA.
- Schmitt, Dirk-Roger und Kaltenhäuser, Sven (2019) Integration of Commercial Spaceflight into the Air Transport System. 35th Space Symposium, 08.-11. April 2019, Colorado Springs, Colorado, USA.
- Morlang, Frank (2019) SecSWIM - Where safety meets security. 10th IAASS Conference, 15.-17. Mai 2019, Los Angeles, USA.
- Morlang, Frank (2019) Future space traffic integration by AFUAS SWIMming. 38th AIAA/IEEE Digital Avionics Systems Conference (DASC), 08.-12. Sep. 2019, San Diego, USA.
- Schmitt, Dirk-Roger und Kaltenhäuser, Sven (2019) Integration of commercial spaceflight into the air transport system. Space Tech Europe, 19. - 21. November 2019, Bremen, Germany.

Task 377-NMT. Nitrous Oxide Composite Tank Testing*Students*

- Luis Ortega, Chris Rood, Matt Hirsh, Angel Chavira, Steven Palmer

*No 2019 Publications***Task 378-FIT/USC. CSII Research & Conference**

- No Students
- No 2019 Publications



Above: Solstar's CEO, Brian Barnett, shows the Schmitt SC-1x space communicator to NASA Administrator, Jim Bridenstein.



Left: Solstar cofounder, Dr. Mark Matossian, and CEO, Brian Barnett, display the SC-1x space communicator before donating it to the collection of the Smithsonian Institute's National Air & Space Museum.

