FAA AST COMMERCIAL SPACE R&D PROGRAM

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FAA OFFICE OF COMMERCIAL SPACE TRANSPORTATION
PRESENTATION TO REDAC SUBCOMMITTEE ON AIRCRAFT SAFETY
12 AUGUST 2020

INTRODUCING MYSELF

Education

- BS, Aero/Astro Engineering, Ohio State University (1978-1983)
- MS, Mech Engineering, Case Western Reserve University (1983-1987)
- PhD, Business/Organization Theory, University of Cape Town Graduate School of Business (2015-2018)

Prior Employment

- NASA HQ, Centennial Challenges (2004-08)
- Paragon Space Development Corp, PM (2001-02, 2003-04)
- X PRIZE Foundation, Director of Operations (2002-03)
- NASA Lewis/Glenn, Liquid Rocket Engine Research (1983-2001)
  - International Space University, Asst. Dir. of Operations (1997-99)

Current Employment

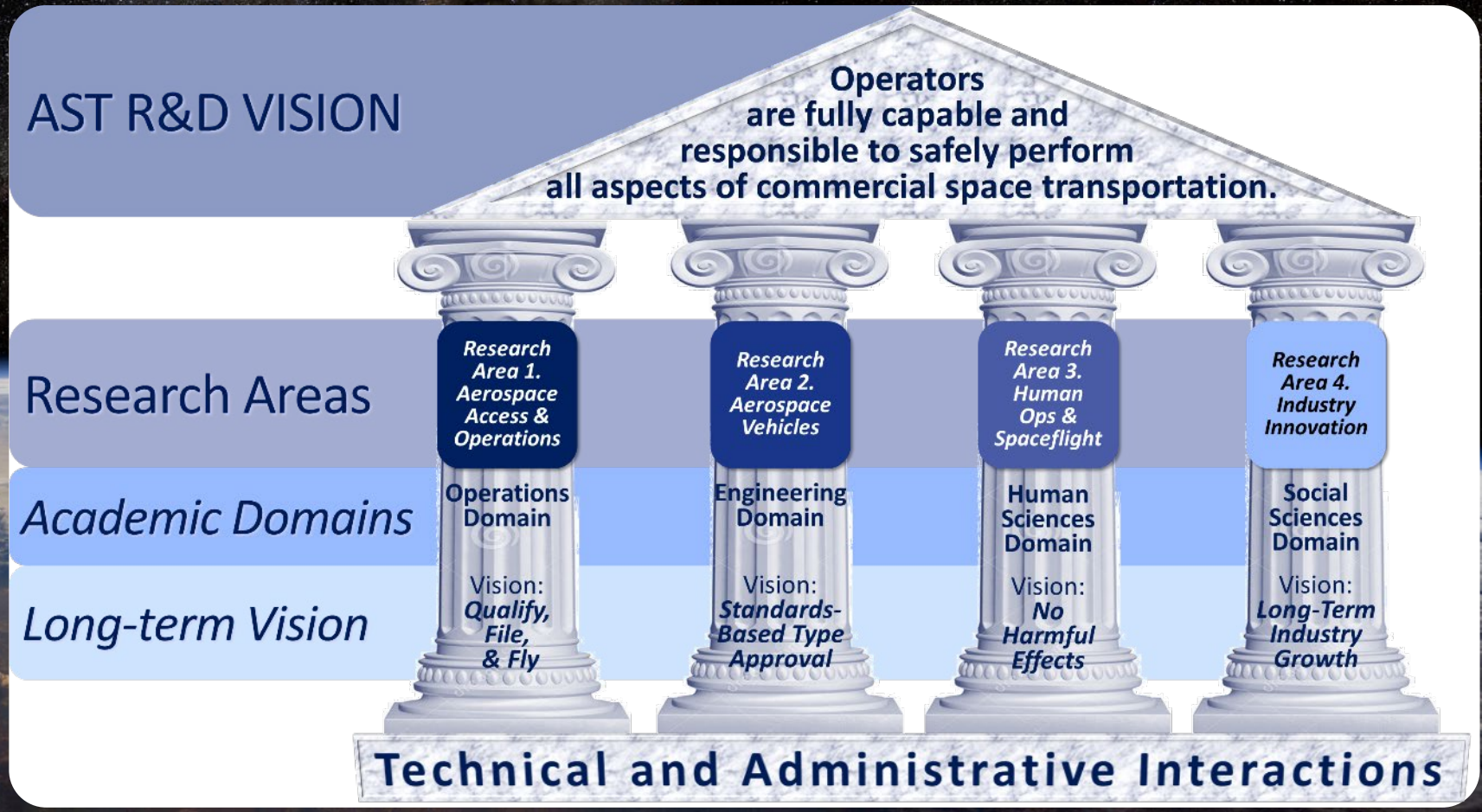
- FAA Office of Commercial Space Transportation, Director of Research (2009-present)
- New Space Journal: Editor-in-Chief (2019-present), Assoc. Editor (2013-2018)
- Virginia Tech, School of Business: Distance Learning Instructor (2020-present)

THE BROAD SCOPE OF AST R&D

- A single BLI to cover FAA AST's mission goals:
  - Safety of uninvolved public
  - Encourage, facilitate, and promote industry
  - Continuous improvement of human space flight safety

BUDGET COMPARISON

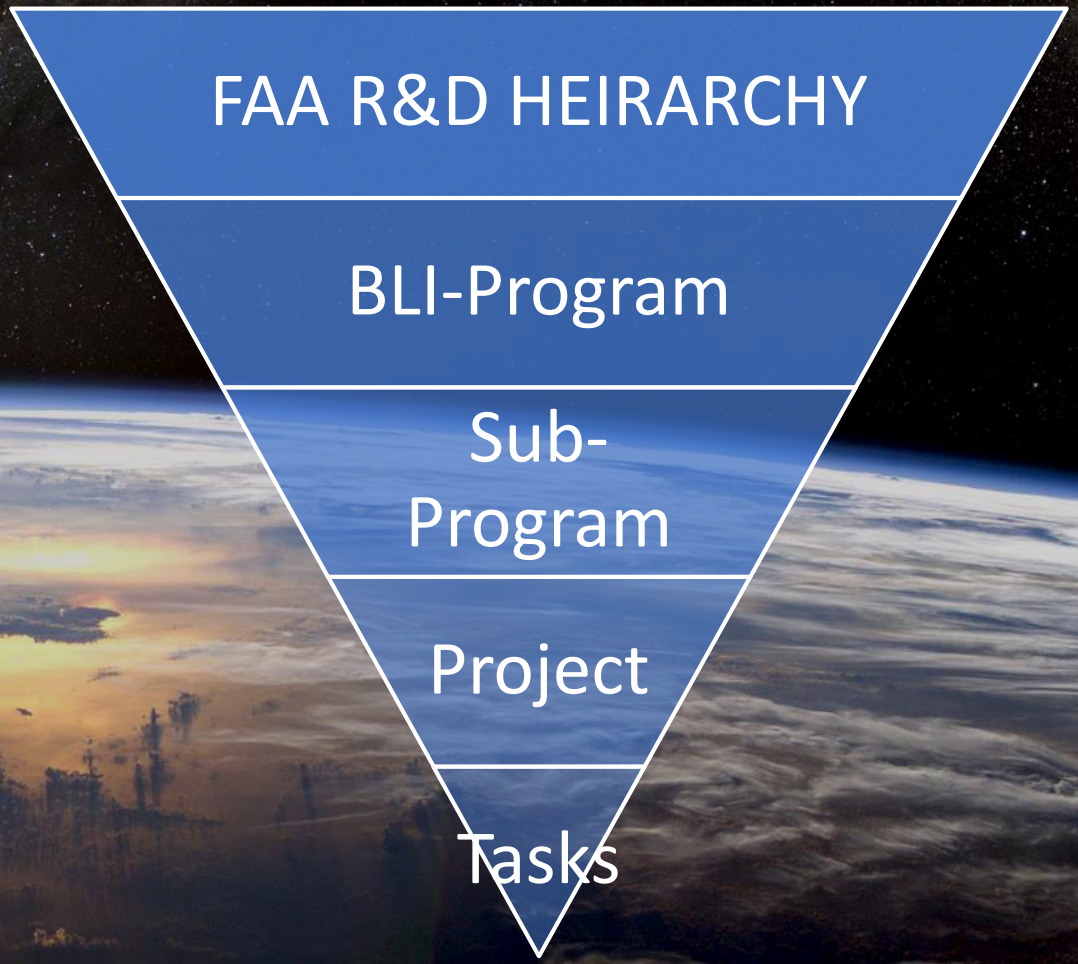
RE&D CATEGORY	BUDGET	%
TOTAL FAA R&D	**$193M**	**100%**
Aviation Safety R&D	$90.5M	46.9%
AST R&D	$2.5	1.2%



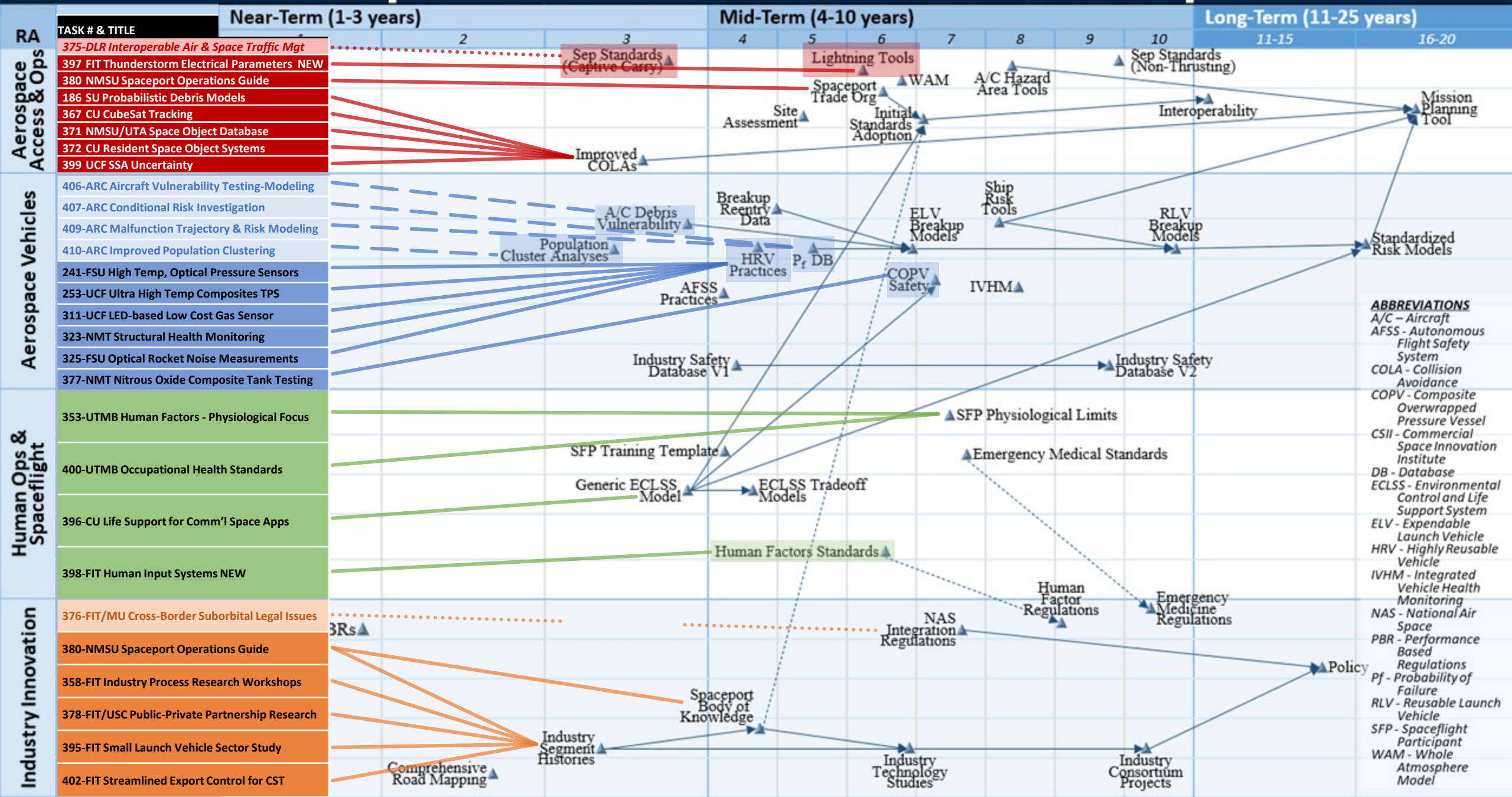

COE CST Member Universities
COE CST Subcontractor Universities
COE CST Affiliate Members
COE CST Associate Members
COE CST
Center of Excellence for
Commercial Space Transportation
Carminati Law
United States
Sovaris Aerospace
NASA
USC
NM State University
New Mexico Tech
Immortal Data
Danish Aerospace
Baylor College of Medicine
utmb Health
The Ohio State University
McGill
NASTAR
MITRE
UNF
UF
IFG
Germany
DLR
Hamburg
Berlin
Cologne
Frankfurt
Prague
Munich
Austria
Mexico
The Bahamas
Gulf of Mexico
Gulf of California

CST RESEARCH TOPICS RELEVANT TO REDAC SAS

- Research affecting the atmospheric operations
- Research on vehicle safety technologies (i.e. sensors, structural health monitoring, etc.)
- Research addressing human/automation interaction



Proposed Plan: AST R&D Road Map



DISCUSSION OF RELEVANT CST RESEARCH TASKS

Separation Standards (Captive Carry)

- 375-DLR: Interoperable Air and Space Traffic Mgt

Lightning Tools

- 397-FIT: Thunderstorm Electrical Parameters Measurements

Population Cluster Analyses

- 410-ACTA: Improved Population Clustering

Aircraft Debris Vulnerability

- 406-ACTA: Aircraft Vulnerability Testing and Modeling

Probability of Failure Database

- 407-ACTA: Conditional Risk Investigation
- 409-ACTA: Medium Fidelity Malfunction Trajectory & Risk Modeling

Carbon Overwrapped Pressure Vessel Safety

- 377-NMT: Nitrous Oxide Composite Case Testing

Highly Reusable Vehicle Practices

- 241-FSU: High Temperature, Optical Sapphire Pressure Sensors for Hypersonic Vehicles
- 253-UCF: Ultra High Temperature Composites For Thermal Protection Systems
- 311-UCF: LED-Based Low Cost Gas Sensor for Crew and Vehicle Safety
- 323-NMT: Structural Health Monitoring Framework
- 325-FSU: Optical Measurements of Rocket Nozzle Thrust and Noise

Human Factors Standards

- 398-FIT: Human Input Systems for Commercial Space Transportation

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

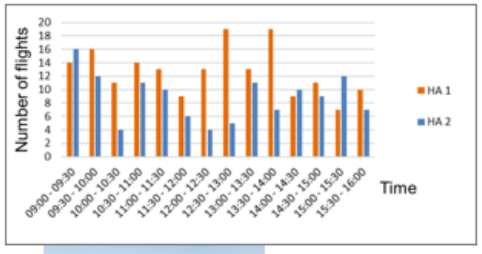
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

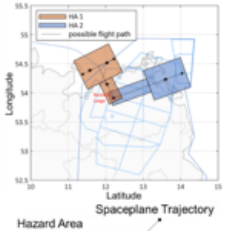
- With global growth of the commercial space industry there is a developing demand for space flight operations in and over Europe. Air Traffic Management (ATM) is playing a key role to address this challenge.
- The goal is to prepare the European ATM system to enable a safe integration of space vehicle 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

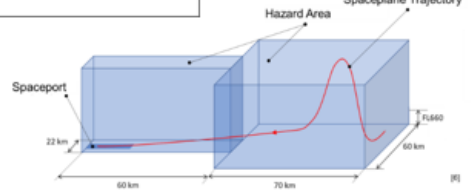
- Categorization of relevant space flight operations and assessing their impact on European airspace using the DLR Space and Air Traffic Management (SATM) testbed.
- Development of measures and procedures for enabling efficient ways to optimize airspace usage for space flight operations while minimizing 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





Virgin Galactic's Spaceship Two



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.

397-FIT: THUNDERSTORM ELECTRICAL PARAMETERS

NEW

TASK DESCRIPTION

- Beyond vehicle and payload issues, weather has been the single largest source of launch delays and scrubs on the Eastern Range. The current growth rate of the commercial space sector means that there will be continued and increasing weather delays and scrubs for the commercial launch operator. One way to minimize launch costs is to reduce the uncertainty associated with the cloud rules that protect a launch vehicle by preventing its interaction with natural lightning or a lightning strike triggered by the vehicle during a launch. By better understanding the environmental conditions that indicate initiation and cessation of thundercloud electrical activity, a more refined electric field threshold could be introduced leading to a relaxation of the cloud constraints. Ultimately, this will lessen the percentage of launch delays and scrubs associated with the lightning launch and flight commit criteria, thus promoting the commercial launch sector.

IMPACT STATEMENT

- The objectives of this proposal will lead to refinement of existing regulations, specifically the code of federal regulations (appendix g to part 417) and will lead to development of improved regulatory criteria and improved management of safety of launch and reentry vehicles. As a result, the goals of this project are aligned with those of AST-1 (improved management of safety of public and property) and ASZ-200 (development of improved methodologies for evaluating the safety of public and property).

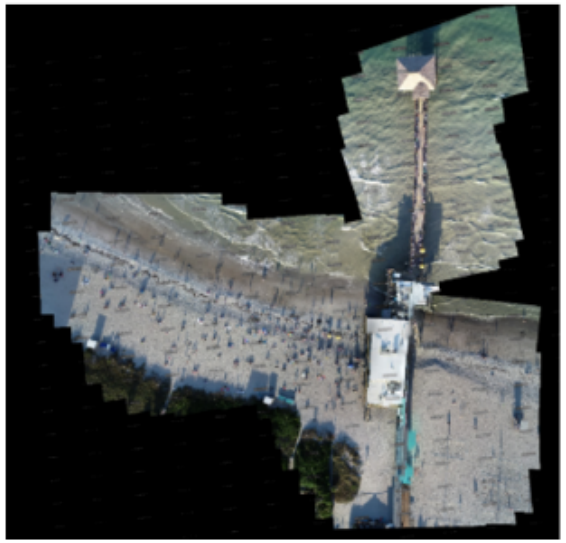
410-ACTA: Improved Population Clustering

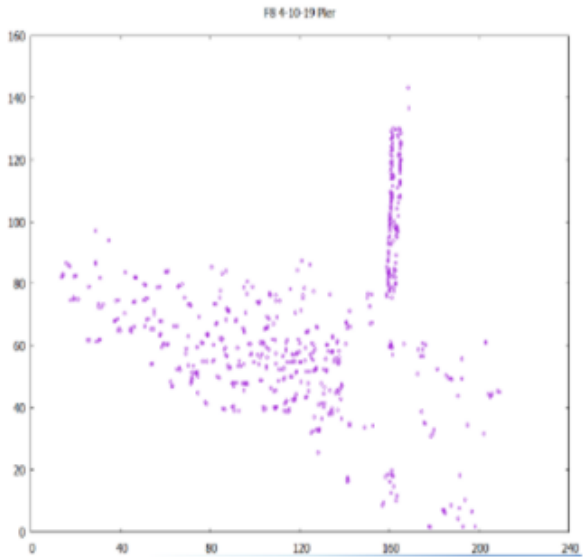
PROJECT AT-A-GLANCE

- COMPANY: ARCTOS
- PRINCIPAL INVESTIGATOR(S): Dr. Wenshui Gan, Dr. Wije Wathugala, Dr. Erik Larson
- TECHNICAL MONITORS: Dr Paul Wilde

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Improved population modeling to provide better estimate of Maximum Probable Loss which affects availability and insurance requirements in space launch industry





STATEMENT OF WORK

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

STATUS

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

ECONOMIC IMPACT

- May result in reduced insurance requirements for launch providers and increased launch availability

FUTURE WORK

- Perform model validation and evaluation

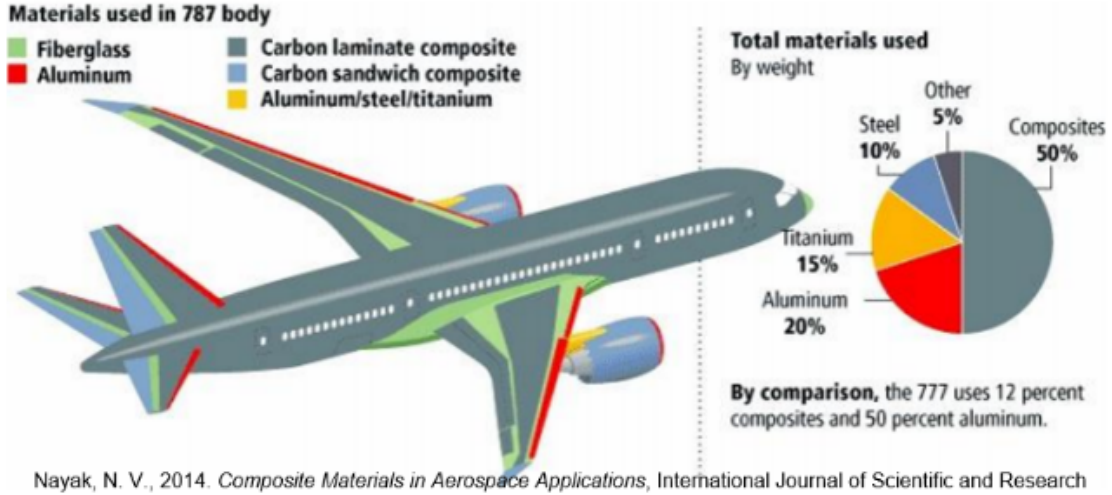
406-ACTA: Composite Aircraft Vulnerability Modeling

PROJECT AT-A-GLANCE

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

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Addresses vulnerability of composite-based aircraft
- Improves upon existing Aircraft Hazard modeling approach



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

STATEMENT OF WORK

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

STATUS

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

ECONOMIC IMPACT

- Analysis may result in adjusted hazard area requirements which would impact the commercial aircraft industry fuel costs

FUTURE WORK

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

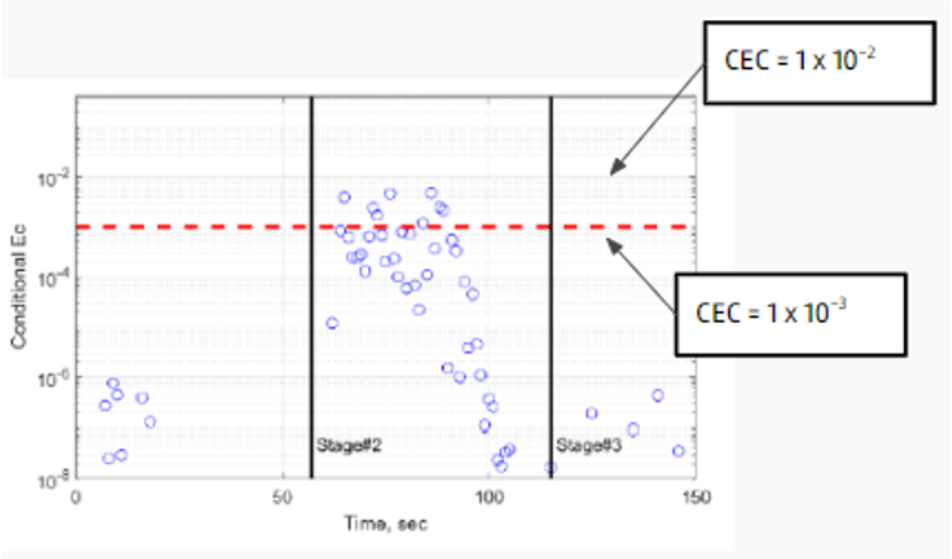
407-ACTA: Conditional Risk Investigation

PROJECT AT-A-GLANCE

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

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Techniques will be developed to help compute risk of multiple casualties to the public in the event of a launch or reentry mishap



STATEMENT OF WORK

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

STATUS

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

ECONOMIC IMPACT

- More accurate determination of FSS requirements.
- Can lead not requiring FSS when not needed

FUTURE WORK

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

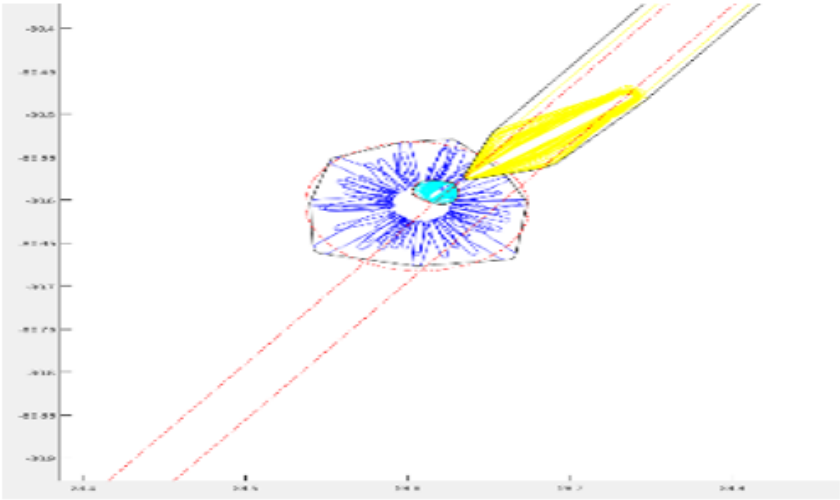
409-ACTA: Med. Fidelity Malfunction Trajectory & Risk Modeling

PROJECT AT-A-GLANCE

- COMPANY: ARCTOS
- PRINCIPAL INVESTIGATOR(S): Dr. Wije Wathugala, Dr. Erik Larson, Dr. Steve Carbon, Mr. Troy Owens
- TECHNICAL MONITORS: Dr Paul Wilde

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Techniques will be developed to reduce the rigor required to complete a launch flight safety analysis when appropriate for a given mission's characteristics



STATEMENT OF WORK

- Develop a medium fidelity approach to capturing the dispersion due to malfunction (off-trajectory) flight that accounts for vehicle structural limits
- Implement the approach in the prototype tool and evaluate comparisons to high-fidelity modeling
- Investigate options to incorporate flight safety limits and flight safety systems in medium fidelity risk assessments

STATUS

- Performed analyses to obtain launch area breakup vectors for different Q-alpha and time segments to understand any patterns
- Evaluating modeling techniques to determine best approach

ECONOMIC IMPACT

- Reduces cost of analysis (time/labor) to perform Flight Safety Analysis, especially in terms of reducing data development

FUTURE WORK

- Develop prototype modelling code to demonstrate concepts

ARCTOS | All In.

Slide

Task 377. Nitrous Oxide Composite Case Testing

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PROJECT AT-A-GLANCE

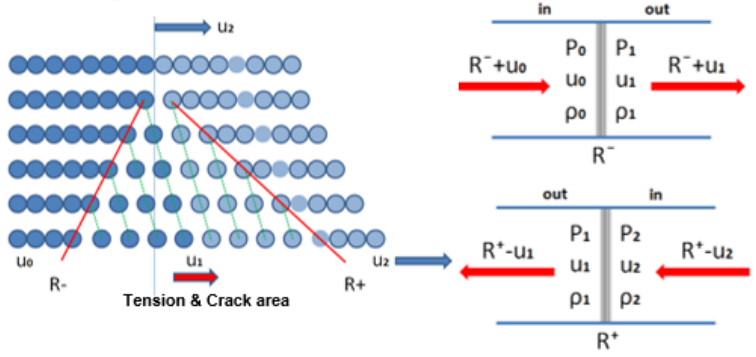
- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR(S): Seokbin (Bin) Lim, Andrei Zagrai
- STUDENT(S): Luis Ortega, Chris Rood, Matt Hirsh, Angel Chavira, Steven Palmer
- TECHNICAL MONITORS: Ken Davidian

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

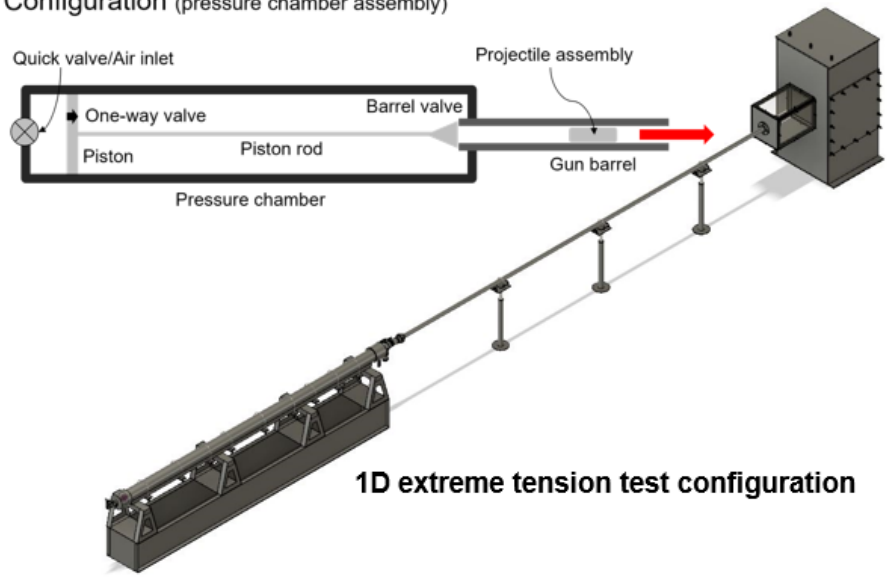
- Develop an understanding of fragmentation hazards from composite tanks used for fuel/oxidizer storage
- Develop a testbed for evaluating different storage tank materials or configurations at small and large scales

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



Configuration (pressure chamber assembly)



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 241. High Temperature, Optical Sapphire Pressure Sensors

PROJECT AT-A-GLANCE

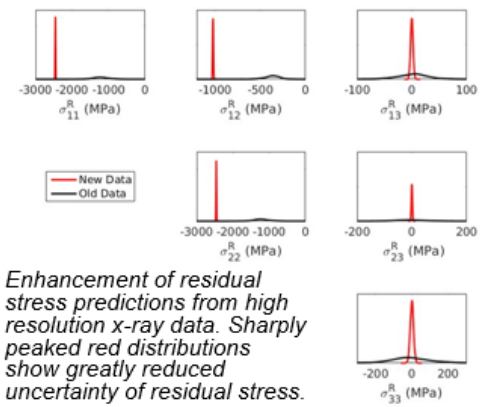
- UNIVERSITY: Florida State University
- PRINCIPAL INVESTIGATOR(S): William S. Oates, Rajan Kumar
- STUDENT: Jakob Consoliver-Zack

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

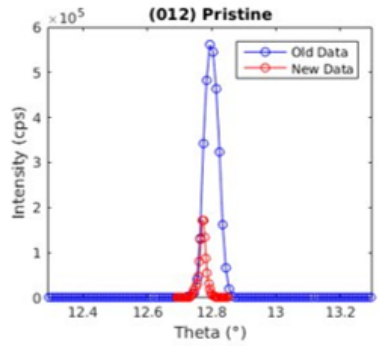
- Structural health monitoring and control of space vehicles.

STATEMENT OF WORK

- Research is focused on advancing high temperature pressure sensor technology for sensors that can sustain elevated temperatures (T >1300°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



Enhancement of residual stress predictions from high resolution x-ray data. Sharply peaked red distributions show greatly reduced uncertainty of residual stress.



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

University of Central Florida

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

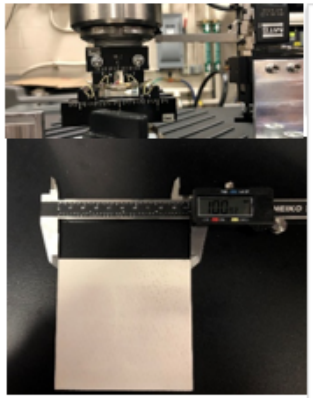
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

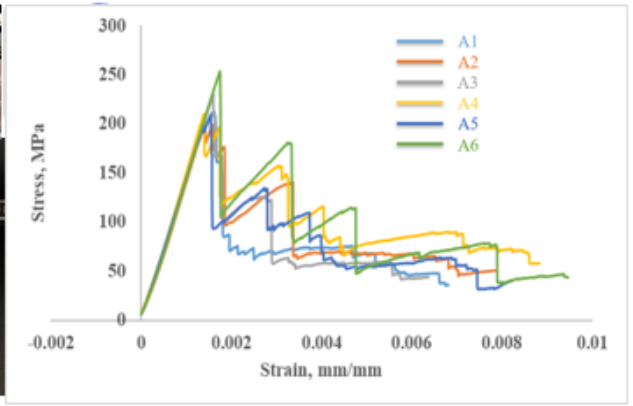
- Ultra-high temperature, light-weight, re-usable and cost-effective composites thermal protection systems (TPS) are enabling technologies for viable commercial spacecraft and launch vehicles.

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

University of Central Florida

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

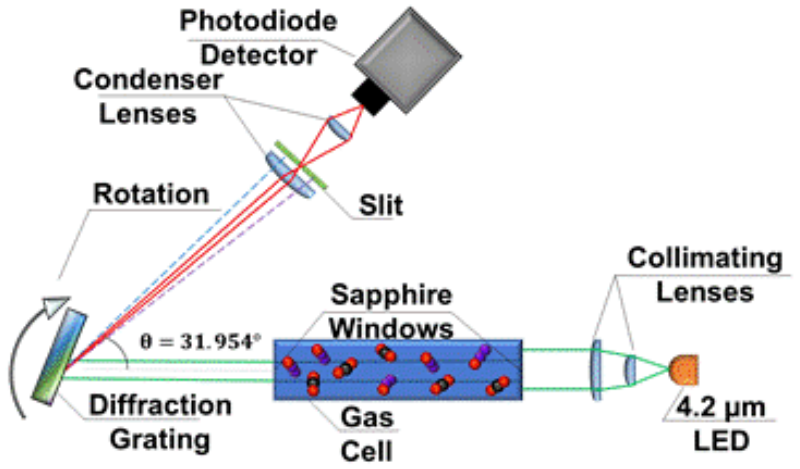
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- CO_2 and N_2O measurements are relevant to the health and safety of the crew.
- Time-resolved measurements of these gases could help quickly detect electrical shorts or fuel leaks

STATEMENT OF WORK

- A sensor is used for the detection of CO_2 and N_2O.
- 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 CO_2 and N_2O balanced in Argon.
- The results show the capabilities for detecting multiple gases with the use of a single LED.

Grating Sensor Design



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 323. Structural Health Monitoring Framework for Commercial Space Transportation

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PROJECT AT-A-GLANCE

- UNIVERSITY: New Mexico Institute of Mining and Technology
- PRINCIPAL INVESTIGATOR(S): Andrei Zagrai
- STUDENT(S): Mary Anderson, David Hunter, Dyllian Powell

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

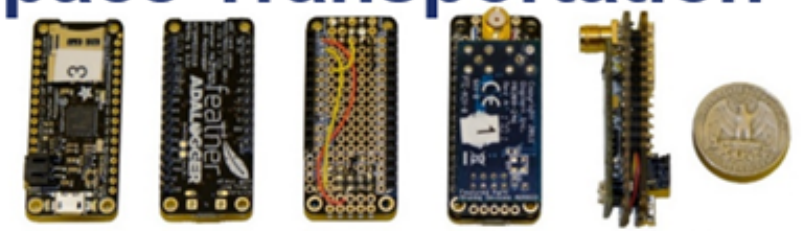
- Information provided by a vehicle's SHM system may be used to predict a component's remaining life and hence enable prognosis and mission scheduling in accordance with current and projected structural performance. SHM data may also assist in accident investigation if needed.

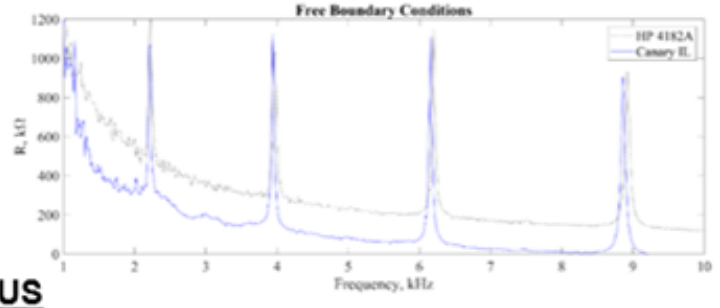
STATEMENT OF WORK

- Sensor and structural deterioration due to space environment
- We further develop approaches to better understand other aspects of environmental influences on space systems and manifestation of these aspects in SHM data.
- Prepare hardware for evaluation of space effects on structural condition and sensor system.
- In preparation for evaluation of space effects on structural condition we have developed portable hardware capable of performing electro-mechanical impedance SHM. At this point, a single channel unit has been developed.

ECONOMIC IMPACT

- The economic benefit includes avoiding very costly catastrophic events and reducing maintenance cost by replacing parts on "as needed" versus "lifespan" basis.





STATUS

- A pathway to improve sensor models under radiation has been proposed.
- Portable hardware for acquisition of electro-mechanical impedance of sensors has been developed
- Software to run electro-mechanical impedance experiments on portable hardware has been developed.
- Performance of hardware and software for portable electro-mechanical impedance acquisition unit has been validated through experimental testing.

FUTURE WORK

- Explore possibility of multi-channel portable impedance measurement unit.
- Improve frequency control of the portable impedance measurement device.

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)

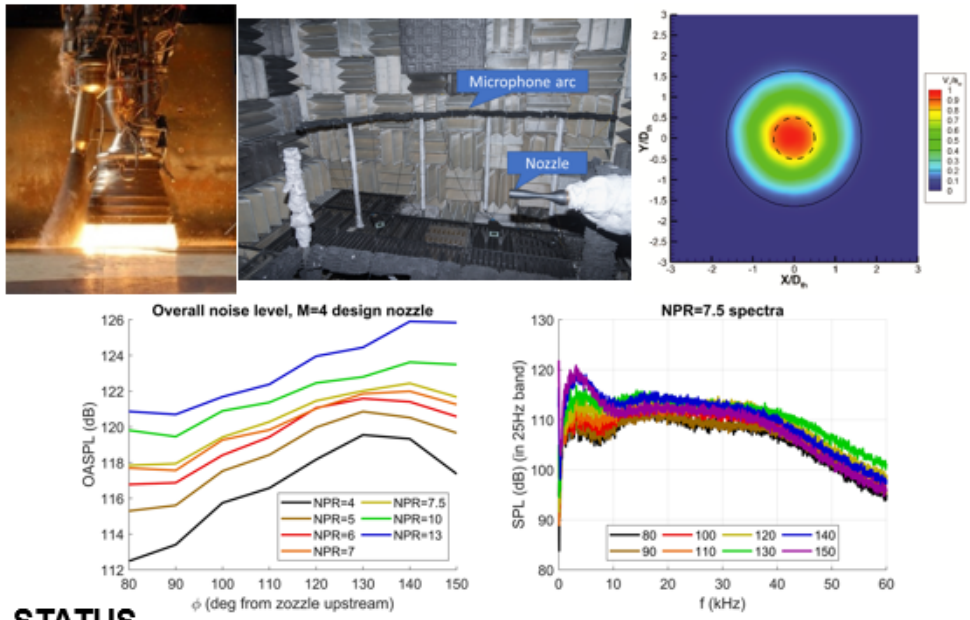
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- 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

398-FIT: HUMAN INPUT SYSTEMS

NEW

TASK DESCRIPTION

- The proposed research project on Human Input Systems for Commercial Space Transportation (HIS CST) will develop guides for CST industry in area of definition and engineering of CST control input devices and systems usable in variable gravity with or without a spacesuit. Experimental research hardware including IVA spacesuit and microgravity head down tilt cockpit simulator will be used to simulate spacecraft cabin and cockpit environment. The FIT's adaptive spaceship cockpit simulator allows smooth transition of individual flight phases in range of 360° by cockpit orientation. This capability provides higher than generally known existing laboratory systems fidelity and very low risk of simulation, enabling quick turnaround of pre-screen research subjects and considering also roles of untrained spaceflight participants (i.e. general public). The entire system operates at minimal cost. A number of different input and control devices will be evaluated in nominal and microgravity positions and general guides for design of the input and control devices will be developed in conjunction with already completed research.

IMPACT STATEMENT

- The interaction and communication between the spaceship and the human occupant is affected by the spaceflight profile context and particularly by the imminent environmental conditions. Humans' physical and cognitive performance changes depending on their "departure" or "distance" from the "home" environment or conditions and depending on the magnitude of the difference, human adaptation is either fast, slow, or impossible. Every space vessel in the history of human spaceflight introduced new input systems and as of now there is no standard that would ensure that human can precisely and with minimum effort, communicate with the onboard computer/spaceship during variety of spaceflight phases. This research proposal addresses a human-system integration gap for Commercial Space Transportation that will affect all individuals considering spaceflight and requiring safe and precise communication with the space vessel.

CONCLUDING REMARKS…

- AST R&D Contract Funding will continue
- AST RGD Grant Funding is ending
  - Last allocation was 5 Feb 2020
  - COE CST POP End is August 2022
- AST Plans to replace COE CST with a Research Consortium
- For more information…
  - Visit www.coe-cst.org
  - Download the COE CST Year 9 Annual Report Executive Summary
  - Plan to (virtually) attend the COE CST 10th Annual Technical Meeting in October…