Florida Institute of Technology

NM STATE UNIVERSITY

NEW MEXICO TECH
SCIENCE • ENGINEERING • RESEARCH • UNIVERSITY

University of Central Florida

UF UNIVERSITY of FLORIDA

utmb Health

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COE CST Center of Excellence for Commercial Space Transportation

Federal Aviation Administration Center of Excellence for Commercial Space Transportation

Year 6 Annual Report
Volume 2
Presentations

December 31, 2016

COE CST YEAR 6 ANNUAL REPORT – VOLUME 2

This report is produced by the FAA Office of Commercial Space Transportation in fulfillment of FAA Centers of Excellence program requirements.

The full report is broken into an Executive Summary and three volumes:

- The Executive Summary gives an overview of the FAA AST, the FAA COE program and the COE CST. A brief description of the member universities precedes a series of "quad charts," one for each task conducted by the COE CST during the sixth year of operation. The document ends with a listing of the Year 6 students, supporting organizations and technical publications.
- Volume 1 gives a description of the FAA COE CST, its research, structure, member universities and research tasks.
- Volume 2 is a comprehensive set of presentation charts of each research task as presented at the Sixth Annual Technical Meeting in October 2016.
- Volume 3 is a comprehensive set of notes from all FAA COE CST teleconferences and face-to-face meetings.

This is Volume 2 of the full report.

Any questions or comments about the content of this report should be directed to Mr. Ken Davidian, FAA Program Manager for the Center of Excellence for Commercial Space Transportation, or Dr. Patricia Watts, FAA COE Program Director.

Introduction

This report includes a comprehensive set of presentations for each research task as presented at the Sixth Annual Technical Meeting in October 2016.

Below is the order of the non-technical presentation slides as they appear in this document:

- “The FAA Center of Excellence for Commercial Space Transportation Annual Technical Meeting - October 11, 2016" presented by James Vanderploeg, MD, MPH - Executive Director, COE-CST - Professor, Aerospace Medicine, University of Texas Medical Branch, Galveston, Texas.

- Speakers for “Industry Viability”, “Human Spaceflight Research”, “Space Traffic Management”, and “Technology” Panels.

Below is the order of the technical presentations as they appear in this document:

Space Traffic Management and Spaceport Operations Research Tasks

- Task 186 “Mitigating threats through space environment modeling/prediction” presented by Tim Fuller-Rowell and Catalin Negrea of University of Colorado, Boulder (CU).
- Task 186 “Space Environment MMOD Modeling and Prediction” presented by Sigrid Close and Diana Madera of Stanford University (SU).
- Task 329 "Tracking and Monitoring Suborbital Commercial Space Vehicles" presented by William Ryan, Eileen Ryan, and Jacob Schirer of New Mexico Tech (NMT).
- Task 331 “Advanced 4D Special Use Airspace Research” presented by Juan J. Alonso and Thomas J. Colvin of Stanford University (SU).
- “Evaluating the Safety of Launch and Reentry Operations in the National Airspace System” Presented by Zheng Tao, Ganghuai Wang, Ashley G. Williams, Tudor Masek, Tom St. Clair, Jon L. Semanek, Jonathan L. Schwartz (The MITRE Corporation).

Space Transportation Vehicle Research Tasks

- Task 299 “Nitrous Oxide Composite Case Testing” presented by Bin Lim and Andrei Zagrai of New Mexico Tech (NMT).
- Task 306 “UAT ADS-B Research and Demonstration for Commercial Space Applications: Progress Report” presented by Richard S. Stansbury, Brandon Neugebauer, Dominic Tournour, Dylan Rudolph, Richard Day, Yosvany Alonso, Kelsey Klein, Andrew "Jack" Strange (ERAU).
- Task 307 “Commercial Satellite Communications Applications for Spacecraft” presented by M. Brian Barnett of Solstar (SOL).
- Task 311 “Fire and Hazard Detection for Space Vehicles Using LEDs” presented by Michael Villar, Justin Urso, Akshita Parupalli, Dr. Jayanta Kapat, and Dr. Subith Vasun (all from UCF) AND Dr. Bill Partridge Jr. (ONRL).
- Task 323 “Structural Health Monitoring Framework” presented by Andrei Zagrai, Mary Anderson, and Blaine Trujillo (NMT).
- Task 325 “Optical Measurements of Rocket Nozzle Thrust and Noise” presented by Rajan Kumar, Farrukh Alvi, and Rohit Vemula (FSU).

Human Spaceflight Research Tasks

- Task 308 "Assessment of Screening and Training Requirements for SFPs Regarding Anxiety During Repeated Exposures to Sustained High Acceleration" presented by Rebecca Blue, MD, MPH (UTMB).
- Task 310 "Assessment of Methods, Procedures, and Technologies Available for Protection of SFPs in Commercial Spaceflight Vehicles" presented by Charles Mathers, MD, MPH and Alejando Garbino, MD, PhD (UTMB).
- Task 320 "Commercial Spaceflight Risk Assessment and Communication" presented by Prof. David Klaus and Robert Ocampo (CU).

Space Transportation Industry Viability Research Tasks

- Task 193 "Emerging Space Industry Leader Workshops" presented by Dan Scheeres and Bradley Cheetham (CU).
- Task 304 "Legal Issues of Cross-Border Sub-Orbital Flights" presented by Dr. Ram S. Jakhu and Aram Daniel Kerkonian (MU).

THE FAA CENTER OF EXCELLENCE FOR COMMERCIAL SPACE TRANSPORTATION

ANNUAL TECHNICAL MEETING | OCTOBER 11, 2016

Federal Aviation Administration
Center of Excellence for
Commercial Space Transportation

Year 5 Annual Report

Executive Summary

December 31, 2015

www.coe-cst.org

James Vanderploeg, MD, MPH
Executive Director, COE-CST
Professor, Aerospace Medicine
University of Texas Medical Branch
Galveston, Texas

WELCOME AND LOGISTICS

- Safety Briefing
- Restrooms
- ISPCS on Wednesday & Thursday
- Tour of WSTF on Friday morning
- COE-CST Organization
  - FAA Office of Commercial Space Transportation
  - Nine Core Universities
  - Growing number of Affiliate Universities and Organizations

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INTRODUCTION
COE FOR COMMERCIAL SPACE TRANSPORTATION

- Established in August 2010
- Nine Core Universities
- Main goals include
  - research
  - training and education
  - outreach
- Self-sustaining by August 2020

Map of Core Member and Affiliate Member Universities

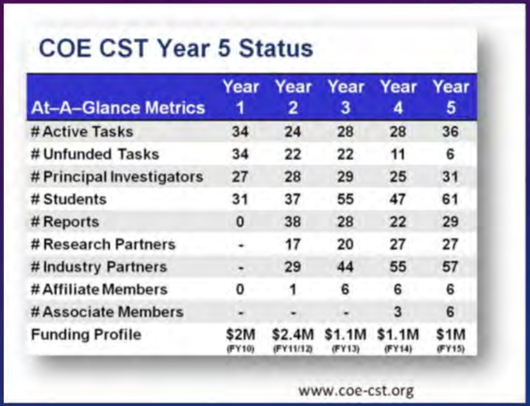
AGENDA MORNING

Start Time	Tuesday, October 11th
7:30 AM	REGISTRATION Hotel Encanto de Las Cruces, San Rafael Ballroom (Breakfast Included in Registration)
7:45 AM	
8:00 AM	
8:15 AM	
8:30 AM	ATM6 OPENING Dr. James M. Vanderploeg, MD, COE CST Exec Director, UTMB
8:45 AM	FAA COE PROGRAM OVERVIEW, Dr. Patricia Watts, FAA COE National Director
9:00 AM	COE CST YEAR 6 STATUS, Ken Davidian, FAA AST
9:15 AM	INDUSTRY VIABILITY PANEL Moderator: Dr. Tristan Fiedler, FIT [James Vanderploeg, UTMB] Panelists: Mr. Brad Cheetham (Task 193-CU, ESIL Workshops), Bailey Reichelt, Esq (Task 305-FIT/CSF, Suborbital Industry Analysis), Aram Kerkonian (Task 304-MU/FIT Legal Issues on Cross-Border Suborbital Flights - Affiliate Task)
9:30 AM	
9:45 AM	
10:00 AM	Sponsored Break
10:15 AM	
10:30 AM	HUMAN SPACEFLIGHT RESEARCH PANEL Moderator: Dr. Jim Vanderploeg, UTMB Panelists: Dr. David Klaus (Task 320-CU, Commercial spaceflight risk assessment and communication), ~~Dr. Guy Boy, (Task 333-FIT, Onboard Context-Sensitive Info System),~~ Dr. Rebecca Blue, (Task 308-UTMB & NASTAR Affiliate, Suborbital SFP Anxiety Assessment), Dr. Tarah Castleberry, Task 309-UTMB, Suborbital Pilot Training Assessment), Dr. Charles Mathers, (Task 310-UTMB, Increasing Cabin Survivability in Commercial Spacecraft)
10:45 AM	
11:00 AM	
11:15 AM	
11:30 AM	
11:45 AM	

AGENDA AFTERNOON

1:00 PM	SPACE TRAFFIC MANAGEMENT PANEL Moderator: Dr. Juan Alonso, Stanford, SU Panelists: Dr. Tim Fuller-Rowell (Task 186-CU, Mitigate threats through space environment modeling and prediction), Dr. Sigrid Close, (Task 186-SU, Space Environment Modeling Prediction), Dr. Dan Scheeres (Task 187-CU, Space Situational Awareness), Dr. Norman Fitz-Coy (Task 319-UF, DebriSat), Dr. Juan Alonso (Task 331-SU, Advanced 4D Special Use Airspace Research), Dr. Chris Draper, (Affiliate Task 332-SIM Defining Class X Air Space), Dr. Zheng Tao, MITRE (Affiliate Task), Mr. Brian Barnett, (Affiliate Task 307-SSC/NMSU COTS Satellite Communications), Dr. Richard Stansbury, (Affiliate Task 306-ERAU/NMSU Advanced ADS-B Prototypes)
1:15 PM	
1:30 PM	
1:45 PM	
2:00 PM	
2:15 PM	
2:30 PM	
2:45 PM	
3:00 PM	Wayne Hale Consultant, NASA (Ret.), Special Aerospace Services
3:15 PM	Sponsored Break
3:30 PM	TECHNOLOGY PANEL Moderator: Dr. Andrei Zagrai, NMT Panelists: Dr. Billy Oates, (Task 241-FSU, High Temperature, Optical Sapphire Pressure Sensors), Dr. Rajan Kumar, (Task 325-FSU, Optical Measurements of Rocket Nozzle Thrust and Noise), Dr. Bin Lim (Task 299-NMT, Nitrous Oxide Composite Tank Testing), Dr. Andrei Zagrai, (Task 323-NMT, Structural Health Monitoring Framework), Dr. Subith Vasu, (Task 311-UCF, Robust and Low-Cost LED Absorption Sensor) Dr. Eileen Ryan, (Task 329-NMT, Tracking & Monitoring Suborbital Commercial Space Vehicles)
3:45 PM	
4:00 PM	
4:15 PM	
4:30 PM	
4:45 PM	
5:00 PM	CLOSING REMARKS Dr. Jim Vanderploeg
5:15 PM	
5:30 PM	ADJOURN

OUTPUT OVER THE FIRST FIVE YEARS



COE CST Year 5 Status

At-A-Glance Metrics	Year 1	Year 2	Year 3	Year 4	Year 5
# Active Tasks	34	24	28	28	36
# Unfunded Tasks	34	22	22	11	6
# Principal Investigators	27	28	29	25	31
# Students	31	37	55	47	61
# Reports	0	38	28	22	29
# Research Partners	-	17	20	27	27
# Industry Partners	-	29	44	55	57
# Affiliate Members	0	1	6	6	6
# Associate Members	-	-	-	3	6
Funding Profile	$2M (FY10)	$2.4M (FY11/12)	$1.1M (FY13)	$1.1M (FY14)	$1M (FY15)

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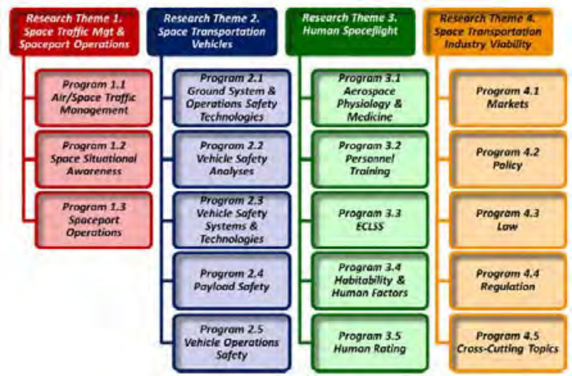
WHERE WE ARE GOING

FEDERAL AVIATION ADMINISTRATION
CENTER OF EXCELLENCE FOR
COMMERCIAL SPACE TRANSPORTATION

COMMERCIAL SPACE TRANSPORTATION RESEARCH ROADMAP

DECEMBER 2015

RESEARCH THEMES



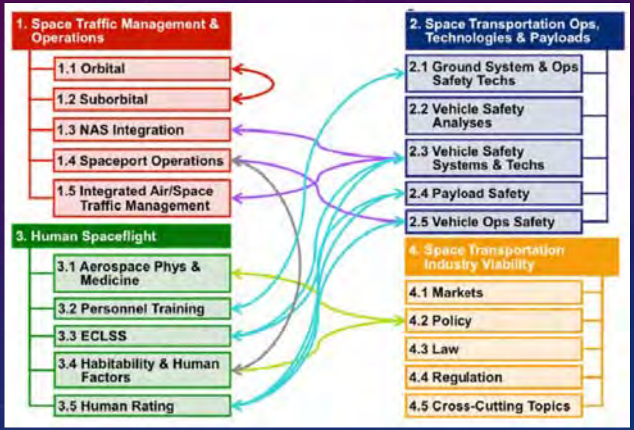
Research Theme 1. Space Traffic Mgt & Spaceport Operations
- Program 1.1 Air/Space Traffic Management
- Program 1.2 Space Situational Awareness
- Program 1.3 Spaceport Operations

Research Theme 2. Space Transportation Vehicles
- Program 2.1 Ground System & Operations Safety Technologies
- Program 2.2 Vehicle Safety Analyses
- Program 2.3 Vehicle Safety Systems & Technologies
- Program 2.4 Payload Safety
- Program 2.5 Vehicle Operations Safety

Research Theme 3. Human Spaceflight
- Program 3.1 Aerospace Physiology & Medicine
- Program 3.2 Personnel Training
- Program 3.3 ECLSS
- Program 3.4 Habitability & Human Factors
- Program 3.5 Human Rating

Research Theme 4. Space Transportation Industry Viability
- Program 4.1 Markets
- Program 4.2 Policy
- Program 4.3 Law
- Program 4.4 Regulation
- Program 4.5 Cross-Cutting Topics

RESEARCH AREA DEPENDENCIES



1. Space Traffic Management & Operations
- 1.1 Orbital
- 1.2 Suborbital
- 1.3 NAS Integration
- 1.4 Spaceport Operations
- 1.5 Integrated Air/Space Traffic Management

3. Human Spaceflight
- 3.1 Aerospace Phys & Medicine
- 3.2 Personnel Training
- 3.3 ECLSS
- 3.4 Habitability & Human Factors
- 3.5 Human Rating

2. Space Transportation Ops, Technologies & Payloads
- 2.1 Ground System & Ops Safety Techs
- 2.2 Vehicle Safety Analyses
- 2.3 Vehicle Safety Systems & Techs
- 2.4 Payload Safety
- 2.5 Vehicle Ops Safety

4. Space Transportation Industry Viability
- 4.1 Markets
- 4.2 Policy
- 4.3 Law
- 4.4 Regulation
- 4.5 Cross-Cutting Topics

WEBSITE

- http://www.coe-cst.org
- Commercial Space Transportation Research Roadmap
- COE-CST Year-Five Annual Report

INDUSTRY VIABILITY PANEL

INDUSTRY VIABILITY PANEL
Moderator: Dr. Tristan Fiedler, FIT [Jim Vanderploeg, UTMB]
Panelists:
Mr. Brad Cheetham (Task 193-CU, ESIL Workshops),
Bailey Reichelt, Esq (Task 305-FIT/CSF, Suborbital Industry Analysis),
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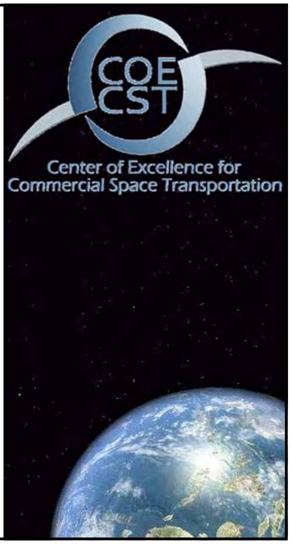
COE CST Sixth Annual Technical Meeting:

Task 186: Mitigating threats through space environment modeling/prediction

PI: Tim Fuller-Rowell
Student: Catalin Negrea

October 11, 2016
Las Cruces, NM



Team Members

Tim Fuller-Rowell, Tomoko Matsuo, Houjun Wang, Tzu-Wei Fang
Cooperative Institute for Research in Environmental Sciences (CIRES)
University of Colorado, Boulder and NOAA Space Weather Prediction Center

Catalin Negrea
Student, Electrical, Computer, and Energy Engineering, University of Colorado

Mihail Codrescu, Rodney Viereck, Mark Iredell
NOAA Space Weather Prediction Center, Boulder, CO
and Environmental Modeling Center, Camp Springs, MD

Jeffrey Forbes
Aerospace Engineering Sciences, University of Colorado, Boulder

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Task Description

Goal:

1. Knowledge of the environmental conditions and their impact on flight conditions from the ground to 600 km, including forecast of:

2. Neutral density, variability, and structure, for spacecraft drag for orbit prediction and collision avoidance, and forecast of near-surface and space weather conditions (winds, wind shear, temperature, variability and turbulence, storms, lightning, etc.),

3. Plasma density, D-region absorption, total electron content, ionospheric structure and irregularities, for communications and navigation

Objectives: *Fill the gap between terrestrial and space weather forecasts and develop a "weather" prediction model extending from Earth's surface to the top of the atmosphere*

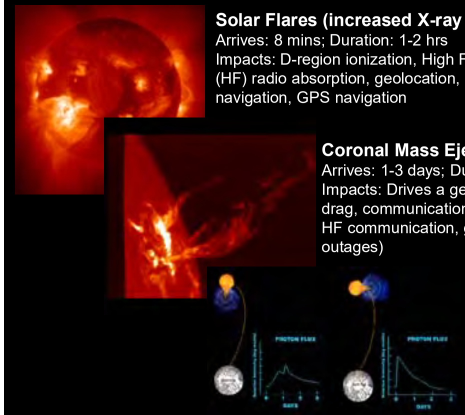
Outcome: *Predict the environmental conditions needed for safe orbital, sub-orbital, re-entry, descent, and landing*

Current:
Aviation Weather Support

: conditions below 50 km from National Weather Service Global Forecast System (GFS) model and Gridpoint Statistical Interpolation (GSI) data assimilation system

- Winds and temperature
- Turbulence
- Icing
- Analysis and Forecasts

So what is Space Weather?



Solar Flares (increased X-ray flux)
Arrives: 8 mins; Duration: 1-2 hrs
Impacts: D-region ionization, High Frequency (HF) radio absorption, geolocation, low-frequency navigation, GPS navigation

Coronal Mass Ejections (plasma)
Arrives: 1-3 days; Duration: 1-2 days
Impacts: Drives a geomagnetic storm, satellite charging, drag, communication, navigation (e.g., GPS), HF communication, ground induced currents (power outages)

Solar Proton Events (energetic particles)
Arrives: 15 mins to a few hours; Duration: days
Impacts: Polar HF absorption, satellite anomalies, radiation hazard

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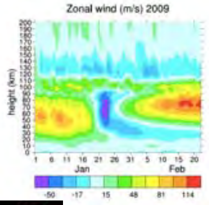
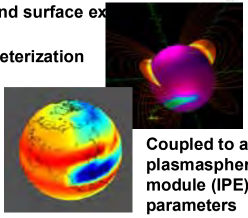
Filling the Gap – weather and space weather



- We have developed a global seamless neutral whole atmosphere model (WAM) 0-600 km, 0.25 scale height, 2° x 2° lat/long, hydrostatic, 10-fold extension of Global Forecasting System (GFS) US weather model.
- O_3 chemistry and transport
- Radiative heating and cooling
- Cloud physics and hydrology
- Sea surface temperature field and surface ex processes
- Orographic gravity wave parameterization
- Eddy mixing and convection
- Diffusive separation of species
- Composition dependent C_p
- Height dependent g(z)
- EUV, UV, and non-LTE IR
- Ion drag and Joule heating



Coupled to a global ionosphere, plasmasphere, electrodynamics module (IPE) for plasma parameters

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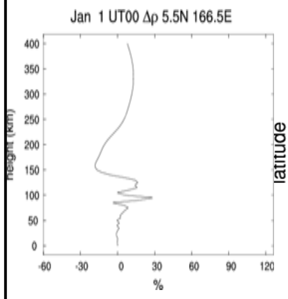
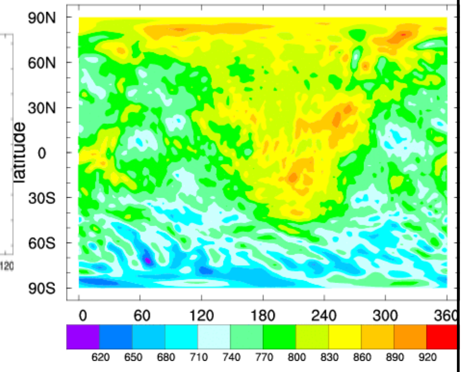
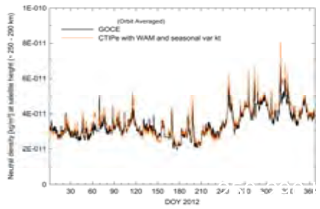
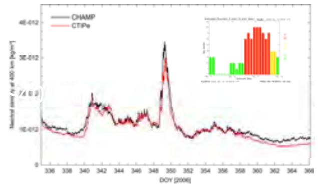


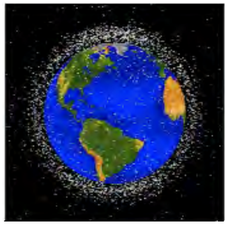
Temperature 200 km altitude
Sep 03 UT00:00 200km WAM T

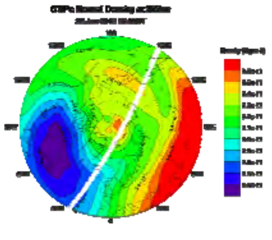


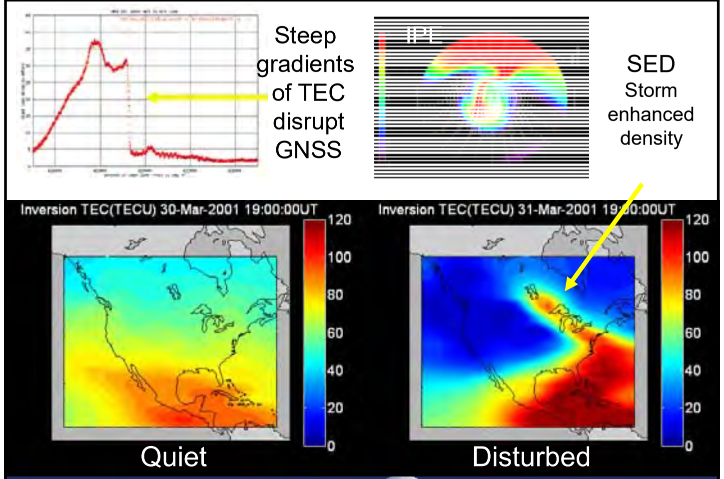
Neutral density
CTIPe vs GOCE and CHAMP











Summary

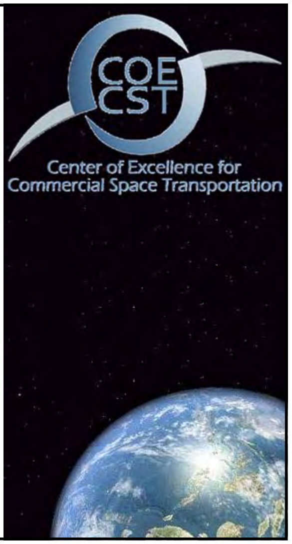
- Goal is to define the weather and space weather conditions for orbital and suborbital flights for commercial space transportation
- Integrate the terrestrial and space weather conditions (from one coordinated source)
- Are developing a seamless model from the ground to 600 km altitude coupled to the plasma to fill gap between conventional weather and space weather
- Provide neutral atmosphere weather forecast for winds, temperature, density, turbulence, wind shears, deviations from average, and vehicle drag
- Ionospheric space weather forecast for plasma density, ionospheric structure, and irregularity conditions for communications and navigation
- Radiation hazard (e.g., NAIRAS potential new start)

COE CST Sixth Annual Technical Meeting

Space Environment MMOD Modeling and Prediction

Sigrid Close and Diana Madera
Stanford University

Las Cruces, NM



Outline

- **Team Members**
- **Task Description**
- **Methodology**
- **Results**
- **Conclusions and Future Work**

Team Members

- **PI: Sigrid Close (Stanford University)**
- **Graduate Students (Stanford University)**
  - Diana Hernandez Juarez-Madera

  - Lorenzo Limonta (supported by NSF)

- **Collaborators**
  - University of Western Ontario
  - NASA Marshall Space Flight Center

Purpose of Task

- **Spacecraft are routinely impacted by micrometeoroids and orbital debris (MMOD)**
  - Mechanical damage: “well-known”, larger (> 120 microns), rare
  - Electrical damage: “unknown”, smaller/fast, more numerous

- **Growing need to characterize MMOD down to smaller sizes and provide predictive threat assessment**

MMOD – Classification

- **Meteoroids**
  - Speeds
    - 11 to 72.8 km/s (interplanetary)
    - 30-60 km/s (average)
  - Densities
    - ≤1 g/cm^3 (icy) or > 1 g/cm^3 (rocky/stony)
  - Sizes
    - < 0.3 m (meteoroid)
    - < 62 µm (dust)

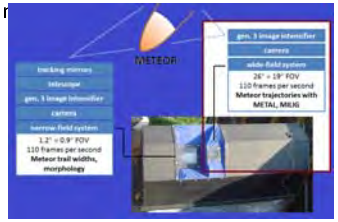
- **Space Debris**
  - Speeds in LEO
    - < 12 km/s
    - 7-10 km/s (average)
  - Densities
    - > 2 g/cm^3
  - Sizes
    - < 10 cm (small)

Definitions

- **Meteoroid**
  - A small, solid extraterrestrial body that hits the Earth's atmosphere
- **Meteor**
  - Signature of the meteoroid entering Earth's atmosphere ("Shooting Star")
- **Meteorite**
  - Meteoroid that has survived to hit the Earth's surface

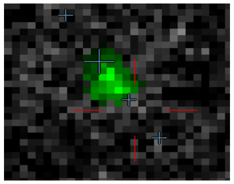
Meteors: Experiment

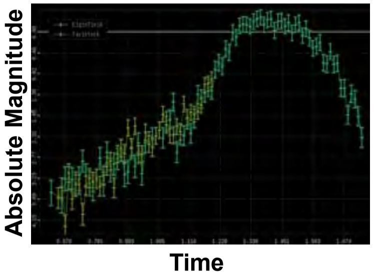
- CAMO: Canadian Automated Meteor Observatory
  - Two observatory stations separated by 44.9 km: Eigenfield and Tavistock
  - Wide field camera with FOV 26º x 19º
  - 110 frames per second, Meteor r



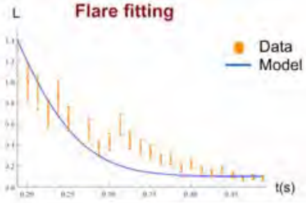
Meteors: Light Curve

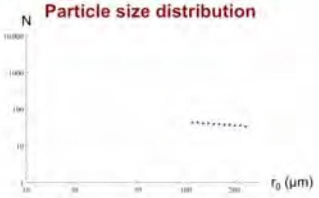
- METAL: METeor AnaLysis software (UWO)





Meteors: Preliminary Results





Event Label	Date & Time	δ (kg m^{-3})	σ (s^2 km^{-2})	m_{grain} $m_b - m_a$	a	h_d (km)	v (km/s)	
0	20110706_054233	3500	0.030	1E-09 - 1E-10	-3.5	119.369	68.770	stony
1	20150319_081706	1800	0.050	1E-07 - 1E-08	-1.1	83.489	20.770	stony
2	20150319_044203	5600	0.080	1E-07 - 1E-10	-1.4	83.860	30.270	stony
3	20101010_005932	2400	0.069	1E-06 - 1E-08	-1.3	85.519	30.018	stony
4	20150323_035632	800	0.080	4E-07 - 1E-07	-1.1	83.351	21.695	cometary

Conclusions and Future Work

- **New student (Diana) researching meteoroid and orbital debris fragmentation**
- **New optical observations for meteoroid fragmentation**
    - Model describe sudden and simultaneous detachment of the particle
    - Traditional models not capturing relevant physics
    - Additional data and modeling efforts needed
- **Next steps**
    - Combine optical and radar data
    - Develop new ablation models

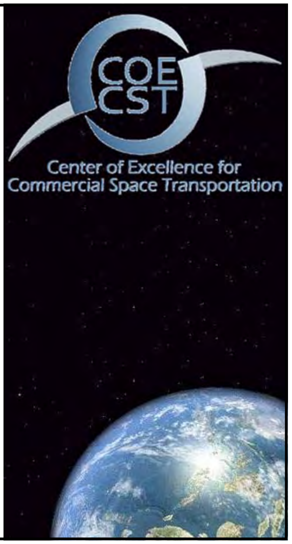
Thank you!

COE CST Sixth Annual Technical Meeting

TASK 329. Tracking and Monitoring Suborbital Commercial Space Vehicles

PI's: William Ryan
Eileen Ryan
Student: Jacob Schirer

October 11, 2016
Las Cruces, NM

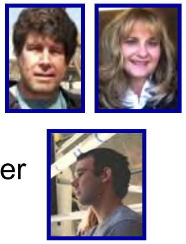


Agenda

- Team Members
- Task Description
- Schedule
- Goals
- Results
- Conclusions and Future Work

Team Members

- Principal Investigators
  - Dr. William H. Ryan
  - Dr. Eileen V. Ryan
- Undergraduate: Jacob Schirer
- Organization:



New Mexico Tech (also providing matching funds)

Task Description

- Develop an asset ~100 km Northwest of **Spaceport America** in New Mexico that can be utilized to assess spacecraft health and assist in launch/re-entry anomaly resolution.
- Develop data products useful for mishap investigation for Commercial Space Vehicle launches.
- Facility: NM Tech's Magdalena Ridge Observatory **2.4-meter fast-tracking telescope.**

Schedule

- The period of performance for this work is December 2015 – December 2016.

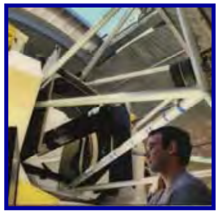
The MRO 2.4-meter telescope (right) and support facility (left) located outside of Socorro, NM on Magdalena Ridge. The telescope is located within line-of-sight to NM Spaceport. Stratospheric balloons serve as good test targets for pointing and tracking-software development in preparation for commercial space vehicle launch monitoring.

Goals

- Develop software to perform fully autonomous, closed-loop tracking using observational data collected via both the acquisition telescope (AT) and the 2.4-meter telescope imaging camera.
- Take 8 half-nights of observational tracking data using **weather balloons (or similar) as targets.**
- Analyze test tracking data, identify limitations, then improve algorithms for target tracking.

Student Software Project

- An undergraduate student in mechanical engineering at NM Tech spent the Summer 2016 developing a Python program to grab target positional information and then interface with and point the telescope to acquire the target.



The pointing software was successfully tested on balloons launched from Ft. Sumner, NM in September 2016.

HASP Float Track: Directly Overhead

The first balloon target (HASP) was launched during monsoon wind patterns and floated West from Ft. Sumner directly toward us. Bad weather, but data collected on pointing accuracy at ~30º telescope elevation.

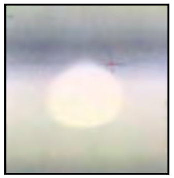
First PointingTest: HASP Balloon

Columbia Scientific Balloon Facility

HASP 2016 Flight # 670N

Flight is descending.

HASP overhead at MRO 2.4-meter telescope site at ~5:00 pm MDT



HASP Balloon (launched 10:10 am MDT) imaged through the 2.4-meter telescope's acquisition tracking camera on 09/01/16.

"Test Flight" Weather

Cloudy weather persisted, but we acquired data on 2 balloons to test tracking in late September. Wind patterns had already shifted such that the balloons floated East, away from the facility. Data was collected on tracking accuracy at ~3º telescope elevation, on targets "JPL Remote" and "Test Flight".

"Test Flight"

Columbia Scientific Balloon Facility

LDB TEST 2016 Flight # 673NT

Flight is at float.

Payload position as of:
Time: 17:33:09Z Date: 09/28/16

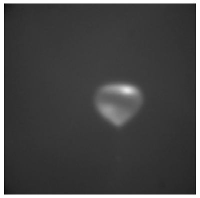
Latitude: 34°44.68 N
Longitude: 103°38.05 W
Altitude: 121843 Feet

9.90 Knots @ 81.40 Deg
-60 Feet / Minute
33 Nm from launch site
26 Nm @ 172° deg radial from VOR Tucumcari,NM.

"Test Flight" 400 km away and 3º above horizon from MRO 2.4-meter telescope site

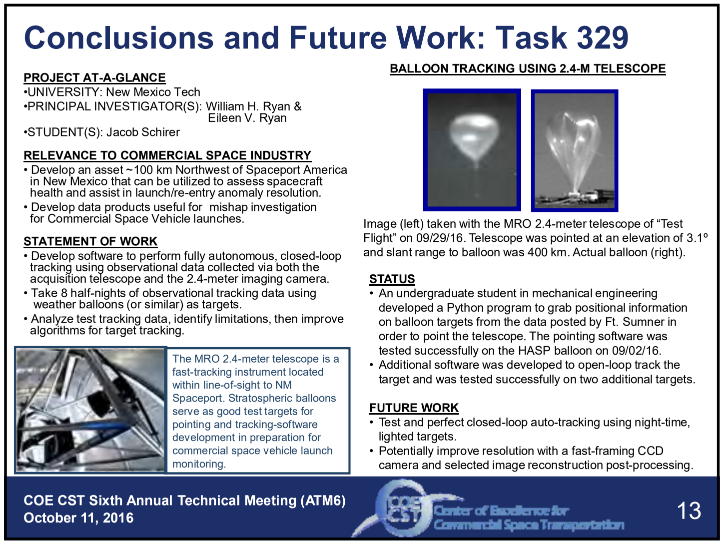
"Test Flight" Balloon (imaged at 02:33 pm MDT) by the 2.4-meter telescope on 09/29/16.

Tracking Results



Static tracking of the "JPL Remote" balloon target launched from Ft. Sumner on 09/28/16.

Dynamic tracking of the "JPL Remote" balloon target launched from Ft. Sumner on 09/28/16.



Conclusions and Future Work: Task 329

PROJECT AT-A-GLANCE

- •UNIVERSITY: New Mexico Tech
- •PRINCIPAL INVESTIGATOR(S): William H. Ryan & Eileen V. Ryan
- •STUDENT(S): Jacob Schirer

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Develop an asset ~100 km Northwest of Spaceport America in New Mexico that can be utilized to assess spacecraft health and assist in launch/re-entry anomaly resolution.
- Develop data products useful for mishap investigation for Commercial Space Vehicle launches.

STATEMENT OF WORK

- Develop software to perform fully autonomous, closed-loop tracking using observational data collected via both the acquisition telescope and the 2.4-meter imaging camera.
- Take 8 half-nights of observational tracking data using weather balloons (or similar) as targets.
- Analyze test tracking data, identify limitations, then improve algorithms for target tracking.

The MRO 2.4-meter telescope is a fast-tracking instrument located within line-of-sight to NM Spaceport. Stratospheric balloons serve as good test targets for pointing and tracking-software development in preparation for commercial space vehicle launch monitoring.

BALLOON TRACKING USING 2.4-M TELESCOPE

Image (left) taken with the MRO 2.4-meter telescope of "Test Flight" on 09/29/16. Telescope was pointed at an elevation of 3.1° and slant range to balloon was 400 km. Actual balloon (right).

STATUS

- An undergraduate student in mechanical engineering developed a Python program to grab positional information on balloon targets from the data posted by Ft. Sumner in order to point the telescope. The pointing software was tested successfully on the HASP balloon on 09/02/16.
- Additional software was developed to open-loop track the target and was tested successfully on two additional targets.

FUTURE WORK

- Test and perfect closed-loop auto-tracking using night-time, lighted targets.
- Potentially improve resolution with a fast-framing CCD camera and selected image reconstruction post-processing.

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October 11, 2016

13

COE CST Sixth Annual Technical Meeting

Advanced 4D Special Use Airspace Research

Juan J. Alonso and Thomas J. Colvin

Department of Aero & Astro
Stanford University
Stanford, CA 94305

October 11, 2016
Las Cruces, NM

Stanford | ENGINEERING
Aeronautics & Astronautics

Center of Excellence for Commercial Space Transportation

aerospacedesignlab

Agenda

- Disruption to Air Traffic from Space Vehicle Operations
- 4D Compact Envelopes
- An Open-Source Tool to Calculate Risk to Aircraft
- Demonstration of Near-Elimination of Airspace Disruption
- Conclusions & Future Work

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October 11, 2016

3

Team Members

- Stanford University
  - Juan J. Alonso, PI
  - Dr. Thomas J. Colvin, Graduate Student
  - Dr. Francisco Capristan, Graduate Student
- Organizations
  - FAA: Drs. Paul Wilde & Dan Murray
  - FAA SVO: Mr. Kevin Hatton (now w/ SpaceX)
  - FAA Tech Center

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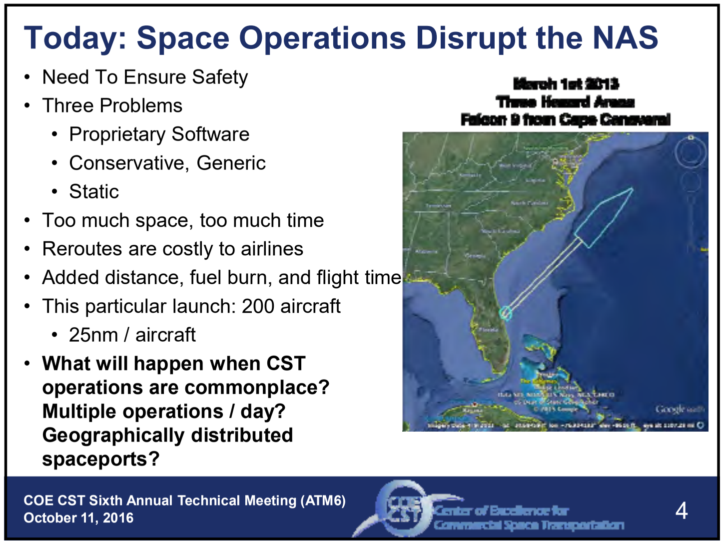

Today: Space Operations Disrupt the NAS

- Need To Ensure Safety
- Three Problems
  - Proprietary Software
  - Conservative, Generic
  - Static
- Too much space, too much time
- Reroutes are costly to airlines
- Added distance, fuel burn, and flight time
- This particular launch: 200 aircraft
  - 25nm / aircraft
- **What will happen when CST operations are commonplace? Multiple operations / day? Geographically distributed spaceports?**

March 1st 2013
Three Hazard Areas
Falcon 9 from Cape Canaveral

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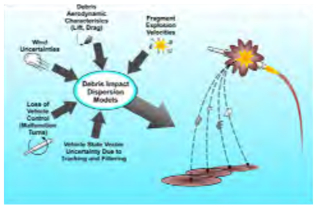
4D Compact Envelopes: A New Approach

- **4D Compact Envelopes**: New framework for calculating and protecting against the probabilistic risk to aircraft from space vehicle debris.
- **Provably safe**: to a regulator-specified safety threshold.
- **NextGen**: incorporates many advances in the capabilities of the modern national airspace. Reaction times and dynamicity.
- **Open-source**: tool to calculate the risk to aircraft from space vehicle operations and necessary compact envelopes.
- **Near-elimination of disruption**: Airspace disruption can be reduced by two orders of magnitude. Virtual elimination of conflicts.

Risk-Based Analyses

Probabilistic Uncertainties
- Probability of Failure
- Failure time distribution
- State vector
- Number of pieces generated
- Imparted velocities
- Aerodynamic properties
- Wind speed and direction
- Atmospheric density

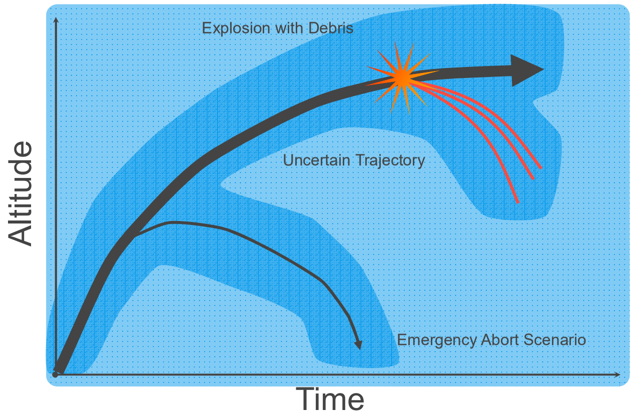


Source: FAA Flight Safety Analysis Handbook

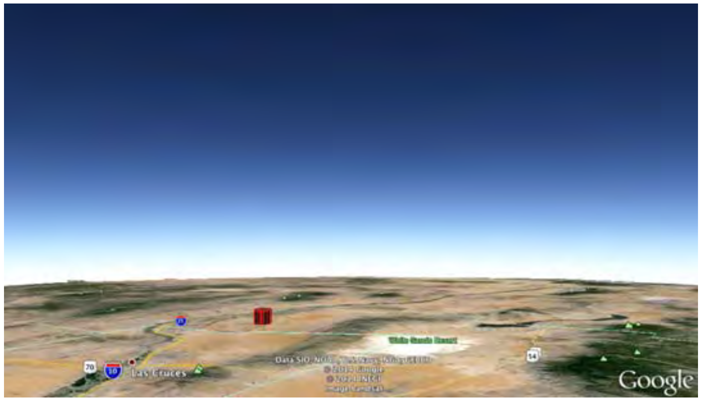
$\xi^{d}(r,t)$

Probability density that piece of debris d is found at location r at time t

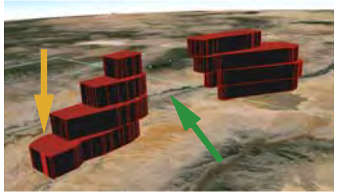
4D Compact Envelopes Concept



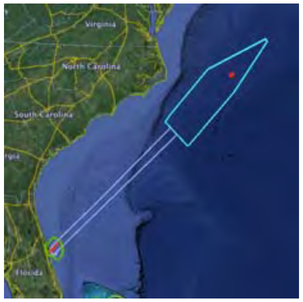
Example



Some Implications



- Suborbital missions may have corridors that are always safe.
- Launch site overflight permitted
- Falcon 9 envelopes much smaller
- Generally, first stage event can be handled reactively

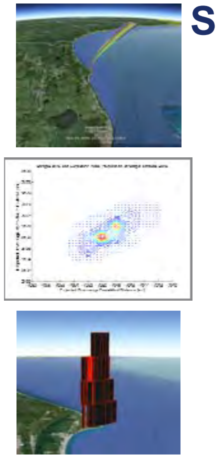


SU-FARM

Stanford University Framework for Aircraft Risk Management

- Calculate the risk to aircraft from space vehicle operations
- Mitigate that risk through the use of 4D Compact Envelopes
- Written in C++, Python
- Open Source, available on github

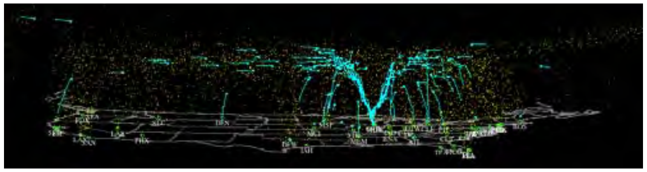
SU-FARM Typical Scenario



Case Study: Airspace Disruption

- Quantify the efficiency of compact envelopes
- 8 vehicles, 10 locations, 14 missions
- Traditional hazard area vs compact envelopes
  - Five minute reaction time
  - Simulate 90 days
- Compare disruptions
- Collaboration with FAA NextGen, Tech Center, and Commercial Space

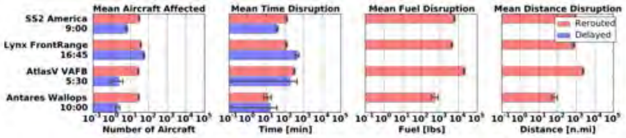
FACET to Measure Disruption



- Future ATM Concepts Evaluation Tool (NASA Ames)
- Simulation environment for preliminary testing of advanced ATM concepts over continental United States
- Uses aircraft performance profiles, airspace models, weather data, and flight schedules, etc.
- Models trajectories for the climb, cruise, and descent phases of flight for each aircraft in the NAS

Results (Traditional Approach)

Traditional: Mean Values of Aggregate Impact (N=90)



Mission	Rerouted	Delayed	Flight Delay	Ground Delay	Added Fuel	Added Distance
SS2 America	30.86	6.56	125.79	37.52	5896.59	804.73
Lynx FrontRange	37.58	54.64	119.78	454.16	4324.11	754.99
AtlasV VAFB	27.46	2.46	318.98	193.29	28267.35	2380.38
Antares Wallops	28.76	2.18	12.39	16.14	569.16	71.93
Units	Aircraft	Aircraft	Minutes	Minutes	Pounds	Nautical Miles

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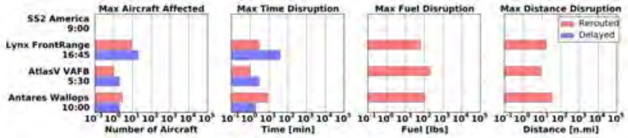
Results (Compact Envelopes)

Envelopes: Maximum Values of Aggregate Impact (N=90)



Mission	Rerouted	Delayed	Flight Delay	Ground Delay	Added Fuel	Added Distance
SS2 America	0.00	0.00	0.00	0.00	0.00	0.00
Lynx FrontRange	9.00	30.00	3.00	40.00	63.67	17.32
AtlasV VAFB	1.00	2.00	1.00	3.00	214.36	8.77
Antares Wallops	3.00	2.00	0.00	2.00	118.06	37.18
Units	Aircraft	Aircraft	Minutes	Minutes	Pounds	Nautical Miles

---

Conclusions & Significance of Work

- Reduced / eliminated aircraft disruption
- Enables high frequency space travel from an ATM perspective
- Spaceports can be collocated with airports
- As airspace capabilities evolve, Compact Envelope framework can handle them

Spaceport Berlin

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Evaluating the Safety of Launch and Reentry Operations in the National Airspace System

Zheng Tao

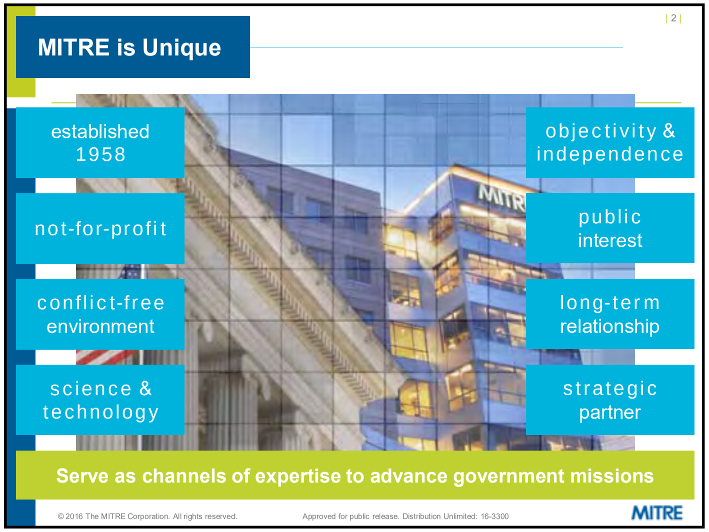
Ganghuai Wang, Ashley G. Williams, Tudor Masek, Tom St. Clair, Jon L. Semanek, Jonathan L. Schwartz

The MITRE Corporation

FAA COE CST ATM6 Conference
October 2016
Las Cruces, NM

(authors clockwise)

MITRE

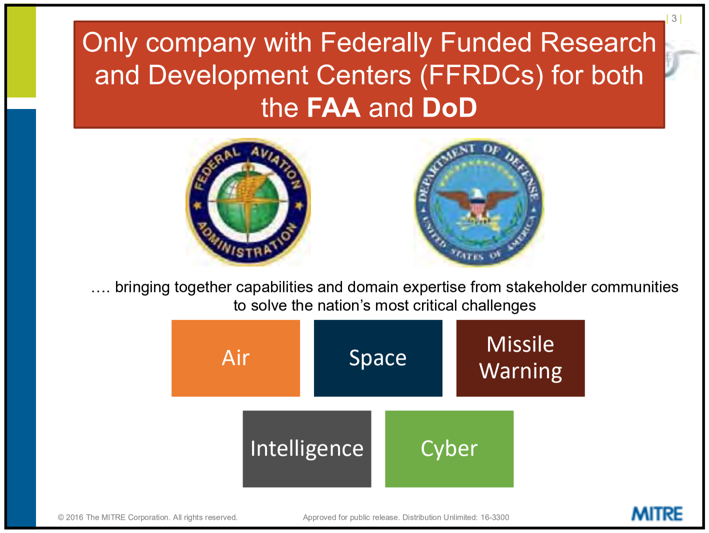


MITRE is Unique

- established 1958
- not-for-profit
- conflict-free environment
- science & technology
- objectivity & independence
- public interest
- long-term relationship
- strategic partner

Serve as channels of expertise to advance government missions

MITRE



Only company with Federally Funded Research and Development Centers (FFRDCs) for both the **FAA** and **DoD**

…. bringing together capabilities and domain expertise from stakeholder communities to solve the nation's most critical challenges

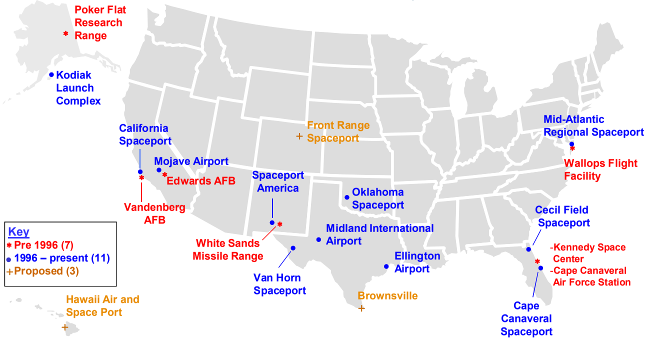
- Air
- Space
- Missile Warning
- Intelligence
- Cyber

MITRE

Private-Public Partnerships

It is Getting Busier in the Airspace…

U.S. Launch Sites and Snapshot of Air Traffic



Source: https://www.faa.gov/about/office_org/headquarters_offices/ast/industry/media/Map_US_spaceports.pdf

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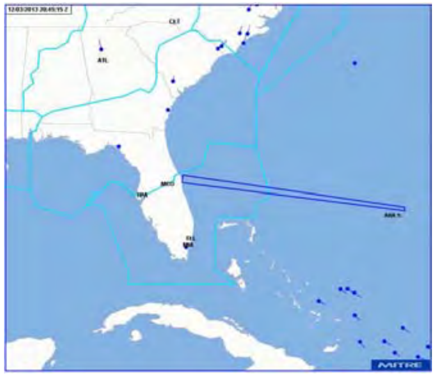
Launch and Reentry Operations Affect Other NAS Users

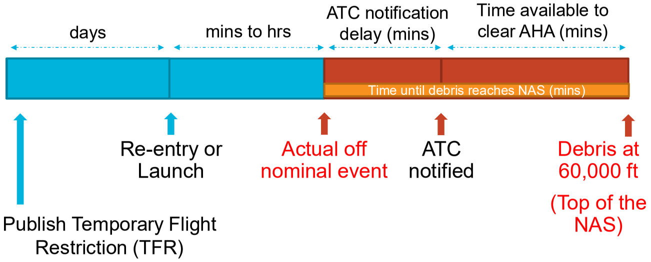


Contingent Aircraft Hazard Areas (AHAs)

- **Contingent (dynamic) AHAs is a method to efficiently integrate more frequent launch and reentry operations**
  - How safe are they?

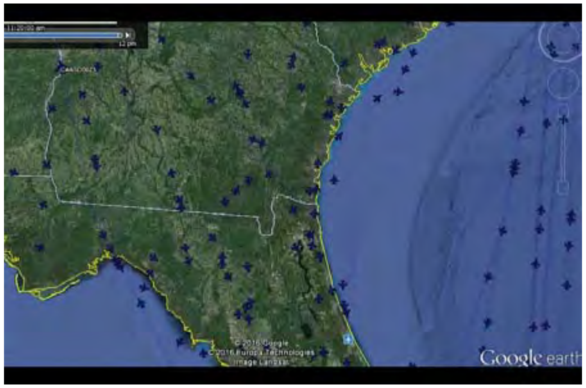
Notional AHAs

Air Traffic Control Timeline for Off-Nominal Case



Can aircraft clear the hazard area before debris reaches the NAS?
(Time to clear <= Time until debris reaches NAS)

Evacuation Due to a Winged Re-entry from Orbit



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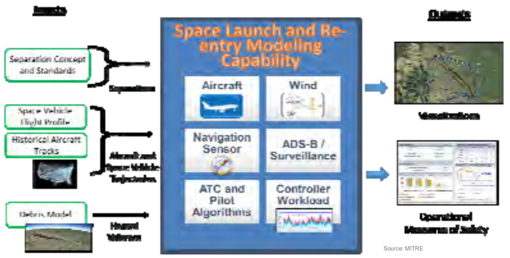
Approach

- Develop a fast-time analysis capability to provide operational measures of safety for launch and reentry operations



Source: MITRE

- Prior versions of model used by FAA and DoD to assess algorithms and performance standards of different systems

MITRE

Collaboration

- **Stanford University**
  - Debris modeling
- **FAA Center of Excellence for Commercial Space Transportation**
  - Research/Industry Member
- **Office of Comercial Space Transportation**
  - Scenario development and trajectories
- **NASA**
  - Trajectory modeling

MITRE

Research Question

- **Past MITRE research has shown that times to clear hazard areas are mostly dependent upon:**
  - Size of the hazard volume
  - Orientation of the flow of traffic to the hazard volume
  - Density of traffic in and around the hazard volume
  - ATC notification delay
- **How sensitive is the time to clear to these factors?**
- **Utilize MITRE's capability to evaluate these factors**

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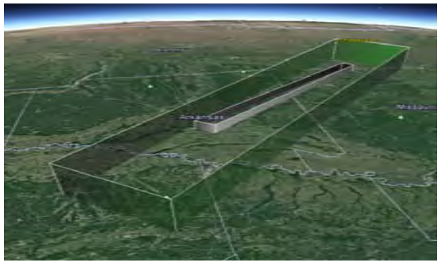
Use Case

- **Off nominal reentry over the continental US**



- **Examine: Traffic orientation, traffic density, ATC Notification Delay, and aircraft surveillance**

MITRE

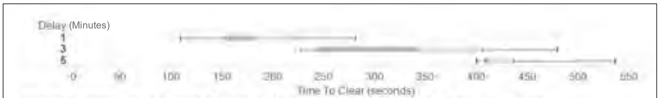
Analysis

- **Examined sensitivity of metrics to the examined factors**
  - "<u>time to clear a hazard area</u>" – time it takes for all aircraft to exit a hazard area after an off nominal event
  - "<u>time in hazard</u>" – time each flight spends in the hazard area

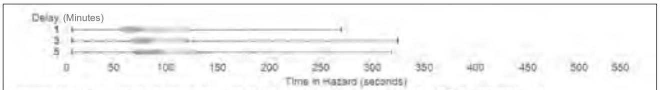
MITRE

Findings: ATC Notification Delay

- **Large sensitivity to ATC notification delay**
  - Time it takes for ATC to be aware of an off-nominal
- **Not a linear relationship**



Sensitivity of Time to Clear to ATC notification delay (with ADS-B surveillance)



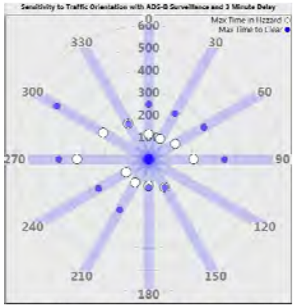
Sensitivity of Time in Hazard to ATC notification delay (with ADS-B surveillance)

MITRE

Findings: Traffic Orientation

- **Sensitive to traffic orientation**
- **Longer times generally coincide with the hazard area orientation (~310/130 degrees)**

Original AHA with aircraft on eastbound headings. ***(source MITRE)***



Sensitivity to traffic orientation with ADS-B and 3-minute ATC notification delay

MITRE

Analysis Results Summary

- **“Time to clear a hazard area” is most sensitive to ATC notification delay, traffic orientation, and traffic density**
- **“Time in hazard” is less sensitive to the factors than “time to clear a hazard area”**

Conclusion

- **MITRE’s capability can assess if contingent (dynamic) AHAs are safe to use**
  - Can determine if aircraft can clear AHA before debris reaches the NAS
  - Detailed, parametric assessments of variety of vehicles and trajectories, ATC strategies, separation concepts and standards, and surveillance performance needs
- **FAA can utilize this sensitivity study to focus resources on factors that could most improve safety for these operations**

Questions?

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COE CST Sixth Annual Technical Meeting

Task 299: Nitrous Oxide Composite Case Testing

PI: Bin Lim
Co-PI: Andrei Zagrai

October 11, 2016
Las Cruces, NM

Center of Excellence for Commercial Space Transportation

Agenda

- Team Members
- Task Description
- Schedule
- Results
- Conclusions

Team Members

- PI: Seokbin (Bin) Lim (NMT)
- Co-PI: Andrei Zagrai (NMT)

- Student: Antonio Garcia (NMT)
- Student: Steven Sweeney (NMT)
- Student: Josh Carroll (NMT)
- Test Engineer/Student: Meliton Flores (EMRTC)

- COE CST Program Manager: Ken Davidian (FAA)
- Technical Monitor: Yvonne Tran (FAA)
- Technical Monitor: Don Sargent (FAA)

Task Description

Objectives

- Develop an understanding of fragmentation hazards from composite tanks used for fuel/oxidizer storage
- Construction of hypothesis and experimental validation of how cracks form in test samples

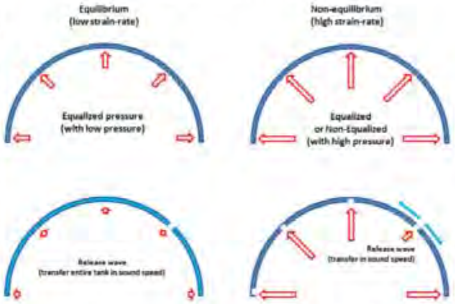
Tasks

- 5 tests each of Al 6061 & composite tubes to understand the crack opening behavior (10 tests total)
- 5 Al liner with composite wrapped tanks (space application grade)
- Develop methods to predict crack opening behavior
- Develop standard test procedures for composite materials under a high-rate loading
- Numerical simulations to predict the fragmentation (in progress)

Hypothesis

Static vs. Dynamic

(Very slow loading Vs. Fast-Continuous loading)

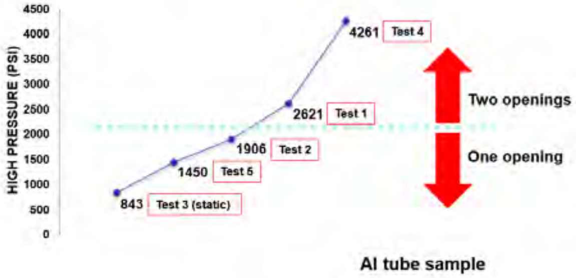


A weak point of the tank will be ruptured, and the subsequent release wave from the ruptured area will lower the stress in entire tank

A weak point of the tank will be ruptured initially, and the subsequent release wave forms but the speed of release wave is not fast enough to prevent extra initiations of ruptures nearby

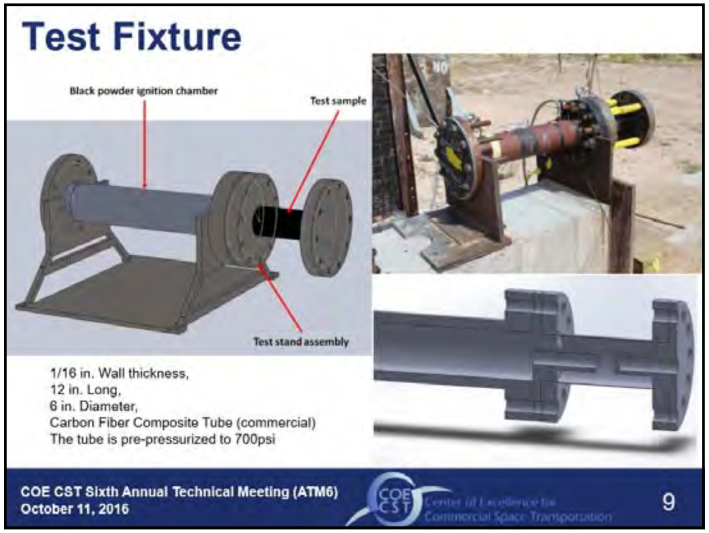
Test from ATM5

Results from ATM5



Test Matrix

Date	Loading Source	Sample Material	Type	Success
8/19/2015	Nitrogen Tank Farm	Aluminum	Cylinder	Yes
9/10/2015	Nitrogen Tank Farm	Aluminum	Cylinder	Yes
9/10/2015	Nitrogen Tank Farm	Aluminum	Cylinder	Yes
9/23/2015	Nitrogen Tank Farm	Aluminum	Cylinder	Yes
9/30/2015	Nitrogen Tank Farm	Aluminum	Cylinder	Yes
4/13/2016	Nitrogen Tank Farm	Carbon Fiber	Cylinder	No
4/14/2016	Nitrogen Tank Farm	Carbon Fiber	Cylinder	No
6/16/2016	Nitrogen Tank Farm	Carbon Fiber	Cylinder	No
6/21/2016	Nitrogen Tank Farm	Carbon Fiber	Cylinder	No
7/10/2016	Nitrogen Tank Farm	Carbon Fiber	Cylinder	No
9/29/2016	Black Powder Chamber	Carbon Fiber	Cylinder	Yes
10/7/2016	Pyrodex Cavity	Carbon Fiber / Aluminum	Tank	No
10/10/2016	Pyrodex Cavity	Carbon Fiber / Aluminum	Tank	Yes
10/10/2016	Pyrodex Cavity	Carbon Fiber / Aluminum	Tank	Yes



Test Fixture

1/16 in. Wall thickness,
12 in. Long,
6 in. Diameter,
Carbon Fiber Composite Tube (commercial)
The tube is pre-pressurized to 700psi

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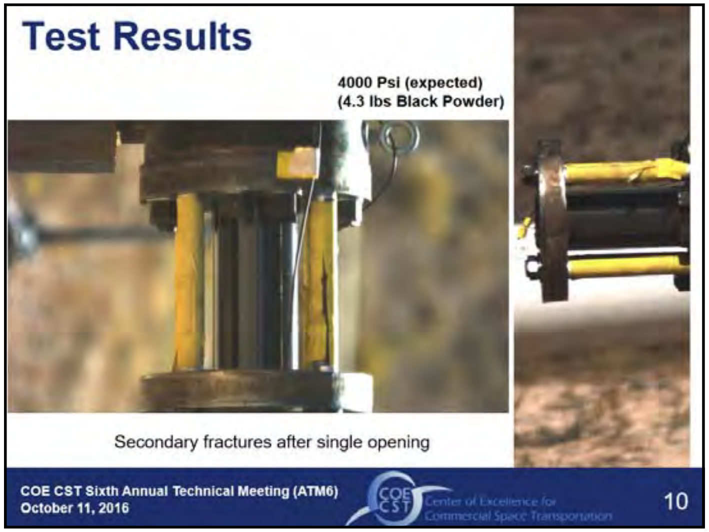

Test Results

4000 Psi (expected)
(4.3 lbs Black Powder)

Secondary fractures after single opening

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Test Fixture

~1/4 in. Al liner with ~1/4in composite (3lbs) wrapped wall
~16 in. Long,
6 in. Diameter, 203 cu in.
Space grade tanks (material properties are not available)
3lbs Pyrodex
20,400 Psi (expected)

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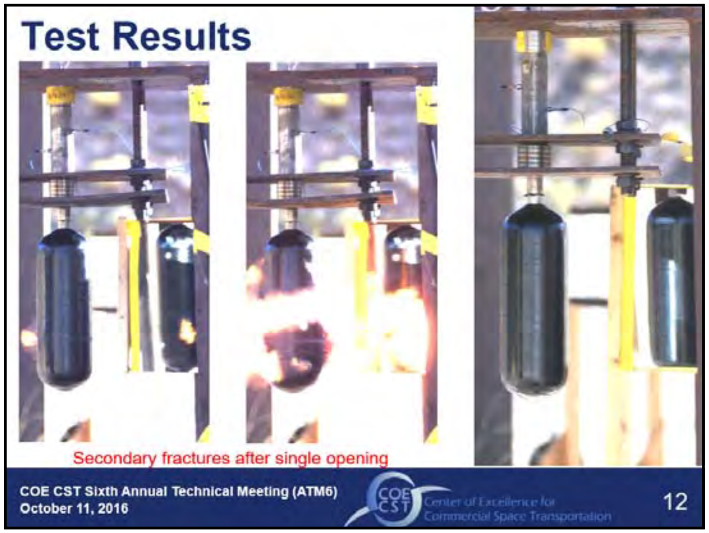

Test Results

Secondary fractures after single opening

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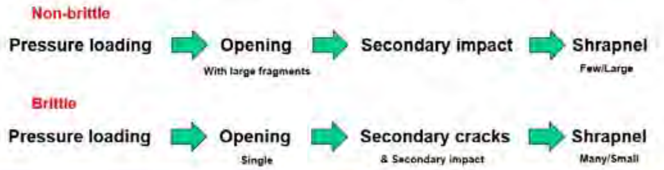
Results

- Two different types of crack/fracture pattern
- Brittle vs. Non-brittle fractures

Type	Non-brittle fracture (ATM5)	Brittle fracture (ATM6)
Shrapnel	Large pieces	Small/Many pieces
Origin	One or Two openings	Single opening (so far)
Material	Aluminum	Carbon fiber and Composite
Pattern	Tend to maintain initial openings	Multiple crack formation after the initial opening
Approach	Shock/Release wave speed in the sample (gas)	Extreme dynamic event

Conclusions

- The number of openings depends on the initial pressure loading (one or two openings)
- The size of fragments gets smaller as they impact to nearby objects
- The number of opening predicts the size of initial fragment (in non-brittle)
- The number of opening provides a way to determine the initial velocity/size of fragments after explosion
- Two different approaches are needed depending on the type of sample (Brittle vs. Non-brittle) fracture patterns and the crack formation



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UAT ADS-B Research and Demonstration for Commercial Space Applications: Progress Report

Richard S. Stansbury

Students:
Brandon Neugebauer
Dominic Tournour
Dylan Rudolph
Richard Day
Yosvany Alonso
Kelsey Klein
Andrew "Jack" Strange

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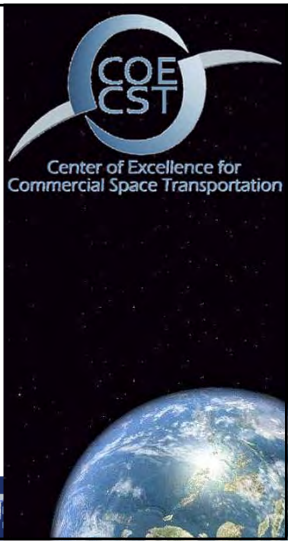


Agenda

- Team Members
- Project Overview
- Current and Near-Term Activities
- Maturation plan and follow-on research plans

Team Members

- **People**
  - Principal Investigators: Richard S. Stansbury; Nick Demidovich
  - Students: Brandon Neugebauer, Richard P. Day, Yosvany Alonso, Dyland Rudolph, and Dominic Tournour, Kelsey Klein, Andrew "Jack" Strange
  - Other faculty: William C. Barott, Massood Towhidnejad
  - Other FAA:, Chuck Greenlow, John Dinofrio, Dan Lovelace, Tammy Will son
- **Organizations**
  - Terminal Velocity Aerospace, LLC.
  - NASA Flight Opportunities Program
    - Up Aerospace
    - Near Space Corporation
  - MITRE

EMBRY-RIDDLE Aeronautical University

TerminalVelocity Aerospace, LLC
A SpaceWorks Company

Goals

- Enhance tracking of vehicles as they traverse through the national airspace system to mitigate the impact of commercial space operations on routine aviation operations by leveraging existing FAA infrastructure
- Sub-goals:
  - Determine suitability for ADS-B for commercial space
  - Determine boundary conditions of system performance
  - Assess performance of prototypes on space vehicles and suitable analogues
  - Identify areas of improvement in ADS-B standard to accommodate ADS-B operations for commercial space
  - Provide stakeholders with information regarding suitability of ADS-B as a primary or secondary tracking source

MITRE UBR-TX

- UAT Beacon Radio – Transmit Only (UBR-TX)
  - Broadcasts state vector once per second
  - Supports both barometric and GPS-based altitudes
- Balloon / Rocket Flight Tests
  - 2008 Red Glare V (amateur rocket)
  - 2009 Red Glare VII (amateur rocket)
  - 2010 AFRL research balloon
  - 2010 NASA Wallops sounding rocket
  - 2012 Up Aerospace Spaceloft 6
  - 2012 Team America Rocket Challenge
  - 2013 Up Aerospace Spaceloft 7
  - 2013 Masten Xombie

MITRE TECHNOLOGY APPLIED

Past Flights:
- **NSC Nano Balloon System**
- **NSC High Altitude Shuttle System**
- **Up Aerospace SpaceLoft-8**
- **NSC Small Balloon System w/ TVA Spacecraft**

Maximum Altitude: 349,700 ft (SL-8)

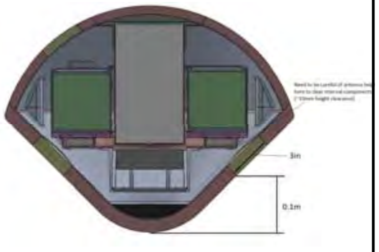
Parameter	Specification
Length	5.75" (14.6 cm)
Width	2.5" (6.35 cm)
Height	2.5" (6.35 cm)
Weight (UBR board, daughter board, GPS, battery, and enclosure)	790 g (27.9 oz)
Weight (cables, antennas, etc.)	85-300g est.
Nominal power Consumption	840mA @ 3VDC
Nominal battery capacity	7.75 Ah

UBR-ERAU Advanced ADS-B Transmitter for sRLVs

Upgraded firmware and GPS hardware

Terminal Velocity Aerospace

- Integration of Advanced ADS-B Unit onboard prototype reentry vehicle
- Funded by NASA Ames
- Goals:
  - Evaluate performance of ADS-B broadcasting through experimental TPS material
  - Demonstration of UBR on new vehicle type

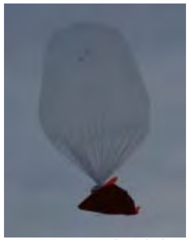


Terminal Velocity Aerospace Reentry Vehicle
Drop from stratospheric balloon

Technology maturation plan

- Project goal to demonstrate viability and test functional envelope of experimental ADS-B payload for sub-orbital commercial space operations
  - TRL-7, proven within its operational environment
- Additional flights needed before transition to TRL-8 (i.e. move out of prototype phase)
- Diversity of new vehicles is desirable to get operator feedback
- Exploring modified message formats with flight damaged equipment (from TVA landing) in lab research to address issues with current ADS-B message standards
  - no message type for space vehicle yet developed / approved.
- Daughterboard demonstrated abillty to provide processed GPS data to vehicle at 1 HZ with TVA vehicle; exploring increasing update rate

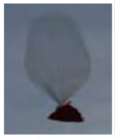
Near-tem Future Commercial Space Flights with Experimental ADS-B Payloads



Source: Near Space Corporation

- Near Space Corporation's High Altitude Shuttle System
  - Surrogate winged suborbital vehicle performing a descent into NAS (from above 60, 000 feet) – ASAP
    - HASS descended from 70Kft w/1090 MHz ADS-B in September; will incorporate lessons learned for ERAU
- SL-11 reflight with GPS through boost phase (16Gs for 12 seconds with FOP – Spring 2017
  First time to pull high-g's with live data
- Mars Flyer (NASA vehicle from balloon>120Kft – 2Q CY2017
- SL-12 mixed airspace demo with UAS TBD
- Pursuing Blue Origin flight (now a NASA FOP vendor)
- Large amateur rocket to >100 miles in consideration
- Virgin Galactic SpaceShip 2 (TBD) via NASA FOP

Planned Future Commercial Space Flights with Experimental ADS-B Payloads



Source: Near Space Corporation

- Expendable Launch Vehicle
  - Currently in planning stages for first stage; preliminary discussions held
  - fly back booster
  - expendable
- Cubesat or International Space Station
  - Investigating emerging opportunities for cubesat integration
  - Preliminary discussions held for ISS flights
  - Proof of concept for on-orbit application

Questions?

Image courtesy of UpAerospace Inc.

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Commercial Satellite Communications Applications for Spacecraft

PI: M. Brian Barnett
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Solstar

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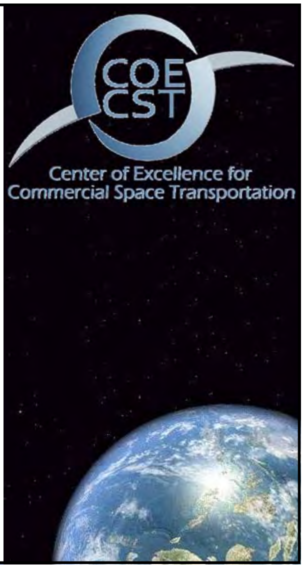
Las Cruces, NM



Agenda

- Team Members
- Task Description
- Schedule
- Goals
- Results
- Conclusions and Future Work

Team Members

- Principal Investigator
  - M. Brian Barnett, Solstar*

Solstar

*Solstar is an affiliate member of the COE CST

- Co-Principal Investigator
  - Pat Hynes, NMSU

Task Description

- Investigate how Solstar's commercial satellite networks and payload communicators could be used to communicate to and from spacecraft

Schedule

- Successful Texts to Space mission, November 12, 2013
- Flight test on Virgin Galactic's SpaceShipTwo, 2017-2018
- Flight tests in LEO, est. 2019

Goals-Relevance to Commercial Space Industry

- Solstar’s goal is to develop technologies and payload & space communicator products and services that:
  - Provide secure, economical, commercial internet/data communications services to/from spacecraft, astronauts, machines in space.
  - Our services enable earth-based customers 24/7 direct access to experiments, cubesats, machines, and colleagues located in space, via their smart phones, or any other internet connected device.
  - Enable positional and other spacecraft data to transmitted securely via commercial networks

Results

- Successful Space test- Nov. 12, 2013
  - Sent first text message to space using entirely commercial satellites, network, payload, rocket.
  - Leveraging Solstar’s Space Act Agreement with NASA’s Flight Opportunities Program (FOP)
- Mission and test results documented in short film published on YouTube in August 2016

Solstar payload communicator receiving text message at 67.4 miles (125KM)

https://www.youtube.com/watch?v=RwQsYKPfYo8

Conclusions and Future Work

- Initial flight tests have been successful and could lead to commercial space traffic control applications.
- Testing has been delayed because of Virgin Galactic accident.
- Next Steps
  - More flight tests in sub orbit and LEO
  - Solstar is continuing to develop proprietary technologies and payload communicators and services

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Fire and Hazard Detection for Space Vehicles Using LEDs

[1]Michael Villar, [1]Justin Urso [1]Akshita Parupalli
[2]Dr. Bill Partridge Jr.,
[1]Dr. Jayanta Kapat, [1]Dr. Subith Vasu

[1]University of Central Florida, Orlando, FL
[2]Oak Ridge National Laboratory, Oak Ridge, TN

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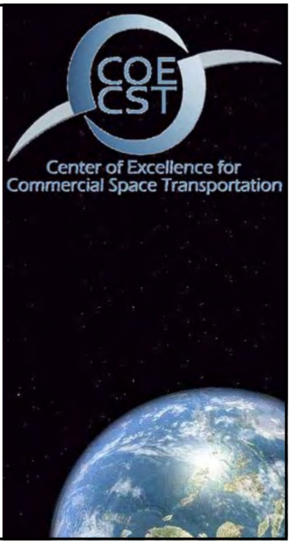


Agenda

- Team Members
- Task Description
- Schedule
- Goals
- Results
- Applicability to the Industry
- Conclusions and Future Work

Team Members

Principal Investigators

Dr. Subith Vasu
University of Central Florida

Dr. Jay Kapat (Co-PI)
University of Central Florida

Collaborators

Dr. Bill Partridge Jr.
Oak Ridge National Laboratory

Graduate Students

Michael Villar
University of Central Florida

Justin Urso
University of Central Florida (Former)

Kyle Thurmond
University of Central Florida (Former)

Undergraduate Students

Akshita Parupalli
University of Central Florida

Organizations

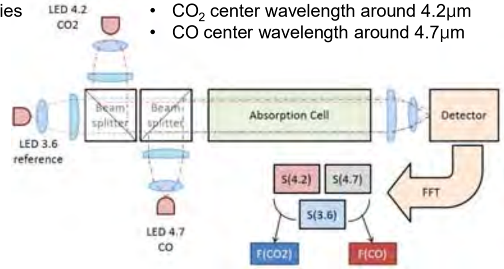
- Center for Advanced Turbomachinery and Energy Research (CATER), University of Central Florida
- Fuels, Engines, and Emissions Research Center, Oak Ridge National Laboratory

Matching Funds: Progress Energy Florida, UCF MAE Department & UCF Research and Commercialization. Support from ORAU and the Oak Ridge National Laboratory sponsored by US Department of Energy, Office of Energy Efficiency and Renewable Energy.

Sensor Design Using LEDs

Non-Dispersive Infrared (NDIR) absorption sensor using LEDs

- Three MIR LEDs centered at
  - 3.6μm (for reference)
  - 4.2μm (CO_2)
  - 4.7μm (CO)
- LEDs amplitude modulated at different frequencies
- Band pass filters
- Collimating lenses
- Pellicle beam splitters
- Thermo-electrically cooled photovoltaic detector
- Detects carbon monoxide and carbon dioxide
  - CO_2 center wavelength around 4.2μm
  - CO center wavelength around 4.7μm



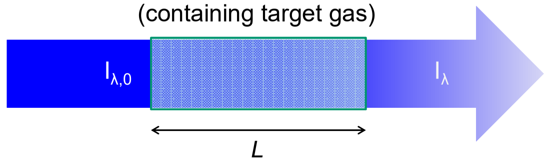
Absorption Spectroscopy and Beer's Law

Beer-Lambert Law of Absorption

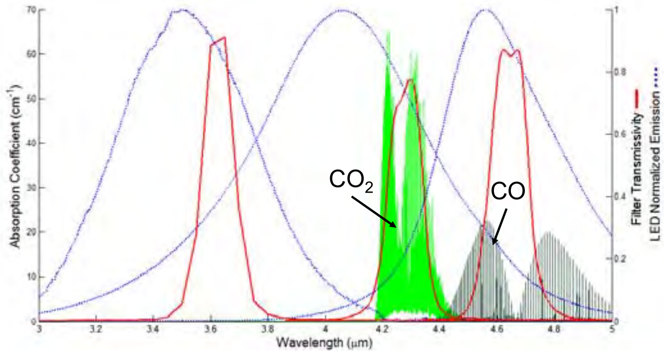
$$A_\lambda = \ln\left(\frac{I_\lambda}{I_{\lambda,0}}\right) = k_\lambda L X$$

A_λ = Spectral Absorbance (Typically 0-1)
I_λ = Transmitted Radiation at λ
$I_{\lambda,0}$ = Incident Radiation at λ
k_λ = Spectral Absorbance Coefficient (Intrinsic Property at λ)
L = Path Length of Gas Cell
X = Mole Fraction of Target Gas

Test Sample
(containing target gas)



Using LEDs in Absorption Spectroscopy



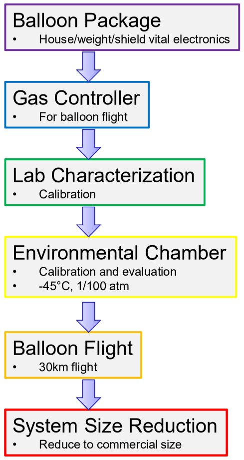
Schedule

Major Milestones

Achieved
- System integration of sensor components
- Sensor housing design for balloon test
- Convert system to run on cRIO DAQ
- Design and fabricate gas delivery system
- Integrate systems into final module
- Environmental Chamber Test Fall 2015
  - Preliminary run 10-12/2015
  - Full system diagnostic run 12/2015-4/2016
- Balloon Flight 9/1//2016

Ongoing
- Data analysis

Planned
- System redesign to decrease size



Balloon Package
- House/weight/shield vital electronics

Gas Controller
- For balloon flight

Lab Characterization
- Calibration

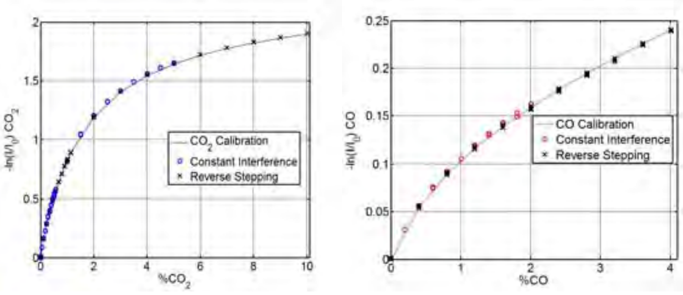
Environmental Chamber
- Calibration and evaluation
- -45°C, 1/100 atm

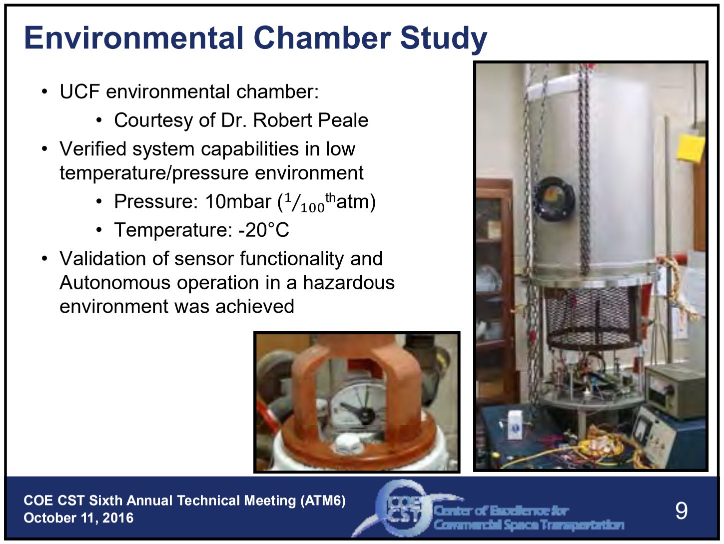
Balloon Flight
- 30km flight

System Size Reduction
- Reduce to commercial size

Fundamental Cross-Interference Study

- Simultaneous measurements of CO and CO$_2$ showed no cross-interference.





Environmental Chamber Study

- UCF environmental chamber:
  - Courtesy of Dr. Robert Peale
- Verified system capabilities in low temperature/pressure environment
  - Pressure: 10mbar ($^1/_{100}$th atm)
  - Temperature: -20°C
- Validation of sensor functionality and Autonomous operation in a hazardous environment was achieved

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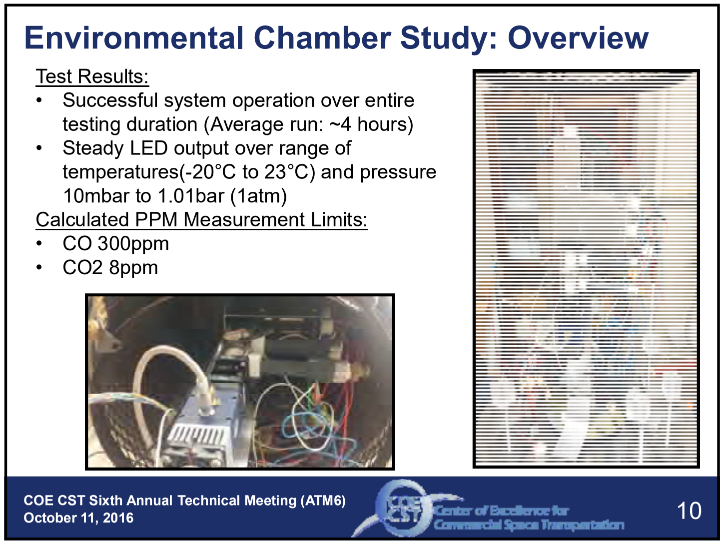

Environmental Chamber Study: Overview

Test Results:

- Successful system operation over entire testing duration (Average run: ~4 hours)
- Steady LED output over range of temperatures(-20°C to 23°C) and pressure 10mbar to 1.01bar (1atm)

Calculated PPM Measurement Limits:

- CO 300ppm
- CO2 8ppm

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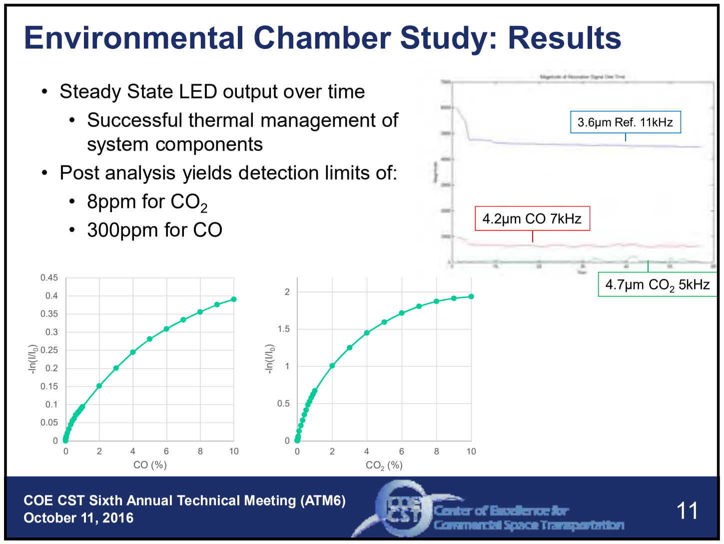

Environmental Chamber Study: Results

- Steady State LED output over time
  - Successful thermal management of system components
- Post analysis yields detection limits of:
  - 8ppm for CO_2
  - 300ppm for CO

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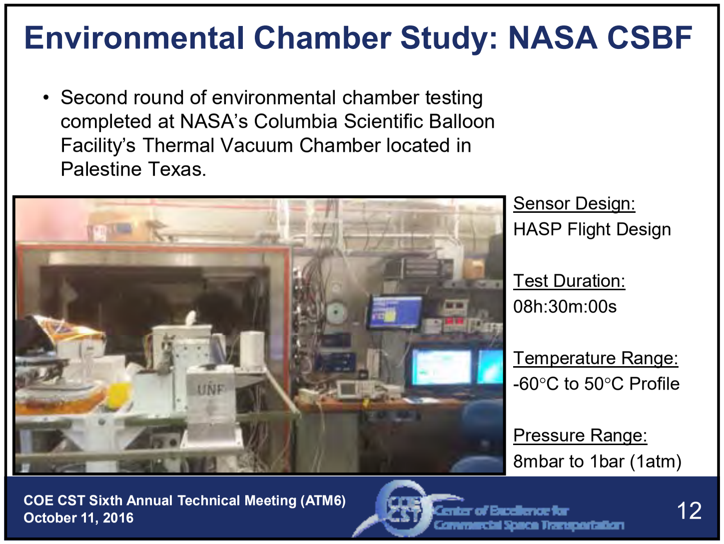

Environmental Chamber Study: NASA CSBF

- Second round of environmental chamber testing completed at NASA's Columbia Scientific Balloon Facility's Thermal Vacuum Chamber located in Palestine Texas.

Sensor Design:
HASP Flight Design

Test Duration:
08h:30m:00s

Temperature Range:
-60°C to 50°C Profile

Pressure Range:
8mbar to 1bar (1atm)

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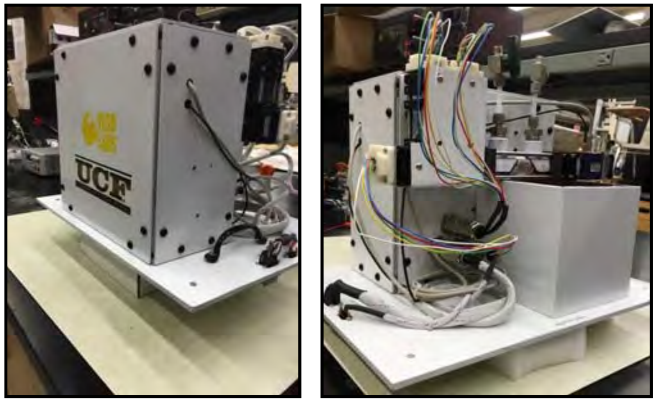
High-Altitude Balloon Flight

- The flight was provided by NASA Columbia Scientific Balloon Facility (Via LSU's HASP Program) from Fort Sumner, NM.
- Opportunity to test system in potential working conditions
  - Autonomous operation in a harsh/hazardous environment
  - Enables validation of Thermal/Vac. study results

High-Altitude Balloon Flight System Design

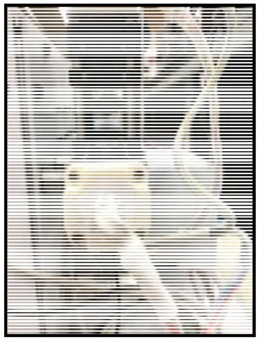


High-Altitude Balloon Flight System Design

- Core system was redesigned to meet the unique constraints of a high-altitude balloon flight.
- Electronic logic boards were redesigned to improve signal integrity in a high noise environment.
- Isolated DC/DC Converters implemented to allow correct power allowances to subsystems:
  - cRIO DAQ: 24V
  - VIGO Detector: 12V
  - LEDs/Drivers: 6V

High-Altitude Balloon Flight System Design

- All electronics were placed inside a sturdy aluminum case for increased protection.
  - Optical rail was mounted to the case and an aluminum box was added to shield the Absorption Cell diaphragm.
- White powder coated external walls with Mirror-finished internals maximized radiation rejection.



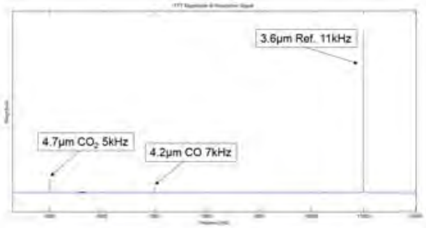
High-Altitude Balloon Flight: Results

Flight Conditions:

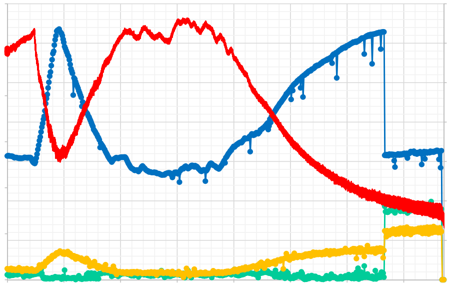
- **Max Altitude:**123,546 ft.
- **Temperature Range:** -54.47 °F to 53.76 °F
- **Pressure Range:** 0mbar to 910mbar
- **Float Duration:** 15h:08m:54s (Total: 18h:09m:30s)

High-Altitude Balloon Flight: Prelim-Results

- The sensor successfully completed high altitude flight testing to simulate harsh working environments
- System was flown with a pre-mixture of N_2(89.51%), CO(4.97%) and CO_2(5.52%).
- Successful sensor operation/data collection was achieved throughout flight duration.



High-Altitude Balloon Flight: Prelim-Results



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Task 323 Structural Health Monitoring Framework

Andrei Zagrai (PI)
Mary Anderson (Student)
Blaine Trujillo (Student)

Contributors
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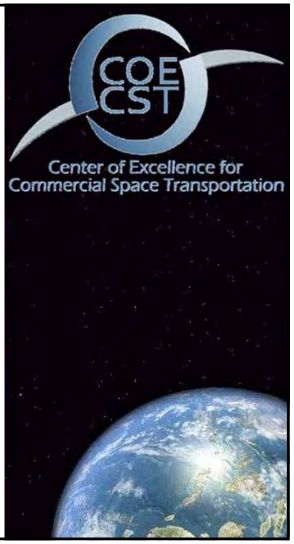
Joshua Daniel, (WSMR)
Dale Henneke, Dave Westpfahl, (NMT)

October 11, 2016
Las Cruces, NM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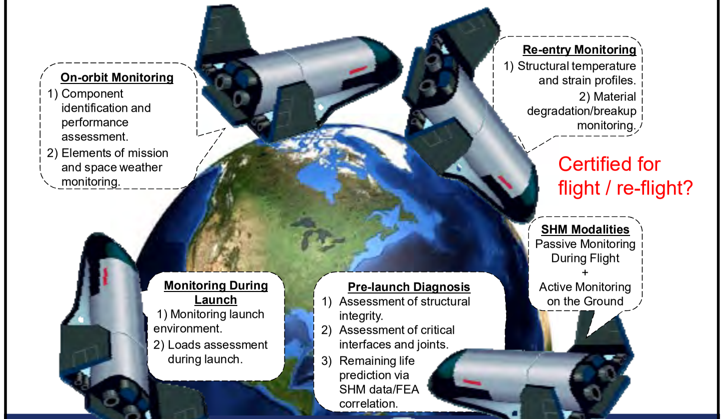
Task 323 SHM Framework

- Task 323 focuses on SHM architecture and guidelines for integrating SHM with spaceflight recorder (aka "black box").
- Investigation of thermal and radiation fatigue of smart structures for assessment of RVL's condition during flight.
- Prepare hardware for evaluation of space effects on structural condition and sensor system.

Motivation



On-orbit Monitoring
1) Component identification and performance assessment.
2) Elements of mission and space weather monitoring.

Monitoring During Launch
1) Monitoring launch environment.
2) Loads assessment during launch.

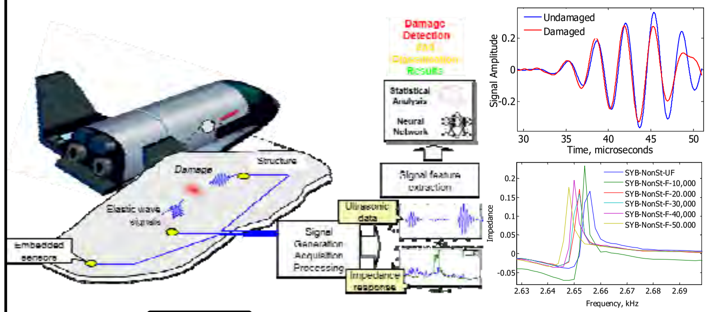
Pre-launch Diagnosis
1) Assessment of structural integrity.
2) Assessment of critical interfaces and joints.
3) Remaining life prediction via SHM data/FEA correlation.

Re-entry Monitoring
1) Structural temperature and strain profiles.
2) Material degradation/breakup monitoring.

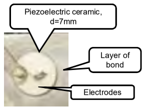
Certified for flight / re-flight?

SHM Modalities
Passive Monitoring During Flight
+
Active Monitoring on the Ground

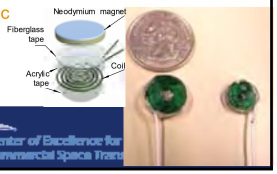
Structural Health Monitoring



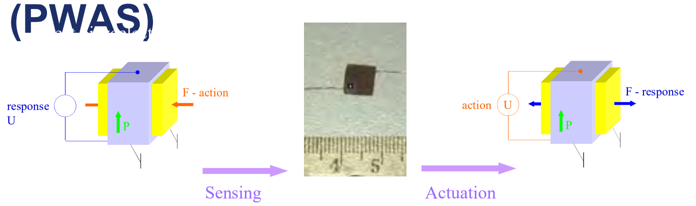
Thin Piezoelectric Sensors 7mm ×0.2mm



Magneto-elastic Active Sensor (MEAS)



Piezoelectric Wafer Active Sensors (PWAS)



3-D equations for PWAS

$$S_1 = s_{11}^E T_1 + s_{12}^E T_2 + s_{13}^E T_3 + d_{31} E_3$$
$$S_2 = s_{21}^E T_1 + s_{22}^E T_2 + s_{23}^E T_3 + d_{32} E_3$$
$$S_3 = s_{31}^E T_1 + s_{32}^E T_2 + s_{33}^E T_3 + d_{33} E_3$$
$$D_3 = d_{31} T_1 + d_{32} T_2 + d_{33} T_3 + \varepsilon_3^T E_3$$

1-D equations for PWAS

$$S_1 = s_{11}^E T_1 + d_{31} E_3$$
$$D_3 = d_{31} T_1 + \varepsilon_3^T E_3$$

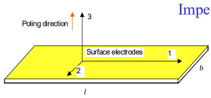
Equation of motion

$$T_1^/ = \rho \ddot{u}_1$$
$$S_1 = u_1'$$
$$\ddot{u}_1 = c^2 u_1''$$
$$c^2 = 1/\rho s_{11}^E$$

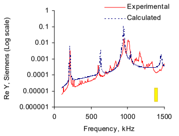
Solution

$$u_1(x,t) = \hat{u}_1(x) e^{i\omega t}$$
$$\hat{u}_1(x) = \left(C_1 \sin\gamma x + C_2 \cos\gamma x\right)$$

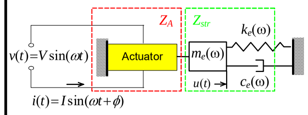
Impedance of the free (unconstrained) sensor

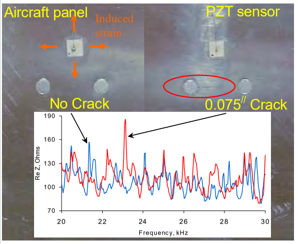


$$Y_{free}(\omega) = \mathrm{i}\omega \cdot C\left[1-\kappa_{31}^2\left(1-\frac{1}{\varphi\cot\varphi}\right)\right]$$



Electro-Mechanical Impedance

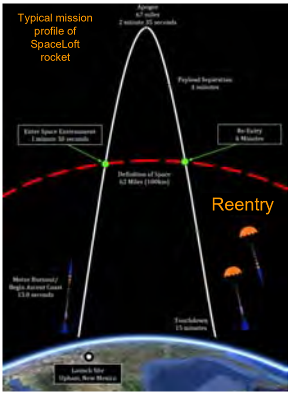




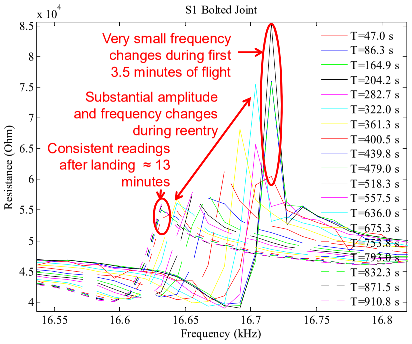
- Under electrical excitation, the bonded piezoelectric active sensor produces a local strain parallel to the structural surface. The reaction of the host structure to this excitation can be presented in terms of dynamic structural impedance/admittance.
- Due to the mechanical coupling between the sensor and the host structure, the structural impedance/admittance affects the sensor and, through electromechanical coupling inside the active element, is reflected in the electrical impedance measured at the sensor's terminals.

$$z_a(\omega) = \frac{1}{y_a(\omega)} = \frac{1}{i\omega C_a}\left[1-k_{31}^2\left(1-\frac{1}{\varphi\cot\varphi + k_{str}(\omega)/k_a}\right)\right]^{-1}$$

Suborbital flight data



Electro-mechanical impedance spectra



Very small frequency changes during first 3.5 minutes of flight

Substantial amplitude and frequency changes during reentry

Consistent readings after landing ≈ 13 minutes

Extreme Space Environment

In space, structure will be exposed to

- Extreme temperatures
- Vacuum
- Radiation
- Atomic oxygen
- Micro-gravity
- Micro-meteroids and debris

On Earth, aspects of space can be emulated

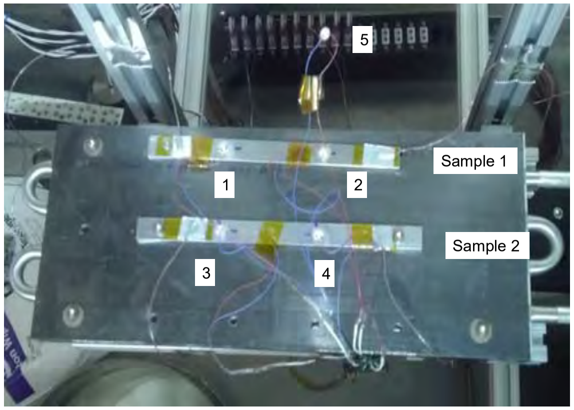
- Extreme temperatures and vacuum at AFRL
- Gamma radiation at WSMR

Temperature and Vacuum Effects

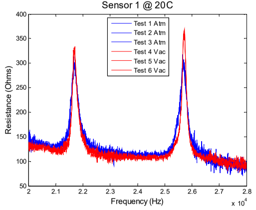
AFRL Vacuum Thermal Chamber

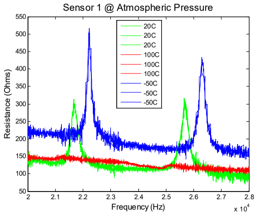
- Chamber Pressure 2 x 10^{-6} Torr
- FTS RC2111 Recirculating Chiller

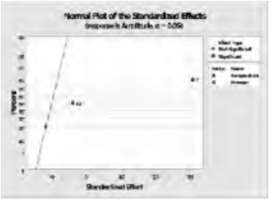
Temperature and Vacuum Effects

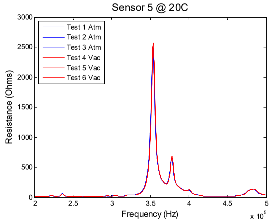


Temperature and Vacuum Effects









Temperature and Vacuum Effects

PIEZOELECTRIC SENSORS

- ❑ Cold temperatures cause electro-mechanical impedance frequency increase and amplitude decrease
- ❑ Hot temperatures cause electro-mechanical impedance frequency decrease
- ❑ Vacuum causes slight increase in amplitude and narrowing of electro-mechanical impedance signal

STRUCTURE

- ❑ Cold temperatures cause electro-mechanical impedance frequency increase in the overall signal
- ❑ Hot temperatures cause electro-mechanical impedance frequency decrease in the overall signal
- ❑ Vacuum causes pronounced increase in amplitude and narrowing of electro-mechanical impedance signal

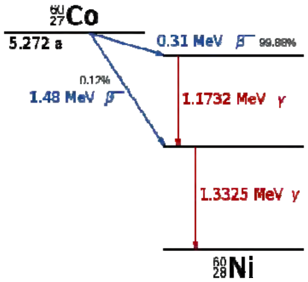
Investigation of Radiation Effects

Radiation in Space

- Background galactic cosmic radiation
- Solar event radiation
- Radiation from particles trapped in the Van Allen Belts

Gamma Radiation

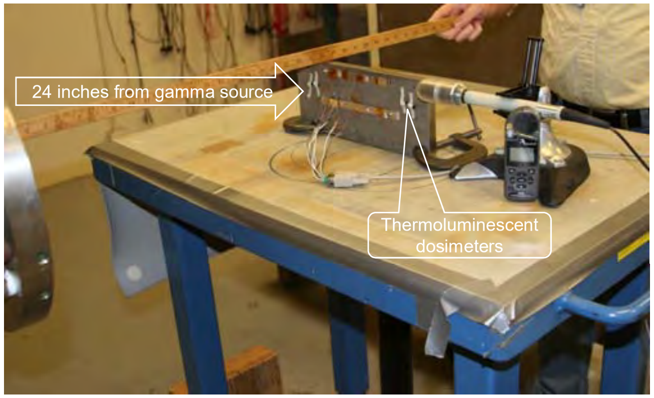
- Suitable for emulating space environment (ESA)



White Sands Gamma Facility Test

- Cobalt 60 gamma radiation
- PZT sensors bonded to 6061-T6 aluminum beams
- Frequency sweeps with impedance analyzer
- Data collection and analysis

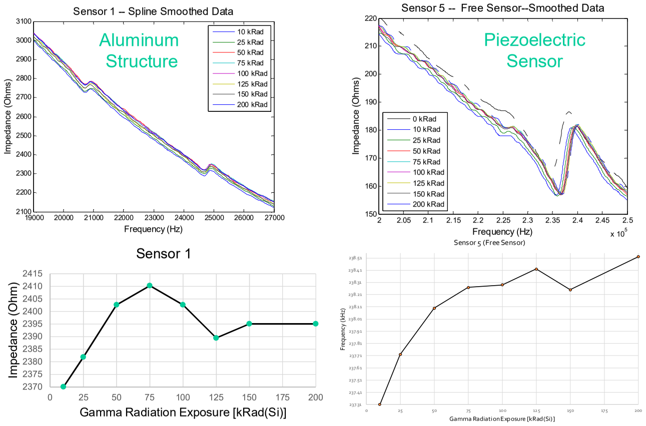
White Sands Gamma Facility Test



Irradiation Plan for LEO Simulations

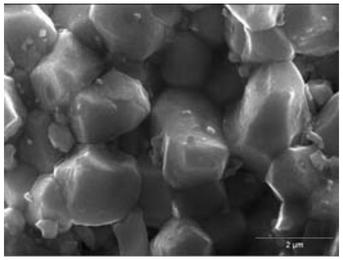
	Target Dose [Rad(Si)]	Target Exposure [R]	Actual Exposure	Estimated Dose [Rad(Si)]
	10,000	11,547	11,494	9,954
	25,000	28,868	16,119	13,959
	50,000	57,737	31,110	26,941
3 month	75,000	86,605	24,560	21,269
	100,000	115,473	33,100	28,665
6 month	125,000	144,342	28,710	24,863
	150,000	173,210	27,320	23,659
1 year	200,000	230,947	62,510	54,134

Effect of Radiation on Impedance Signatures

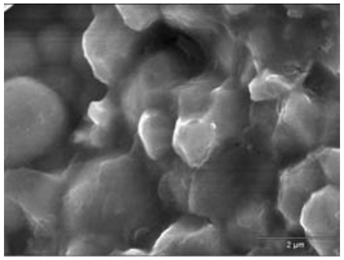


Effect of Radiation on Piezoelectric Ceramic

Before Irradiation



After Irradiation



Analytical Model

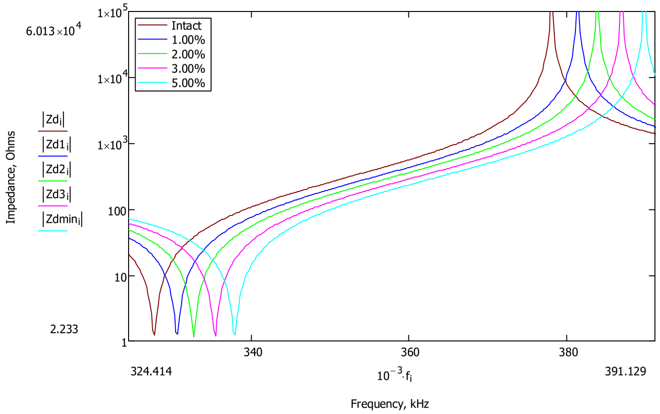
In our modeling efforts,

we propose that exposure to gamma radiation causes:

- Density loss in piezoelectric ceramics
- Decreased capacitance in PZT sensors

$$\mathrm{Ydmin}_i := i \cdot \omega_i \cdot C_a \cdot \left[1 - \left(k'_p\right)^2\right] \cdot \left[1 + \frac{\left(k'_p\right)^2}{1 - \left(k'_p\right)^2} \cdot \frac{\left(1 + \sigma_{PZT}\right) \cdot J1\left(\phi\mathrm{min}_{\,i}\right)}{\phi\mathrm{min}_{\,i} \cdot J0\left(\phi\mathrm{min}_{\,i}\right) - \left(1 - \sigma_{PZT}\right) \cdot J1\left(\phi\mathrm{min}_{\,i}\right)}\right]$$

Analytical Model

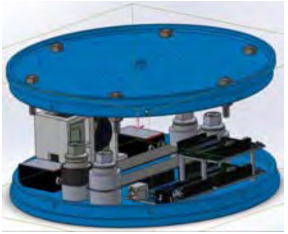


Radiation Effects

- Electro-mechanical impedance of smart structure increases with radiation exposure. This is likely due to loss of capacitance of the piezoelectric sensor.
- No significant changes in structural natural frequencies were observed, suggesting minuscule effect of radiation on aluminum host structure.
- Electro-mechanical impedance frequency and amplitude of piezoelectric sensors increased with radiation exposure, accompanied by degradation of the piezoelectric ceramic grain structure.
- Electro-mechanical impedance model suggests multiple mechanisms for changes in impedance signature.

Undergraduate SHM Team

- Develop SHM capability for space structures
- Evaluate via NASA suborbital flight opportunity (NASA USIP proposal)
- Participation in future FOP



Acknowledgements

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  - ❑ Dr. Nickolas Demidovich
- AFRL Space Vehicles Directorate,
  - ❑ Michael R. Wilson
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  - ❑ Josh Blundell, Installation Safety Office, Health Physicist, WSMR
  - ❑ Jerame Lopez and Ricardo Ortiz, Gamma Range Facility Operators, WSMR
  - ❑ Freddy H. Torres, BSEE, MSNE
- New Mexico Space Grant Consortium
  - ❑ Patricia C. Hynes
- New Mexico Institute of Mining and Technology
  - ❑ Graduate Student Association,
  - ❑ Ian Lopez-Pulliam, William Valiant and Ryan Borden, NMT Machine Shop
  - ❑ Gary Chandler, NMT Materials Department.

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A. N. Zagrai and V. Giurgiutiu, Encyclopedia of Structural Health Monitoring, John Wiley & Sons, Ltd., 2009.

E. F. Sturcken, "Irradiation Effects in Magnesium and Aluminum Alloys," *Journal of Nuclear Materials,* vol. 82, pp. 39-53, 1979.

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Publications/Presentations

- Zagrai, A., and Demidovich, N. (2016) “Structural Health Monitoring Potential of Commercial Space Vehicles,” **invited talk** at Commercial and Government Responsive Access to Space Technology Exchange (CRASTE), June 20-23, 2016, Westminster, Colorado.
- Zagrai, A., Trujillo, B. and Demidovich, N. (2016) “Acoustic Emission during Thermal Fatigue of Aluminum Alloy,” presentation at Commercial and Government Responsive Access to Space Technology Exchange (CRASTE), June 20-23, 2016, Westminster, Colorado.
- Anderson, M., Zagrai, A., Daniel, J.D. (2016) “Potential Use of Piezoelectric Sensors For Structural Health Monitoring In Radioactive Environments”, presentation for the workshop organized by Institute of Nuclear Materials Management Technical Exchange, Taos, New Mexico, May 19, 2016.
- Trujillo, B. and Zagrai, A., (2016) “Embedded and Conventional Ultrasonic Sensors for Monitoring Acoustic Emission During Thermal Fatigue,” SPIE's 23rd Annual International Symposium on Smart Structures and Materials + Nondestructive Evaluation and Health Monitoring, 20-24 March 2016, San Diego, CA, v 9805, paper 98051K.

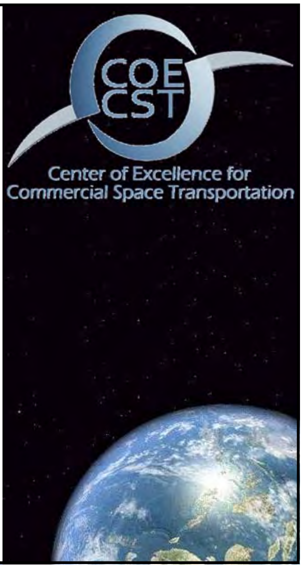
COE CST Sixth Annual Technical Meeting

Task 325: Optical Measurements of Rocket Nozzle Thrust and Noise

PI (s): Rajan Kumar & Farrukh Alvi
Student: Rohit Vemula

FAA Technical Monitor:
Nick Demidovich

October 11, 2016
Las Cruces, NM



Agenda

- Team Members
- Challenges and Motivation
- Task Description
- Test Facilities
- Nozzle Design
- Thrust Measurements
- Particle Image Velocimetry
- Schedule & Milestones
- Future Work

Team Members

- Team
  - Rajan Kumar & Farrukh Alvi
  - Rohit Vemula
- Organizations Involved
  - FSU / FCAAP
  - Space Florida
  - SpaceX

Challenges & Motivation

70% accidents in aerospace missions are due to engine malfunction or propulsion system failures!!

Rocket propulsion studies are limited (only National Labs. & big corporations)

- **High temperature and pressure environment**
- **Complex chemistry – unstable fuels**
- **Large scale tests are expensive & require specialized rigs**

- **Need to develop high temperature pressure sensors – activity initiated under COE-CST**
- **Measure steady and transient loading on the nozzle and ground surface – material characterization**
- **Jet plume development and flow field analysis**
- **Nearfield & farfield noise measurement and prediction tools**
- **Study of next generation hybrid fuels**

Tasks Description

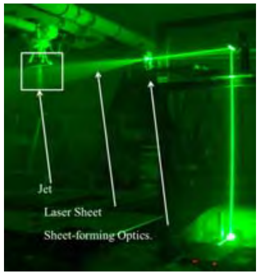
- Development of a research plan based on state-of-art thrust and noise measurement techniques.
- Discussion with NASA /commercial launch engineers to ensure the transition of technology from laboratory to full-scale implementation.
- Design of a scaled nozzle and simulate realistic temperature and pressure conditions of the jet exhaust in the FSU jet facility
- 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.

Test Facilities

Nozzle

Ground Plate with Transducer Block

Operational/Test Capabilities
- *Mach Number = 0.5 - 2.5*
- *T_o= 70 - 2000 F*
- *D_{Jet} = 25.4 – 76.2 mm*
- *NPR = Under-ideal-over expanded*
- *Anechoic chamber: 5.8 m x 5.2 m x 4.0 m, Calibrated to 100 Hz*



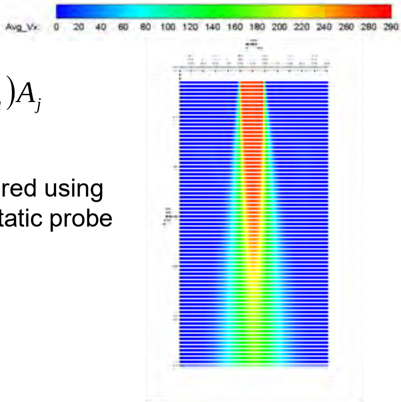
Thrust Measurements

$$F = F_m + F_p$$

$$F = \dot{m}u_j + (p_e - p_a)A_j$$

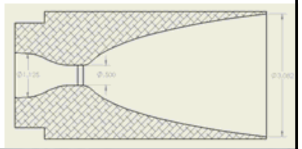
Measured using PIV

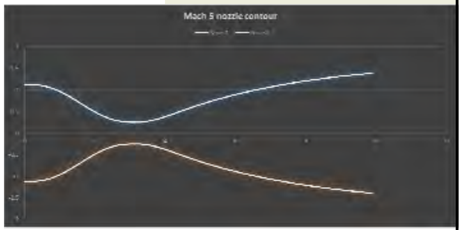
Measured using Pitot-static probe



Rocket Nozzle Design

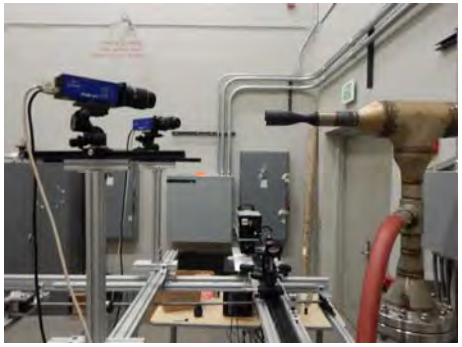
Thrust optimized parabolic (TOP) contour nozzle



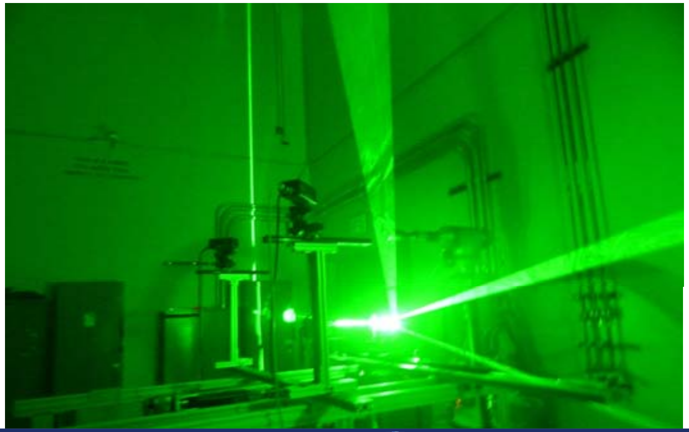


Rocket Nozzle Fabrication

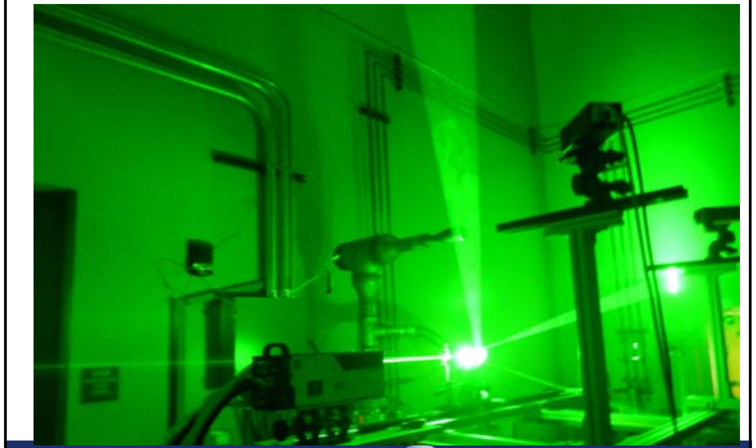
Design Mach #: 5.6
A/A* = 38



Particle Image Velocimetry

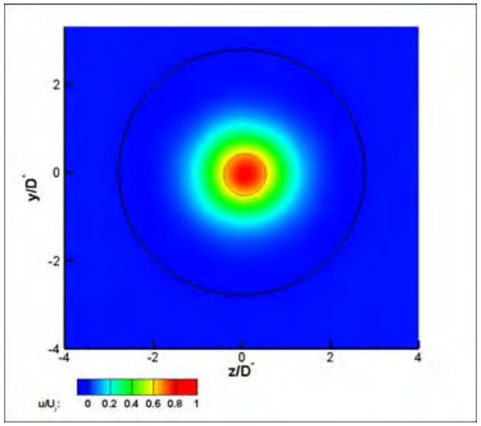


Particle Image Velocimetry



Mean Velocity Field

Nozzle Pressure
Ratio = 7
Temperature
Ratio = 1.5



Mean Velocity Field

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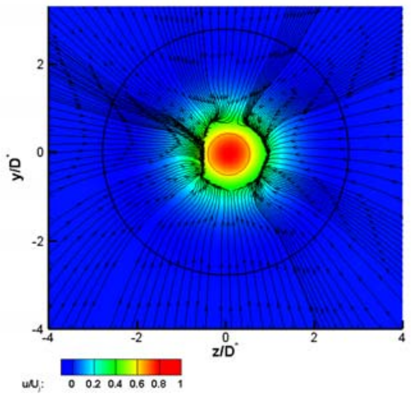
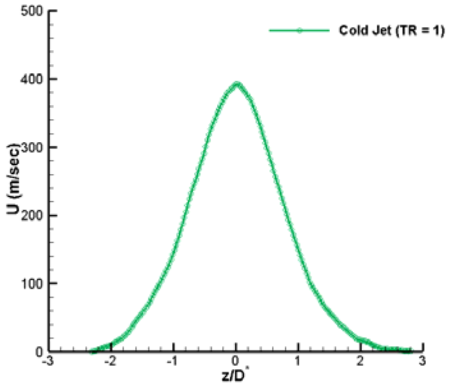
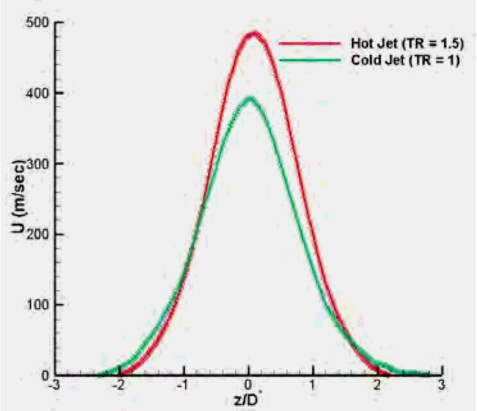
Ratio = 7
Temperature
Ratio = 1.5



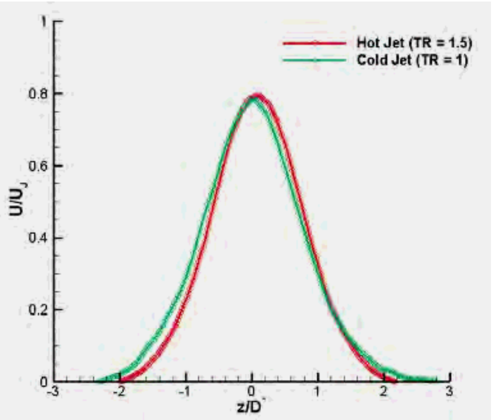
Mean Velocity Profiles



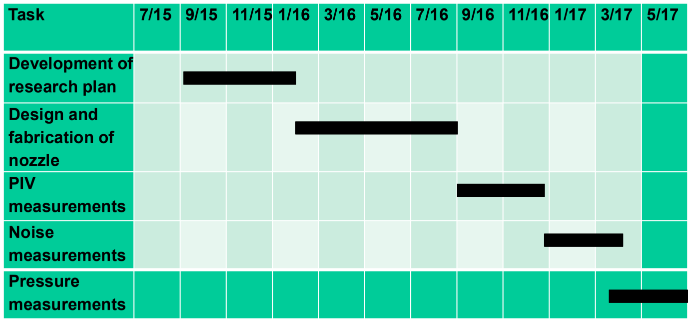
Mean Velocity Profiles



Mean Velocity Profiles



Schedule and Milestones



Task	7/15	9/15	11/15	1/16	3/16	5/16	7/16	9/16	11/16	1/17	3/17	5/17
Development of research plan		■	■									
Design and fabrication of nozzle				■	■	■	■					
PIV measurements								■	■			
Noise measurements										■	■	
Pressure measurements											■	■

Conclusions and Future Work

- A significant progress has been made toward the overall goal of Rocket thrust & noise measurements:
  - ➢Rocket nozzle design and fabrication completed
  - ➢Velocity measurement at the nozzle exit in progress
  - ➢Facility ready to perform noise & pressure measurements
- In addition to the goals highlighted in previous charts, we would like to introduce flow control methods
  - ➢ to enhance thrust levels at low NPRs
  - ➢ to reduce noise during launch operations

COE CST Sixth Annual Technical Meeting

Task 308: Assessment of Screening and Training Requirements for SFPs regarding Anxiety during Repeated Exposures to Sustained High Acceleration

Rebecca Blue, MD, MPH

October 11, 2016
Las Cruces, NM

Center of Excellence for Commercial Space Transportation

Agenda

- Team Members
- Task Description
- Schedule
- Goals
- Results
- Conclusions and Future Work

COE CST Sixth Annual Technical Meeting (ATM6)
October 11, 2016

Team Members

- Rebecca S. Blue, MD, MPH; James M. Vanderploeg, MD, MPH; Johnené L. Vardiman, MS; Charles Mathers, MD, MPH; Tarah L. Castleberry, DO, MPH
- Collaborators: ; Frederick Bonato, PhD; Kimberly Seaton, PhD; Andrea Bubka, PhD
- Students: Rahul Suresh, MD
- Organizations
  - University of Texas Medical Branch
  - National AeroSpace Training and Research Center (NASTAR)
  - Montclair State University
  - St Peter's University

COE CST Sixth Annual Technical Meeting (ATM6)
October 11, 2016

Task Description

- In commercial suborbital spaceflight, anxiousness could become mission-impacting, causing negative experiences or endangering the flight itself.
- It is important to identify and mitigate anxiety in spaceflight participants (SFPs) before it becomes problematic. However, there are currently no known effective methods to best identify or mitigate significant SFP anxiety in commercial spaceflight.

COE CST Sixth Annual Technical Meeting (ATM6)
October 11, 2016

Preliminary Studies

- Multiple previous studies designed to provide understanding of layperson physiological response to hypergravity/acceleration (2012-2014)

- Blue RS, Pattarini JM, Reyes DP, Mulcahy RA, Garbino A, Mathers CH,Vardiman JL, Castleberry TL, Vanderploeg JM. Tolerance of Centrifuge-Simulated Suborbital Spaceflight by Medical Condition. Aviat Space Environ Med 2014; 85(7): 721-9.
  - 86 subjects, 20-78y, participated in centrifuge trials
  - 3 subjects voluntarily withdrew from testing for anxiety reasons
  - 12 subjects with anxiousness that interfered with experience or disrupted training

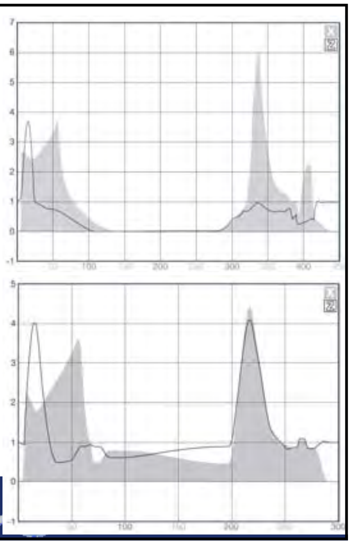
Schedule

- Literature review: completed in 2015, published Oct 2016
  - Mulcahy RA, Blue RS, Vardiman JL, Castleberry TL, Vanderploeg JM. Screening and mitigation of layperson anxiety in aerospace environments. Aerosp Med Hum Perform. 2016; 87(10): 1-8.
  - Addressed methods of screening and mitigating anxiety during analogue and high stress environments
  - Provided background and literature supporting development of follow-on study protocol

Schedule

- 2015-2016: Evaluation of Training Effects on Anxiety and Task Performance in Simulated Suborbital Spaceflight
  - Study design:
    - Comparison of training techniques, including alterations of length of training, didactics, psychological training and mitigation strategies, calming exercises
    - Evaluation of techniques to identify subject anxiety, predictors or factors related to high anxiety or subject withdrawal
  - Centrifuge trials: began Nov 2015; completed June 2016
  - Data analysis: June 2016-present

Centrifuge Profiles



- Centrifuge profiles:
  - Single-directional acceleration
    - +Gz (head-to-toe)
    - +Gx (chest-to-back)
  - Combined profiles
    - Designed to simulate flight

Goals

- Identify factors related to poor psychological tolerance of simulated spaceflight experience
- Provide data on how individuals with high anxiety levels can best be identified and prepared for suborbital spaceflight through training and anxiety mitigation techniques.
- Develop recommendations for optimal training protocols to reduce anxiety prior to and during suborbital flight

COE CST Sixth Annual Technical Meeting (ATM6)
October 11, 2016

Results

- 157 subjects recruited for participation in centrifuge trials
  - 29 subjects identified by investigators as concerning for poor tolerance or anxiety
  - 10 subjects opted out of one or more centrifuge runs secondary to poor tolerance (generally related to anxiety, motion sickness, or both)
  - Most successful training techniques include high-fidelity simulation independent of length of training; sequential and repetitive exposure can improve comfort
  - Few factors indicate a subject's ability to tolerate experience
  - Subjects most likely to report anxiety-related symptoms in anonymous format

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Conclusions and Future Work

- SFP anxiety, panic, and withdrawal, and identifying those at greatest risk, will continue to be a challenge for the suborbital spaceflight industry.
- Training techniques should be designed to be as high-fidelity as possible
- Calming techniques may have some role in reducing anxiety

- Analysis ongoing –
- Presentation and publication of significant findings – anticipated 2017
- Presentation anticipated: Aerospace Medical Association Annual Scientific Meeting 2017, Denver, CO

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October 11, 2016

TASK 308. ASSESSMENT OF SCREENING AND TRAINING REQUIREMENTS FOR SFPS REGARDING ANXIETY DURING REPEATED EXPOSURES TO SUSTAINED HIGH ACCELERATION

PROJECT AT-A-GLANCE

- University: The University of Texas Medical Branch
- Principal Investigator: Rebecca Blue, MD, MPH
- Co-Investigators: James Vanderploeg, MD, MPH; Tarah Castleberry, DO, MPH; Charles Mathers, MD, MPH
- Residents: Rahul Suresh, MD

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Psychological stressors can be significant challenges in the operational environment, and laypersons with minimal training are at risk for high anxiety and potentially mission-impacting psychological sequelae during commercial flight.
- This study aims to evaluate the risk of anxiety during commercial spaceflight activities and to develop effective mitigation techniques and identify and best assist those at greatest risk.

STATEMENT OF WORK

- Identify individuals with high anxiety levels through screening questionnaires and psychological testing
- Develop risk mitigation strategies and training techniques for individuals with higher levels of anxiety
- Develop recommendations for optimum training protocols to reduce anxiety prior to and during suborbital flight

STATUS

- Project data collection completed
- 157 subjects recruited, centrifuge trials completed June 2016
- Data analysis ongoing 2016

FUTURE WORK

- Presentation and publication of significant findings – publication anticipated 2017, presentation expected at Aerospace Medical Association Annual Scientific Meeting 2017, Denver, CO

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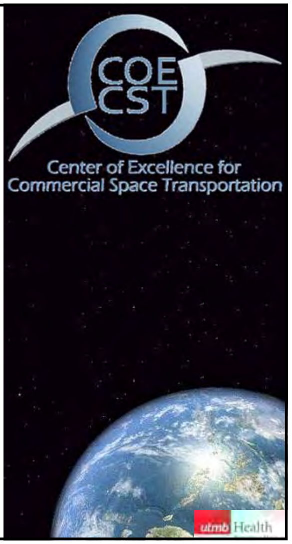
Task 310: Assessment of methods, procedures, and technologies available for protection of SFPs in commercial spaceflight vehicles

Charles Mathers, MD, MPH
Alejando Garbino, MD, PhD

October 11, 2016
Las Cruces, NM



Agenda

- Team Members
- Task Description
- Schedule
- Goals
- Results
- Conclusions and Future Work

Team Members

- Principal Investigator: Charles Mathers, MD, MPH
- Co-Investigators: James Vanderploeg, MD, MPH; Rebecca Blue, MD, MPH; Tarah Castleberry, DO, MPH
- Resident: Alejandro Garbino, MD, PhD

Task Description

- This project will evaluate methods to enhance the safety of the cabin environment
- Focusing on crew extraction

Schedule

- Complete literature review and analysis in 2016 – *in progress*
- Submit abstract for Aerospace Medical Association 2017 Annual Scientific Meeting in Denver, CO
  - Build a model of "best practices" for commercial space operations support
  - Reference NTSB recommendations from Scaled Composites crash investigation report
- Extraction Workshop – *tentative Spring 2017*
  - IndyCar
  - USAF 17th Test Squadron
  - NASA
  - Commercial Space Operators

Goals

- Dedicated efforts towards the enhanced safety of crew extraction in spaceflight vehicles will improve the success of commercial space endeavors.
- Direct applicability demonstrated by NTSB safety recommendations from Scaled Composites crash investigation
  - A-15-027 → Emergency response procedures and planning
  - A-15-028 → Human factors guidance throughout design and operation of crewed vehicle

Results

- Pending

Conclusions and Future Work

- Literature review in progress
- AsMA 2017 abstract
- Extrication Workshop planned for Spring 2017

Task 310: Assessment of methods, procedures, and technologies available for protection of SFPs in commercial spaceflight vehicles

PROJECT AT-A-GLANCE
- UNIVERSITY: University of Texas Medical Branch
- PRINCIPAL INVESTIGATOR(S): Charles Mathers, M.D., M.P.H
- STUDENT(S): Alejandro Garbino, M.D., Ph.D.

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- Dedicated efforts towards the enhanced safety of crew extraction in spaceflight vehicles will improve the success of commercial space endeavors.
- Direct applicability demonstrated by NTSB safety recommendations from Scaled Composites crash investigation

STATEMENT OF WORK
- This project will evaluate methods to enhance the safety of the cabin environment
- Focusing on crew extraction

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- Complete literature review and analysis in 2016 – *in progress*
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  - Build a model of "best practices" for commercial space operations support
  - Reference NTSB recommendations from Scaled Composites crash investigation report

FUTURE WORK
- Extraction Workshop – *tentative Spring 2017*
  - IndyCar
  - USAF 17th Test Squadron
  - NASA
  - Commercial Space Operators

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Technical Meeting (ATM6)

Publications, Presentations & Awards

PUBLICATIONS

Menon AS, Jourdan D, Nusbaum DM, Garbino A, Buckland DM, Norton S, Clark JB, Antonsen EL. Crew Recovery and Contingency Planning for a Manned Stratospheric Balloon Flight - the StratEx Program. Prehosp Disaster Med. 2016 Aug 30:1-8. [Epub ahead of print] PMID: 27573155.

Garbino A, Nusbaum DM, Buckland DM, Menon AS, Clark JB, Antonsen EL. Emergency Medical Considerations in a Space-Suited Patient. Aerosp Med Hum Perform. 2016 (in press)

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Task 320: Commercial Spaceflight Risk Assessment and Communication

Prof. David Klaus, Robert Ocampo

University of Colorado Boulder

October 11, 2016
Las Cruces, NM

Task 320 Team Members

- Principal Investigator: **David Klaus**
- PhD Student: **Robert Ocampo**

graduated May 2016

University of Colorado Boulder

- FAA AST TM: **Henry Lampazzi** *(no photo)*

Task Description

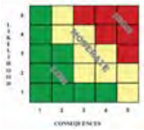
- **Task 320 (2015-2017) Commercial Space Flight Risk Assessment and Communication**
- *Builds on prior Task 184 Human-Rating of Commercial Spacecraft (2011-2014) - Accommodate, Utilize and Protect*
  - *Neis, S.M. and Klaus, D.M. (2014) Considerations toward Defining Medical 'Levels of Care' for Commercial Spaceflight. New Space, December 2014, 2(4): 165-177*
  - *Klaus, D.M., Ocampo, R.P. and Fanchiang, C. (2014) Spacecraft Human-Rating: Historical Overview and Implementation Considerations. IEEE Aerospace Proceedings (978-1-4799-1622-1/14, no. 2272)*
  - *Ocampo, R.P. and Klaus, D.M. (2013) A Review of Spacecraft Safety: from Vostok to the International Space Station. New Space 1(2): 73-80*
  - *Klaus, D.M., Fanchiang, C. and Ocampo, R.P. (2012) Perspectives on Spacecraft Human-Rating. AIAA-2012-3419*

Task Description

- Commercial space travel, as with any mode of transportation, inherently introduces some degree of risk to the onboard occupants and uninvolved public
  - Risks arise from potential for vehicle failures, environmental hazard interactions, or human errors
  - Outcomes range from discomfort or incomplete objectives, up to health impacts and loss of life
  - Potential for onboard illness or injury unrelated to vehicle failure can also be considered as a risk
  - Risks that cannot be mitigated must be characterized and effectively communicated to crewmembers and spaceflight participants

Task Description

- Process of identifying, quantifying and mitigating risk is typically accomplished using various techniques in systems engineering design and through operational protocols.
- Implementation of risk reduction is generally vehicle-specific
  - Design for Minimum Risk (DFMR)
  - Design for Demise (D4D)
  - Hazard Analysis, MTBF, FMEA, PRA, Fault Tree, etc.
  - Characterized as Likelihood vs. Consequences

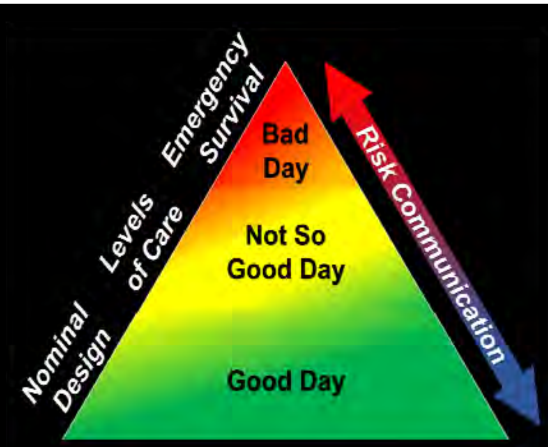


- Proposed more generally applicable design-independent aspects defined within high-level categories tentatively titled:

‘Good Day, Not so Good Day, and Bad Day’

Task Description

- ***Good Day*** **–necessary elements in place for a safe and successful flight**
  - ‘human-rated’ system
  - preflight participant ‘fitness to fly’ and medical certification for the crew
  - no occurrence of injury or illness during the flight
- ***Not so Good Day*** **– successful flight accomplished with ‘fault tolerance’**
  - non-catastrophic vehicle failure, workaround available
  - minor (non-life threatening) injury or illness, onboard medical ‘Level of Care’ provided
- ***Bad Day*** **– emergency survival to keep a ‘bad day’ from getting ‘worse’**
  - catastrophic vehicle failure or occurrence of a life threatening illness or injury
  - planned emergency scenarios such as aborts, bailouts, pressure suits, etc.
  - characterization of human tolerance limits associated with potentially extreme environments experienced in the event of such maneuvers
  - ensure appropriate medical care is on standby at the landing site



Task Description

- **Year 1 of Task 320 (June 1, 2015 through May 31, 2016)**
  - Defined relative degrees of ‘safe’ and means of quantifying ‘acceptable’ levels of risk for commercial spaceflight
  - Framework developed to deal with inflight medical issues
  - Comparative perspective offered for understandable ways of communicating risks of spaceflight to the general public
- **Year 2 of Task 320 (June 1, 2016 through May 31, 2017)**
  - Characterize and evaluate risk reduction strategies associated with each phase of the various commercial space flight profiles, with emphasis on medical level of care
  - Outcome intended to facilitate the ability of commercial launch operators and the FAA to fulfill their responsibilities related to informed consent

Alignment with FAA AST Goals

- *The risks and hazards of space flight must be presented to space flight participants "in a manner that can be readily understood by a space flight participant with no specialized education or training."*

14 CFR 460.45, Operator Informing Space Flight Participant of Risk, 2013

- "*The FAA expects space flight participants to come from all walks of life, with varying degrees of technical expertise and understanding. Congress requires that a space flight participant be informed of the risks, not that he or she acquire an understanding of basic engineering principles in order to understand that risk.*" The operator may provide additional information, as necessary, if it helps to explain the risk.

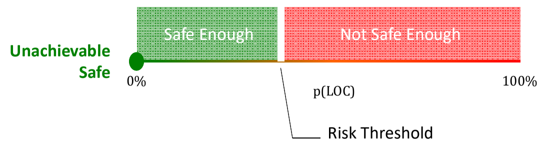
FAA Guidance on Informing Crew and Space Flight Participants of Risk, Draft, Feb 17, 2016

- Recommended Practices for Human Space Flight Occupant Safety – Version 1.0, August 27, 2014, FAA, TC14-003
- FAA Environmental Control and Life Support Systems for Flight Crew and Space Flight Participants in Suborbital Space Flight, Version 1.0, April 2010

Results: Risk Assessment

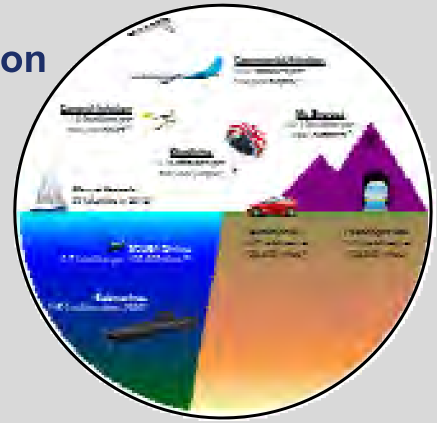
- **Safety** - *Freedom from those conditions that can cause death, injury, occupational illness, damage to or loss of equipment or property, or damage to the environment…"*
- **Safety Assurance** - *Providing confidence that acceptable risk for the safety of personnel, equipment, facilities, and the public during and from the performance of operations is being achieved.*

NPR 8715.3C (2008) NASA General Safety Program Requirements (w/Change 9 dated 2/08/13), *Washington DC*



Ocampo and Klaus (2016a)

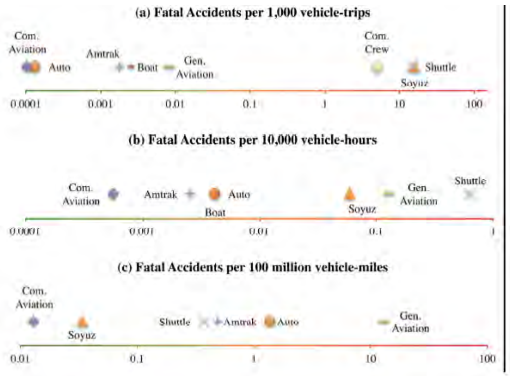
Results: Risk Communication



Results: person-centric

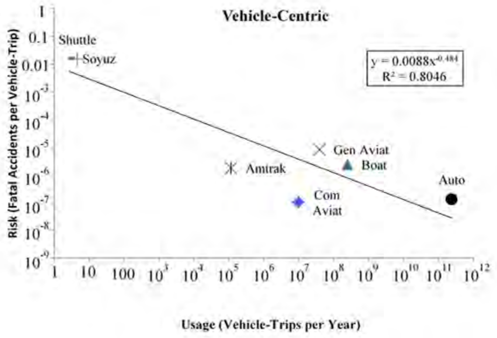
Ocampo, RP and Klaus, DM (2016b)

Results: vehicle-centric



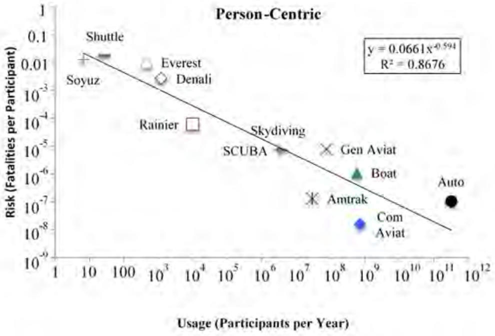
Ocampo, RP and Klaus, DM (2016b)

Results: vehicle-centric



Ocampo (2016)

Results: person-centric

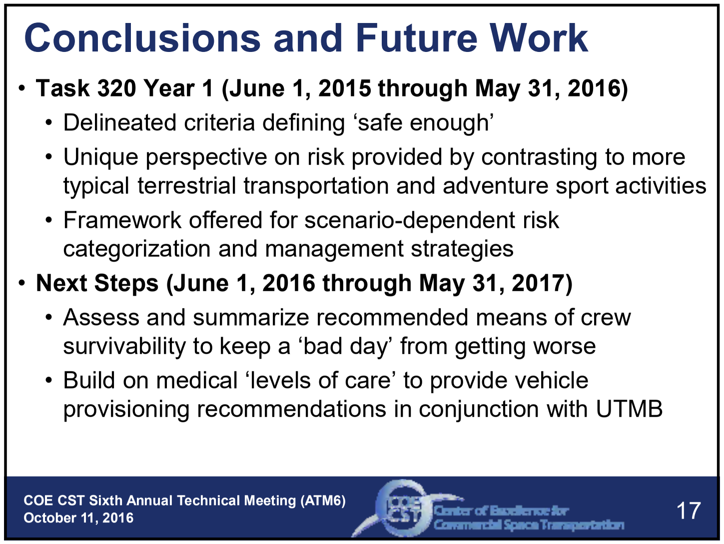


Ocampo (2016)

Publications – Task 320 (2015-16)

- Ocampo, RP and Klaus, DM (2016e) Challenges in Determining ‘Safe Enough’ in Human Space Flight [in prep]
- Ocampo, RP and Klaus, DM (2016d) Adapting Pre-Hospital Emergency Medical Protocols for Commercial Space Flight [in prep]
- Ocampo, RP and Klaus, DM (2016c) A Heuristic Method for Predicting Risk in Human Space Flight. *J. Spacecraft and Rockets* [in review]

- Ocampo, RP and Klaus, DM (2016b) Comparing the Relative Risk of Space Flight to Terrestrial Modes of Transportation and Adventure Sport Activities. *New Space* [accepted]
- Ocampo, R. and Klaus, D. (2016a) A Quantitative Framework for Defining “How Safe is Safe Enough?” in Crewed Spacecraft. *New Space*, 4(2): 75-82. doi:10.1089/space.2015.0040
- Ocampo, R.P. (2016) Defining, Characterizing, and Establishing “Safe Enough” Risk Thresholds for Human Space Flight, *Doctoral Dissertation*, University of Colorado Boulder



Conclusions and Future Work

- **Task 320 Year 1 (June 1, 2015 through May 31, 2016)**
  - Delineated criteria defining ‘safe enough’
  - Unique perspective on risk provided by contrasting to more typical terrestrial transportation and adventure sport activities
  - Framework offered for scenario-dependent risk categorization and management strategies
- **Next Steps (June 1, 2016 through May 31, 2017)**
  - Assess and summarize recommended means of crew survivability to keep a ‘bad day’ from getting worse
  - Build on medical ‘levels of care’ to provide vehicle provisioning recommendations in conjunction with UTMB

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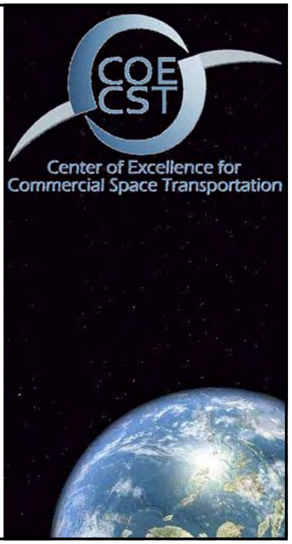
Task 193:Role of COE CST in EFP

PI: Dan Scheeres
Bradley Cheetham

October 11, 2016
Las Cruces, NM



Agenda

- Team Members
- Task Description/Goals
- ESIL Format
- Results
- Relevance
- Conclusions and Future Work

Team Members

- New PI – Daniel Scheeres
- Task support – Bradley Cheetham
- Industry Partners

LOCKHEED MARTIN
BLUE ORIGIN
SECURE WORLD FOUNDATION
SNC SIERRA NEVADA CORPORATION Space Systems
Advanced SPACE
ULA United Launch Alliance

Task Description/Goals

- Host targeted workshops using game-theory based framework for emerging industry leaders
  - Increase industry viability through research, training, and outreach
  - Disseminate information about the commercial space industry
  - Enhance participation and research in key industry topic areas

ESIL Format

- Emerging Space Industry Leaders Workshop
- Length: 1.5 – 2 days
- Attendees: 8-14 Emerging Leaders
- Key Components:
  - 6-8 hours of learning
  - Industry context and workshop motivation
  - Subject matter experts
  - Night 1 working dinner
- Products: Presentations/Papers
- Methodology: Game Theory PARTS Analysis

Results – ESIL-08

- Topic: Cis-lunar resource utilization
- Sponsors: ULA, Advanced Space
- Supporters: Space Angels Network, Masten Space Systems, Altius Space Machines
- Participants: 10
- Product: Presentation at Space Resources Roundtable

Results – ESIL-08

Results – ESIL-09

- Topic: Space Traffic Management
- Sponsors: Secure World Foundation, Advanced Space
- Supporters: AGI, FAA-AST
- Participants: 10
- Product: Ongoing discussion of workshop product

Results – ESIL-09

Relevance

- Extensive industry involvement in subject matter presentations and sponsorship
- Focus on relevant topics: STM, Lunar Resources, Microgravity Research, Commercial Remote Sensing, Smallsat Dedicated Launch, Spaceflight Training, etc…
- Inform, Perform, Network – targeted workforce and research development
- Over 100 participants to date

Conclusions and Future Work

- ESIL workshop format is continually refined and improved
- Next workshop in conceptual planning stages – considering financial/insurance focus possibly in NYC
- Seeking industry partners and sponsors
- Opportunity for others to host and manage
- Documentation available online www.ESIL.space

www.ESIL.space

Bradley.Cheetham@Colorado.edu

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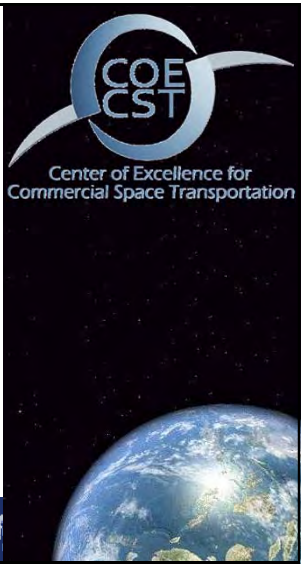
Legal Issues of Cross-Border Sub-Orbital Flights

Dr. Ram S. Jakhu
Aram Daniel Kerkonian



Agenda

- Team Members
- Task Description
- Schedule
- Goals
- Results
- Conclusions and Future Work

Team Members

Institute of Air and Space Law
McGill University

Dr. Ram S. Jakhu
Director
Institute of Air and Space Law
McGill University

Aram Daniel Kerkonian
LLM Candidate
Institute of Air and Space Law
McGill University

Task Description

- Cross-border sub-orbital flights (CBSOFs) offer unique advantages over traditional transportation models.
- Progress has been made in recent years to the point where CBSOFs will soon prove viable from a technological standpoint.
- Unlike domestic sub-orbital flights, cross-border flights will require unique legal considerations.
- There is no current regulatory framework for the operation of CBSOFs either between the United States and specific countries or internationally among all countries.
- Would a strong regulatory framework incentivize the commercial development and viability of CBSOFs?

Schedule

- Phase I: September – October 2016
- Phase II: November – December 2016
- Phase III: January – February 2017
- Phase IV: March – April 2017
- Phase V: May – June 2017

Goals

- What regulatory framework currently applies to CBSOFs?
- What area of law would apply to CBSOFs?
  - What would this determination be based on?
  - What would be the consequences of this determination?
- What existing legal regulatory frameworks would apply?
- What would a regulatory framework of CBSOFs look like?
  - Would this be a national or international regulatory framework?
  - Who would participate in creating such a framework?
  - What components would it need to address?
- What historical parallels can we draw from?
  - Air law?
  - Law of the sea?

Commercial Interests

- Why is a regulatory framework relevant and necessary for commercial CBSOFs?
  - What benefits does a regulatory framework offer to private entities interested in CBSOFs?
  - What added costs would a regulatory framework burden private entities with?
- What elements ought to be included in a regulatory framework to encourage the development of commercial CBSOF services?
- Are there any unique considerations that ought to be made regarding the cross-border component that isn't necessarily present in the current national regime?

Results

- Identification of Key Concepts:
  - Air Space vs Outer Space
    - Sovereignty vs Freedom of Use and Exploration
    - Assistance vs. Rescue and Return Obligations
  - Astronauts or Personnel of a Spacecraft
  - Aircraft or Spacecraft
  - Public or Private Responsibility, Liability and Jurisdiction

- Identification of the Key Players:
  - Departments of State/Foreign Affairs vs International Organization
    - Negotiating bilateral agreements vs international treaties
  - Departments of Justice
    - Drafting the regulatory framework to create national laws arising out of international agreements
  - Domestic Aviation Regulators
    - Implementing the regulatory framework arising from the international/bilateral agreements
    - Ensuring commercial entities follow regulatory framework
  - Commercial Space Operators
    - What kinds of things do they need in the regulatory framework vs what kinds of things can they handle?

Conclusions and Future Work

- Final Remarks
  - There will likely be a market for commercial, cross-border sub-orbital flights but what that market looks like or how that market would be regulated remains unclear.
  - Adding stability to the regulatory framework would give commercial operators more confidence to undertake their activities.

- Next Steps
  - Investigate in more depth the issues we have highlighted and report back on the progress of answering these questions.

- Requests
  - We would appreciate any questions or comments regarding potential issues we may have overlooked, parallel areas we may be ignoring or existing answers that can shorten the study.

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