



Florida Institute of Technology



www.coe-cst.org

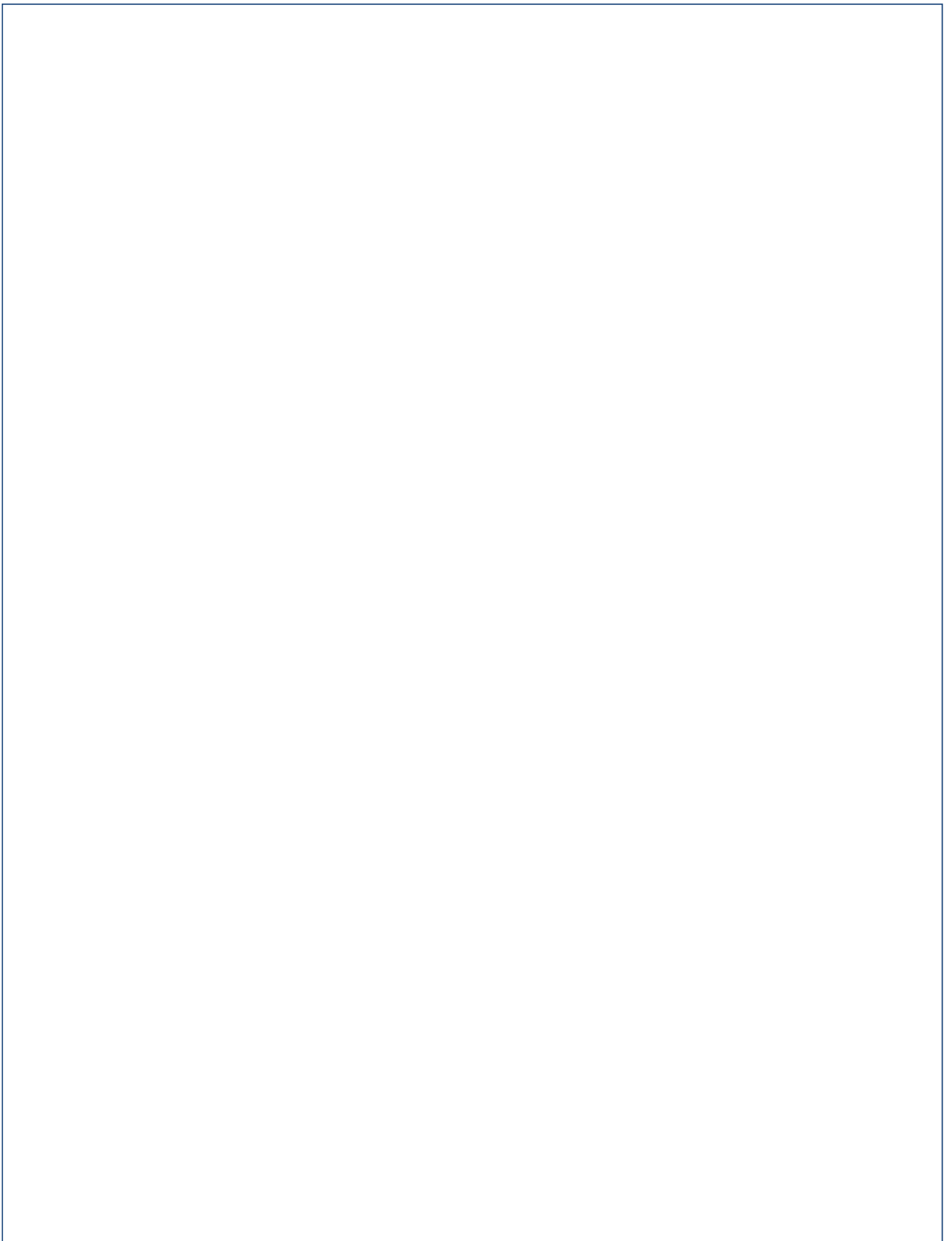


Center of Excellence for Commercial Space Transportation

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 Alejandro 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



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

ATM6 – Las Cruces October 11, 2016



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

ATM6 – Las Cruces October 11, 2016



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



ATM6 – Las Cruces October 11, 2016



Map of Core Member and Affiliate Member Universities



ATM6 – Las Cruces October 11, 2016



AGENDA MORNING

Tuesday, October 11th

7:30 AM	REGISTRATION
7:45 AM	Hotel Encanto de Las Cruces, San Rafael Ballroom (Breakfast included in Registration)
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 Davidson, FAA AST
9:15 AM	INDUSTRY VIABILITY PANEL
9:30 AM	Moderator: Dr. Tristram Fiedler, RT (James Vanderploeg, UTMB)
9:45 AM	Panelists: Mr. Brad Chesterton (Task 193-CU, ESL Workshops), Bailey Reynolds, Esq (Task 308-UTMB, Suborbital Industry Analysis), Richard M. Smith (Task 304-NU/PT, Legal Issues on Cross-Border Suborbital Flights - Affiliate Task)
10:00 AM	
10:15 AM	Sponsored Break
10:30 AM	HUMAN SPACEFLIGHT RESEARCH PANEL
10:45 AM	Moderator: Dr. Jim Vanderploeg, UTMB
11:00 AM	Panelists: Dr. David Klaus (Task 320-CU, Commercial spaceflight risk assessment and communication), Dr. Guy Lewis (Task 322-RT, Orbital Context Sensitive In-Habit Systems), Dr. Rebecca Blue (Task 308-UTMB & NASA, Affiliate, Suborbital SP Anxiety Assessment), Dr. Tarah Castleberry, Task 309-UTMB, Suborbital Pilot Training Assessment), Dr. Charles Mathers, (Task 310-UTMB, Increasing Cabin Survivability in Commercial Spacecraft)

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OUTPUT OVER THE FIRST FIVE YEARS

COE CST Year 5 Status

At-A-Glance Metrics	Year				
	1	2	3	4	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	\$2.4M	\$1.1M	\$1.1M	\$1M
	(F110)	(F1112)	(F113)	(F114)	(F115)

WWW.COE-CST.ORG

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AGENDA AFTERNOON

Tuesday, October 11th

1:00 PM	SPACE TRAFFIC MANAGEMENT PANEL
1:15 PM	Moderator: Dr. Juan Alonso, Stanford, SU
1:30 PM	Panelists: Dr. Tim Fuller-Bowell (Task 186-CU, Mitigate threats through space environment modeling and prediction), Dr. Sigrid Close, (Task 186-SU, Space Environment Modeling Prediction), Dr. Dan Scheres (Task 187-CU, Space Situational Awareness), Dr. Norman Fitz-Coy (Task 319-UF, DebrisSat), Dr. Juan Alonso (Task 331-SU, Advanced 4D Special Use Airspace Research), Dr. Chris Draper, (Affiliate Task 332-SM Defining Class X Air Space), Dr. Zheng 'Bo, MITRE (Affiliate Task), Mr. Brian Barnett, (Affiliate Task 307-S5C/NMSU COTS Sae Iite Communications), Dr. Richard Stanbury, (Affiliate Task 306-EPAU/NMSU Advanced ADS-B Prototypes)
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	
3:30 PM	Sponsored Break
3:30 PM	TECHNOLOGY PANEL
3:45 PM	Moderator: Dr. Andrei Zagrai, NMT
4:00 PM	Panelists: Dr. Billy Dates, (Task 241-FSU, High Temperature, Optical Sapphire Pressure Sensors), Dr. Rajan Kumar, (Task 325-FSU, Optical Measurements of Rocket Nozzle Thrust and Noise), Dr. Ian Lim (Task 299-NMT, Nitrous Oxide Composites Tank Testing), Dr. Andrei Zagrai (Task 323-NMT, Modeling of Spacecraft Thermal Environment), Dr. Shirb Vaidya (Task 311-LCE, Robust and Low-Cost LED Array Manufacturing Process), Dr. Eileen Ryan, (Task 329-NMT, Teaching & Monitoring Suborbital Commercial Space Vehicles)
4:15 PM	
4:30 PM	
4:45 PM	
5:00 PM	CLOSING REMARKS
5:15 PM	Dr. Jim Vanderploeg
5:30 PM	
	ADJOURN

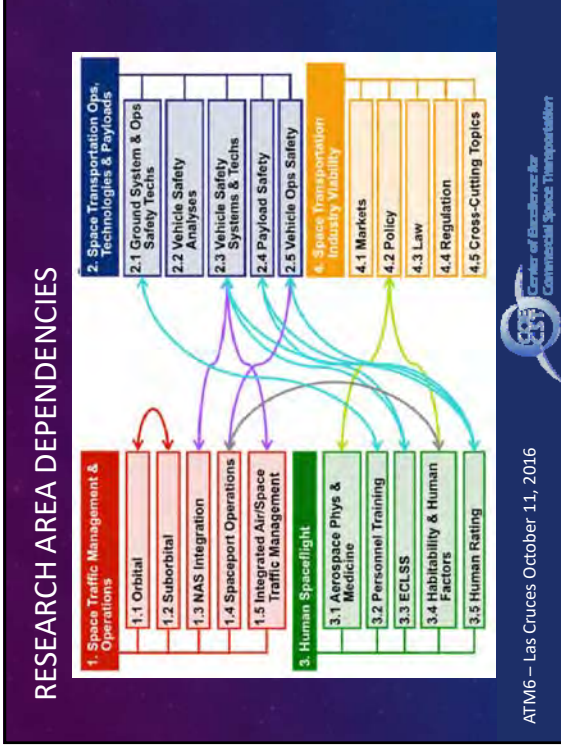
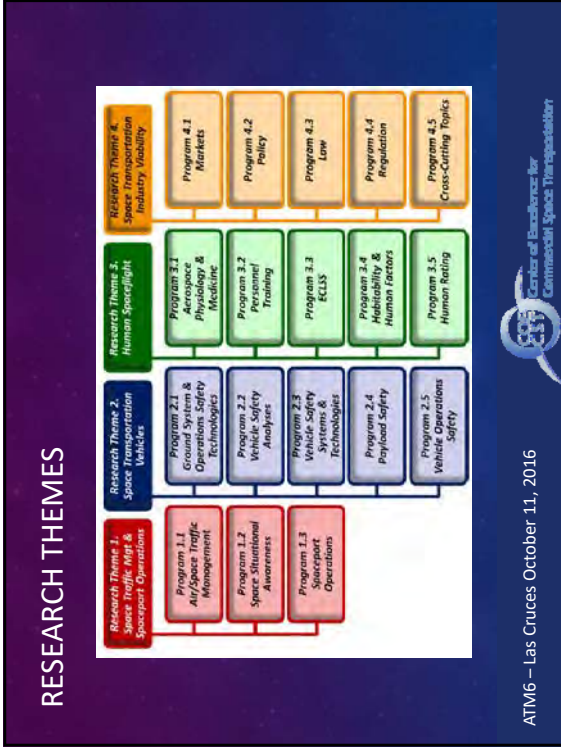
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WHERE WE ARE GOING

COMMERCIAL SPACE TRANSPORTATION RESEARCH ROADMAP
DECEMBER 2015

FEDERAL AVIATION ADMINISTRATION
CENTER OF EXCELLENCE FOR
COMMERCIAL SPACE TRANSPORTATION

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WEBSITE

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

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INDUSTRY VIABILITY PANEL

INDUSTRY VIABILITY PANEL

Moderator: Dr. Tristan Friedler, FIT [Jim 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)

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HUMAN SPACEFLIGHT RESEARCH PANEL

HUMAN SPACEFLIGHT RESEARCH PANEL

Moderator: Dr. Jim Vanderploeg, UTMB

Panelists:

- Dr. David Klaus (Task 320-CU, Commercial spaceflight risk assessment and communication),
- ~~Dr. Guy-Boyer (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)

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Moderator: Dr. Juan Alonso, Stanford, SU

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- 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-ERA/NMSU Advanced ADS-B Prototypes)

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Moderator: Dr. Andrei Zagrai, NMT

Panelists:

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

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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




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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




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Current:

Aviation Weather Support

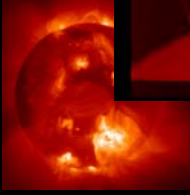
: conditions below 50 km from National Weather Service Global Forecast System (GFS) model and Gridpoint Statistical Interpolation (GSI) data assimilation system

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



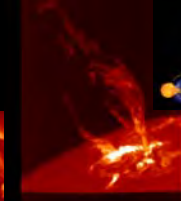
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So what is Space Weather?



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



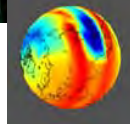
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 October 11, 2016



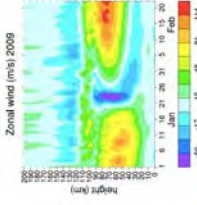
Filling the Gap – weather and space weather

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.

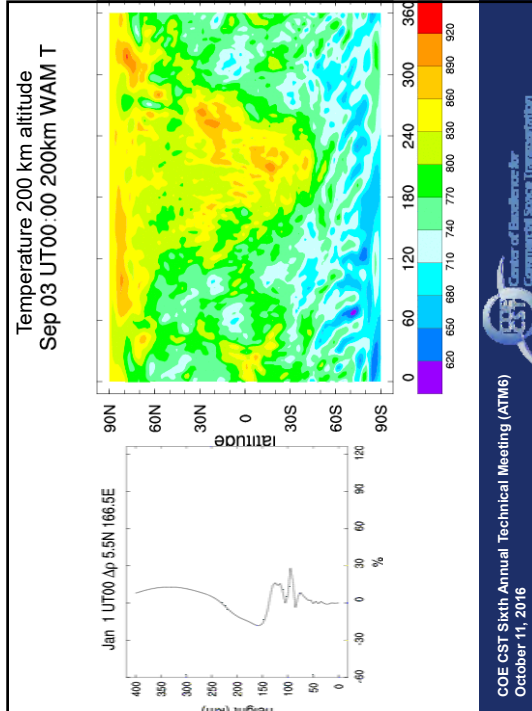
- O₃ chemistry and transport
- Radiative heating and cooling
- Cloud physics and hydrology
- Sea surface temperature field and surface exchange processes
- Orographic gravity wave parameterization
- Eddy mixing and convection
- Diffusive separation of species
- Composition dependent C_p
- Height dependent g(z)
- EUV, UV, and non-LTE IR
- Ion drag and Joule heating



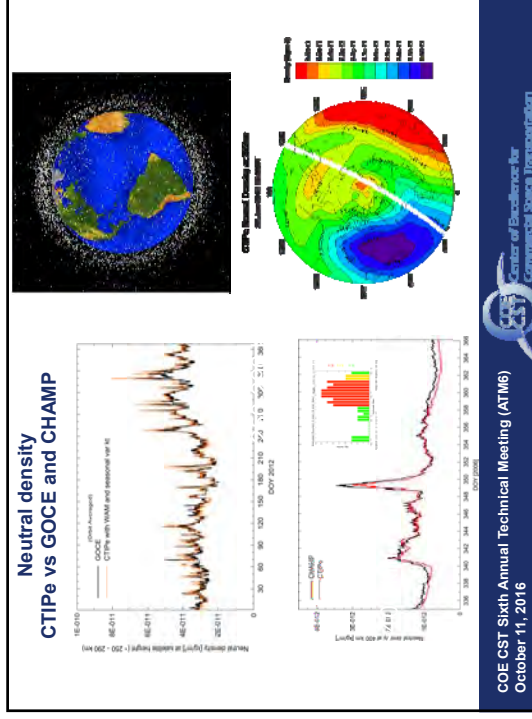
Coupled to a global ionosphere, plasmasphere, electrodynamic module (IPE) for plasma parameters



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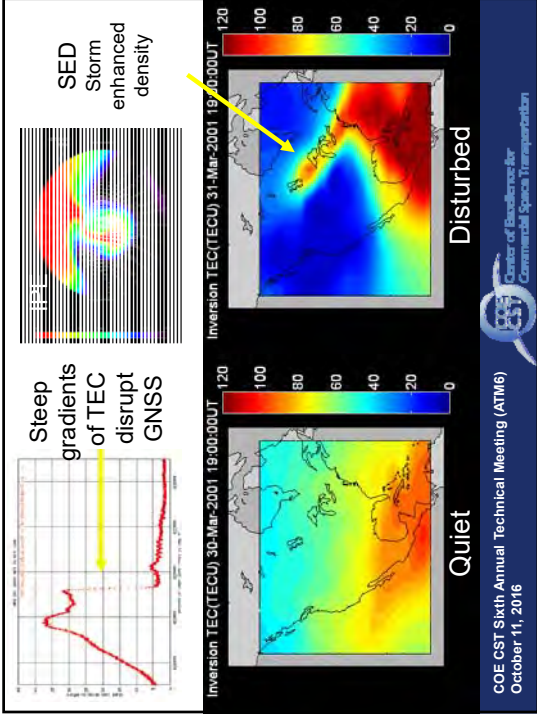



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Summary

- 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)

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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



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October 11, 2016



2

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



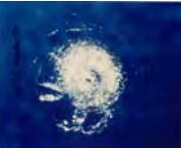
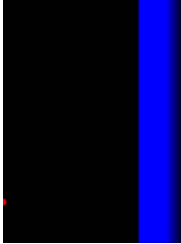

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3

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/faster, more numerous
- **Growing need to characterize MMOD down to smaller sizes and provide predictive threat assessment**

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4

MMOD – Classification

- **Meteoroids**
 - **Speeds**
 - 11 to 72.8 km/s (interplanetary)
 - 30-60 km/s (average)
 - **Densities**
 - $\leq 1 \text{ g/cm}^3$ (icy) or $> 1 \text{ g/cm}^3$ (rocky/stony)
 - **Sizes**
 - $< 0.3 \text{ m}$ (meteoroid)
 - $< 62 \mu\text{m}$ (dust)
- **Space Debris**
 - **Speeds in LEO**
 - $< 12 \text{ km/s}$
 - 7-10 km/s (average)
 - **Densities**
 - $> 2 \text{ g/cm}^3$
 - **Sizes**
 - $< 10 \text{ cm}$ (small)



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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

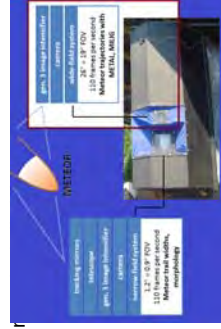
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Meteors: Experiment

- **CAMO: Canadian Automated Meteor Observatory**
 - Two observatory stations separated by 44.9 km: Eigenfield and Tavistock
 - Wide field camera with FOV $26^\circ \times 19^\circ$
 - 110 frames per second, Meteor f



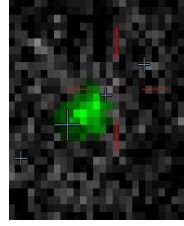
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Meteors: Light Curve

- **METAL: METeor Analysis software (UWO)**

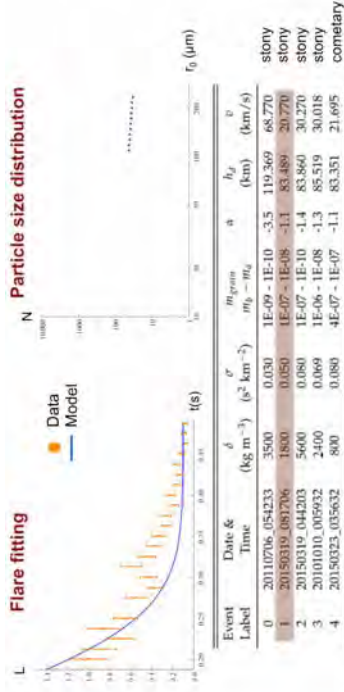


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Meteors: Preliminary Results



Thank you!

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

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




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Agenda

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



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Team Members

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



NEW MEXICO TECH
UNIVERSITY


New Mexico Tech (also providing matching funds)




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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.**



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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.

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5

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.

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6

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.

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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 ~30° telescope elevation.

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First Pointing Test: HASP Balloon

Flight is descending.
 Pinned position as of:
 Time: 17:12:42 (UTC -0800)
 Latitude: 34.04442 N
 Longitude: 121.8437 W
 Altitude: 20477 Feet
 IIR: 3.0 km @ 0.10 Deg
 IIR FOV: 1.00 Deg
 IIR Resolution: 423 Meters
 IIR FOV: 0.15 Deg
 IIR Resolution: 103 Meters

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

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

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9

“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 ~3° telescope elevation, on targets “JPL Remote” and “Test Flight”.

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 October 11, 2016

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10

“Test Flight”

Flight is at level.
 Pinned position as of:
 Time: 17:33:02 (UTC -0800)
 Latitude: 34.04442 N
 Longitude: 121.8437 W
 Altitude: 21843 Feet
 IIR: 3.0 km @ 0.10 Deg
 IIR FOV: 1.00 Deg
 IIR Resolution: 423 Meters
 IIR FOV: 0.15 Deg
 IIR Resolution: 103 Meters

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

“Test Flight” 400 km away and 3° above horizon from MRO 2.4-meter telescope site

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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.

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Conclusions and Future Work: Task 329

BALLOON TRACKING USING 2.4-M TELESCOPE

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 in an essential manner during primary operations.
- Develop data products used for deep investigation for Commercial Space Vehicle launches.

STATEMENT OF WORK

- Develop a software program 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 the 2.4-meter telescope.
- Analyze test track data, verify limitations, then improve algorithms for target tracking.



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



Image (left) taken with the MRO 2.4-meter telescope of "Test Flight" on 09/20/16. 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 determine the tracking error.
- 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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**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



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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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?**




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4D Compact Envelopes: A New Approach

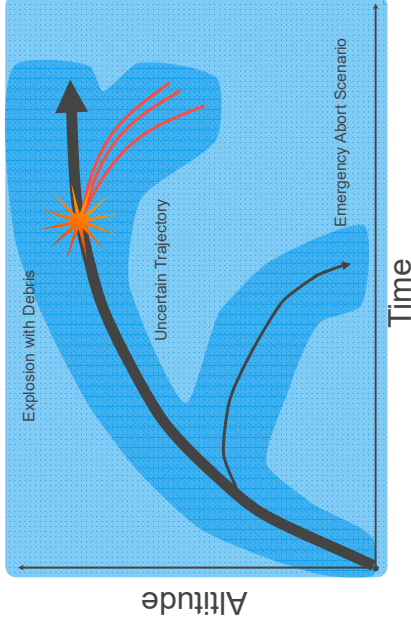
- **4D Compact Envelopes:** New framework for calculating and protecting against the probabilistic risk to aircraft from space vehicle debris.
- **Provably safe:** to a regulator-specified safety threshold.
- **NextGen:** incorporates many advances in the capabilities of the modern national airspace. 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.**

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4D Compact Envelopes Concept



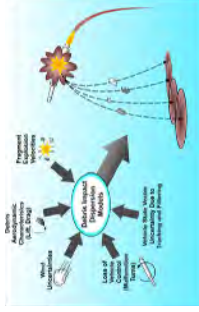
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Risk-Based Analyses

- 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

$$f^d(r, t)$$

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

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Example

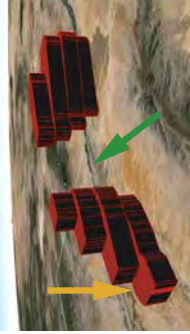


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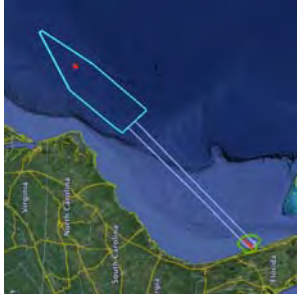
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Some Implications



- Falcon 9 envelopes much smaller
- Generally, first stage event can be handled reactively



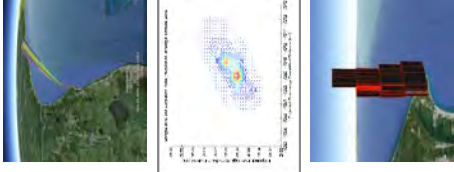
- Suborbital missions may have corridors that are always safe.
- Launch site overflight permitted

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SU-FARM Typical Scenario



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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

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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

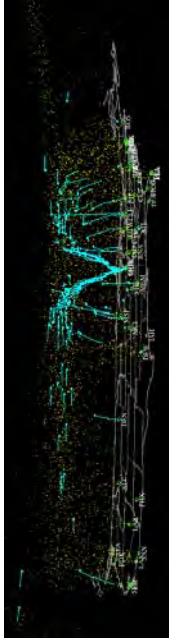


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FACET to Measure Disruption



- 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

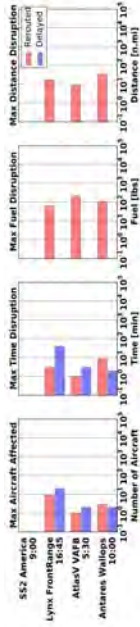
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Results (Compact Envelopes)

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



Metrics	Recreated	Delayed	Flight Delay	Ground Delay	Added Fuel	Added Distance
552 Aircraft	14.70	0.01	0.03	0.03	0.00	0.00
Lynx FrontRange	9.00	90.00	3.00	40.00	00.07	17.38
Alaska VAFB	1.00	1.00	1.00	1.00	274.36	0.77
Andreas Wiggins	3.00	3.00	3.00	3.00	116.05	87.18

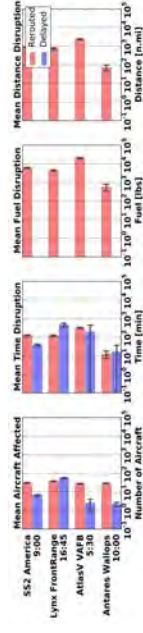
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Results (Traditional Approach)

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



Metrics	Recreated	Delayed	Flight Delay	Ground Delay	Added Fuel	Added Distance
552 Aircraft	31.26	0.26	125.75	37.43	3993.59	84.73
Lynx FrontRange	21.44	64.68	444.10	4094.11	194.39	194.39
Alaska VAFB	27.45	2.05	213.85	2007.25	2003.25	2003.25
Andreas Wiggins	26.15	9.15	14.39	16.14	658.15	91.05

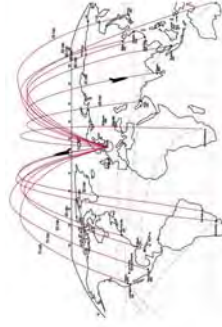
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Conclusions & Significance of Work

- 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



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Spaceport
t Belkin



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

Zheng Tao
 Ganghui Wang, Ashley G. Williams, Tudor Masek, Tom St. Clair,
 Jon L. Semanek, Jonathan L. Schwartz
 The MITRE Corporation










(authors clockwise)

FAA COE CST ATM6 Conference
 October 2016
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Space

Missile Warning

Intelligence

Cyber


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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

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

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Collaboration

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

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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

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Analysis

- Examined sensitivity of metrics to the examined factors
 - “time to clear a hazard area” – time it takes for all aircraft to exit a hazard area after an off nominal event
 - “time in hazard” – time each flight spends in the hazard area

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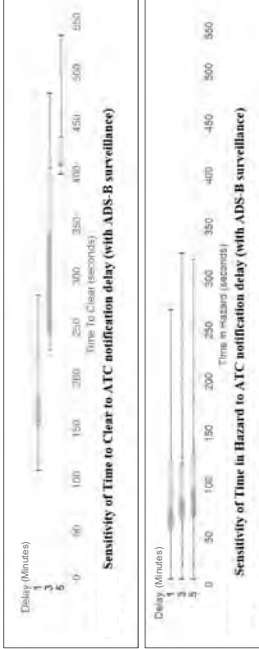


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Findings: ATC Notification Delay


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



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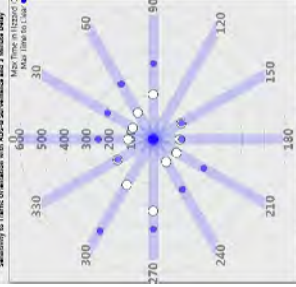


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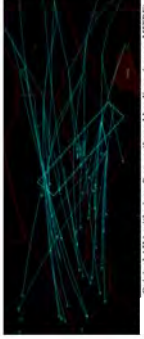


Findings: Traffic Orientation

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




Sensitivity to Traffic Orientation with ADS-B Surveillance and 3 Minute Delay
 Max Time Allowed for Aircraft to Exit Hazard Area




Original XMA with aircraft on pathhead headings. Source: MITRE

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

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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”

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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

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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

Agenda

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

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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)

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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

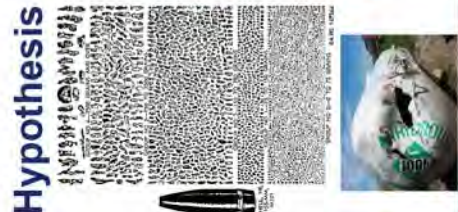

Tasks

- 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)

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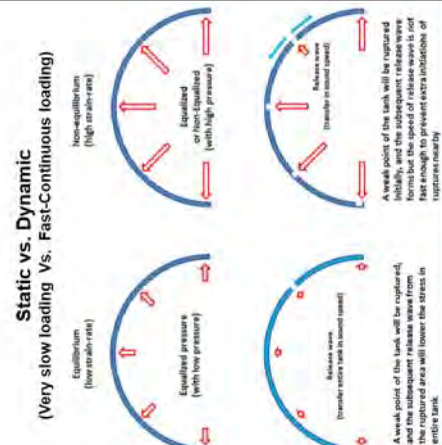
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Hypothesis

Static vs. Dynamic

(Very slow loading (low strain rate) vs. Fast-Continuous loading) (High strain rate)



Equilibrium (low strain rate)
Equalized pressure (with low pressure)
Reduces stress (transfer stress tank to second vessel)

Non-equilibrium (high strain rate)
Equalized (with high pressure)
Reduces stress (transfer to second vessel)

A weak point of the tank will be ruptured, locally, and the subsequent release will be fast enough to prevent extra propagation of rupture nearby.

A weak point of the tank will be ruptured, locally, and the subsequent release will be fast enough to prevent extra propagation of rupture nearby.

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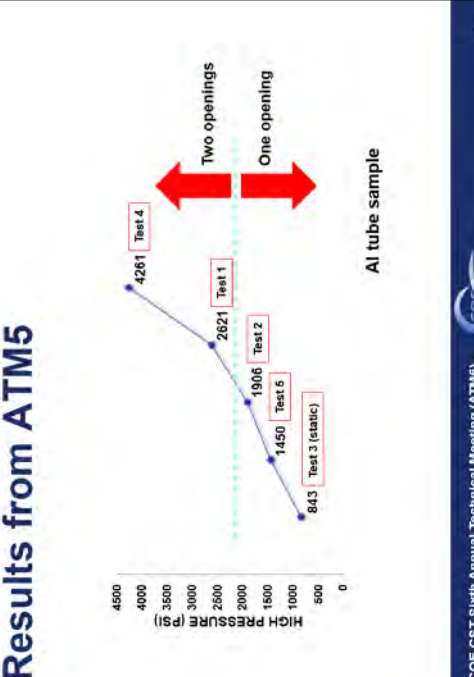
Test from ATM5



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Results from ATM5



4500
4000
3500
3000
2500
2000
1500
1000
500
0

4281 Test 4
2821 Test 1
1906 Test 2
1450 Test 5
843 Test 3 (static)

Two openings
One opening

Al tube sample

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Test Matrix

Date	Loading Source	Sample Material	Type	Success
8/11/2013	Nitrogen Tank Farm	Aluminum	Cylinder	Yes
9/10/2013	Nitrogen Tank Farm	aluminum	Cylinder	Yes
9/10/2013	Nitrogen Tank Farm	aluminum	Cylinder	Yes
9/23/2013	Nitrogen Tank Farm	Aluminum	Cylinder	Yes
9/26/2013	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
7/16/2016	Nitrogen Tank Farm	Carbon Fiber	Cylinder	No
9/29/2016	Black Powder Chamber	Carbon Fiber	Cylinder	Yes
10/27/2016	Pyrodes Cavity	Carbon Fiber / Aluminum	Tank	No
10/18/2016	Pyrodes Cavity	Carbon Fiber / Aluminum	Tank	No
10/10/2016	Pyrodes Cavity	Carbon Fiber / Aluminum	Tank	Yes

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Test Fixture



Black powder ignition chamber

Test sample

Test stand assembly

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

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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

Non-brittle

Pressure loading → Opening → Secondary impact → Shrapnel
With large fragments *Few/Large*

Brittle

Pressure loading → Opening → Secondary cracks → Shrapnel
Single *& Secondary Impact* *Many/Small*

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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


October 11, 2016
Las Cruces, NM



Agenda

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

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Team Members

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





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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

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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



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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



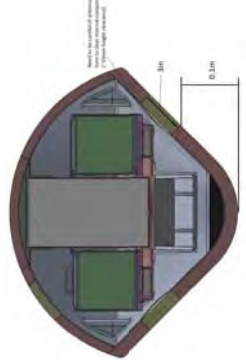
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Terminal Velocity Aerospace

- 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





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Terminal Velocity Aerospace Reentry Vehicle

Drop from stratospheric balloon






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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.
- Daughterbord demonstrated ability to provide processed GPS data to vehicle at 1 HZ with TVA vehicle; exploring increasing update rate

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

- 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

- 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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Technical Meeting**

**Commercial
Satellite Communications
Applications for Spacecraft**

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Solstar
 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








Center of Excellence for
 Commercial Space Transportation

Team Members

- Principal Investigator
 - M. Brian Barnett, Solstar*
- Co-Principal Investigator
 - Pat Hynes, NMSU

* Solstar is an affiliate member of the COE CST


Center of Excellence for
 Commercial Space Transportation

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



Center of Excellence for
 Commercial Space Transportation

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 be transmitted securely via commercial networks

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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
receives first text message at 67.4 miles (125KM)

<https://www.youtube.com/watch?v=RwQsYKPFY08>

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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

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

¹University of Central Florida, Orlando, FL
²Oak 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

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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



CATER *Center for the energy needs of society*




UCF

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.

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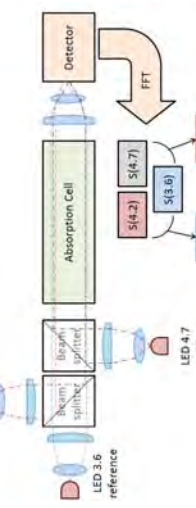


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Sensor Design Using LEDs

Non-Dispersive Infrared (NDIR) absorption sensor using LEDs

- Three MIR LEDs centered at
 - Band pass filters
 - 3.6µm (for reference)
 - 4.2µm (CO₂)
 - 4.7µm (CO)
- LEDs amplitude modulated at different frequencies
 - CO₂ center wavelength around 4.2µm
 - CO center wavelength around 4.7µm



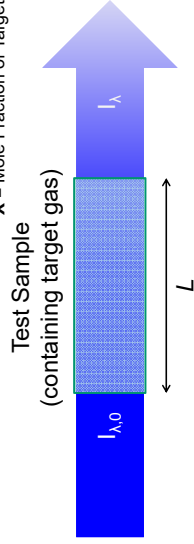
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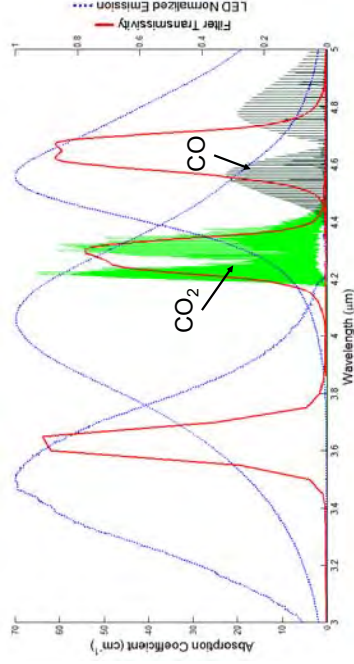
Absorption Spectroscopy and Beer's Law

Beer-Lambert Law of Absorption $A_\lambda = \text{Spectral Absorbance}$ (Typically 0-1)
 $I_\lambda = \text{Transmitted Radiation at } \lambda$
 $I_{\lambda,0} = \text{Incident Radiation at } \lambda$
 $k_\lambda = \text{Spectral Absorbance Coefficient}$ (Intrinsic Property at λ)
 $L = \text{Path Length of Gas Cell}$
 $X = \text{Mole Fraction of Target Gas}$

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



Using LEDs in Absorption Spectroscopy



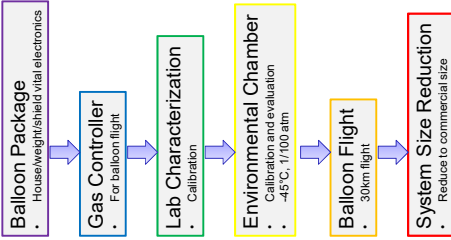
Schedule

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

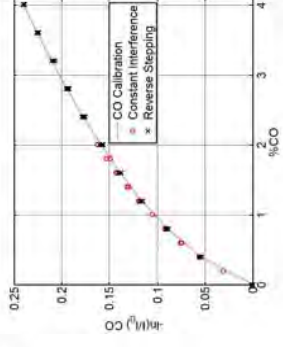
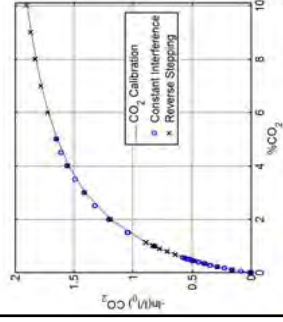
- Ongoing**
- Data analysis

- Planned**
- System redesign to decrease size



Fundamental Cross-Interference Study

- Simultaneous measurements of CO and CO₂ 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 ($1/1,000^{\text{th}}$ atm)
 - Temperature: -20°C
- Validation of sensor functionality and Autonomous operation in a hazardous environment was achieved



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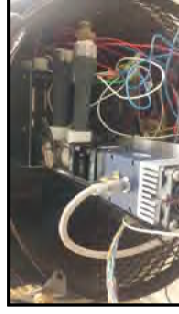
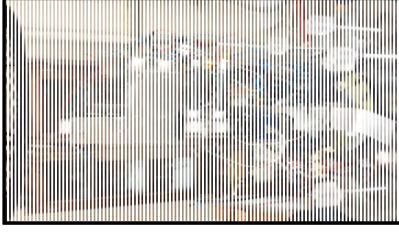
Environmental Chamber Study: Overview

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



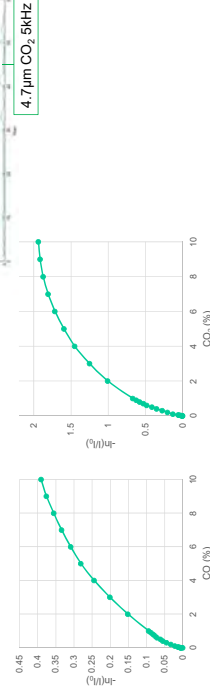
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Environmental Chamber Study: Results

- Steady State LED output over time
- Successful thermal management of system components
- Post analysis yields detection limits of:
 - 8ppm for CO₂
 - 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)

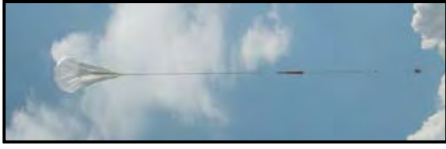
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High-Altitude Balloon Flight

- 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



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High-Altitude Balloon Flight System Design



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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



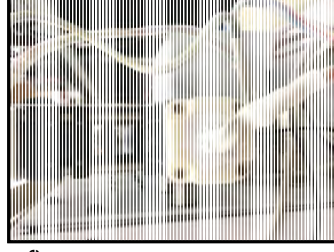
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High-Altitude Balloon Flight System Design

- 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.



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High-Altitude Balloon Flight: Results

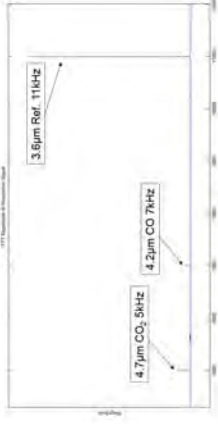
Flight Conditions:

- **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)

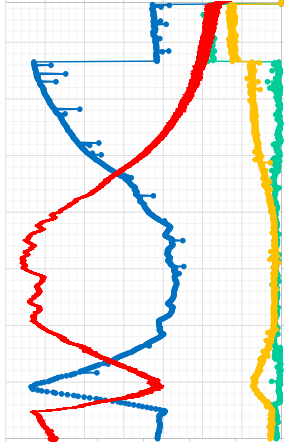


High-Altitude Balloon Flight: Prelim-Results

- The sensor successfully completed high altitude flight testing to simulate harsh working environments
- System was flown with a pre-mixture of N₂(89.51%), CO(4.97%) and CO₂(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
 Derek Doyle, Derek Hengeveld,(AFRL)
 Joshua Daniel, (WSMR)
 Dale Henneke, Dave Westpfahl, (NMT)

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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.



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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 fields
- 2) Material degradation/breakup monitoring.

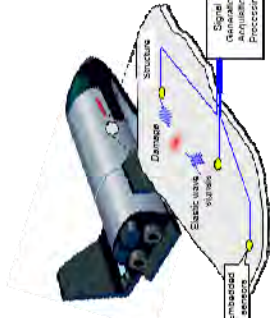

Certified for flight / re-flight?

SHM Modalities
 Passive Monitoring
 Active Monitoring on the Ground

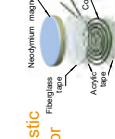


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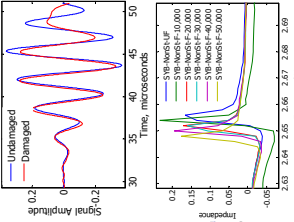
Structural Health Monitoring

Thin Piezoelectric Sensors
 7mm x 0.2mm

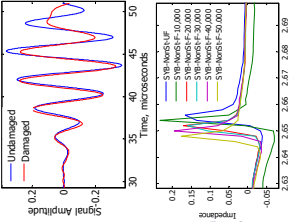


Magneto-elastic Active Sensor (MEAS)



Damage Detection
 Statistical Analysis
 Neural Network

Signal Processing
 Digital Acquisition
 Signal Processing
 Data Storage




Undamaged
Damaged

Time, microseconds

Signal Amplitude

Frequency, Hz



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Piezoelectric Wafer Active Sensors (PWAS)

Sensing

Actuation

3-D equations for PWAS

$$S_1 = d_{31}^E T_1 + d_{32}^E T_2 + d_{33}^E T_3 + d_{31}^E E_1$$

$$S_2 = d_{31}^E T_1 + d_{32}^E T_2 + d_{33}^E T_3 + d_{32}^E E_2$$

$$S_3 = d_{31}^E T_1 + d_{32}^E T_2 + d_{33}^E T_3 + d_{33}^E E_3$$

Impedance of the free (unconstrained) sensor

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

Solution

$$u_1(x,t) = \tilde{u}_1(x) e^{i\omega t}$$

$$\tilde{u}_1(x) = (C_1 \sin \gamma x + C_2 \cos \gamma x)$$

Exponential and sinusoidal components in the graph.

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.

$$Z_m(\omega) = \frac{1}{Y_e(\omega)} = \frac{1}{i\omega C_s} \left[1 - K_{31}^2 \left(1 - \frac{1}{\phi \cot(\phi) + k_{31}(\omega)/k_{31}} \right) \right]^{-1}$$

Graphs showing aircraft panel impedance and a piezoelectric sensor response with a crack.

Suborbital flight data

Electro-mechanical impedance spectra

Typical mission profile of Spaceflight rocket

Reentry

Very small frequency changes during first 3.5 minutes of flight

Substantial amplitude and frequency changes during reentry

Consistent readings after landing ≈ 13 minutes

Time points: T=47.0 s, T=86.3 s, T=164.9 s, T=204.2 s, T=282.7 s, T=341.8 s, T=400.5 s, T=439.8 s, T=479.0 s, T=518.3 s, T=557.5 s, T=636.0 s, T=675.3 s, T=754.8 s, T=832.3 s, T=910.8 s

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 2×10^{-6} Torr
- FTS RC2111 Recirculating Chiller

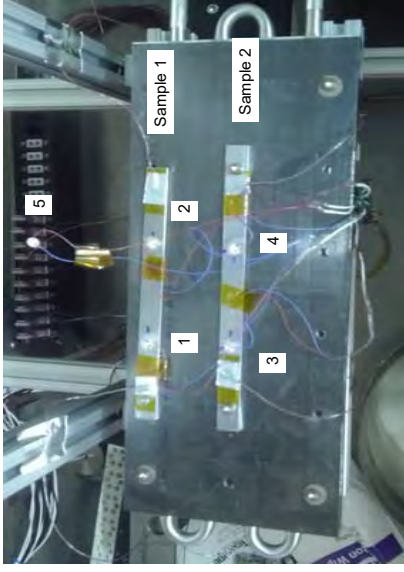


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Temperature and Vacuum Effects

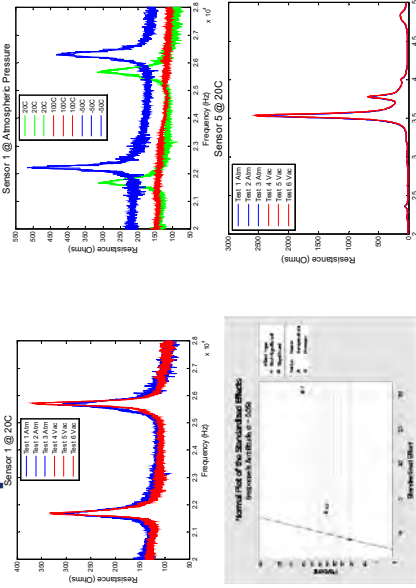


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Temperature and Vacuum Effects



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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

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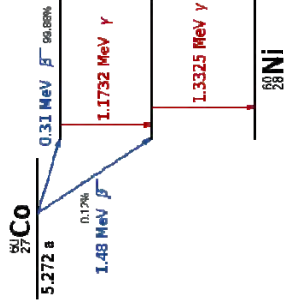
Investigation of Radiation Effects

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)



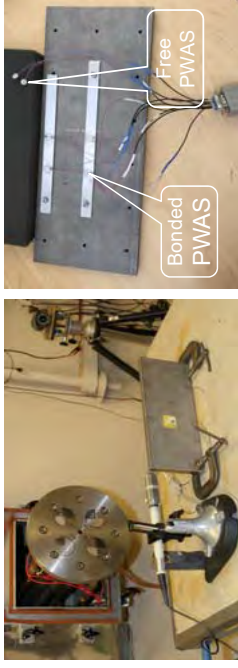
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White Sands Gamma Facility Test

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

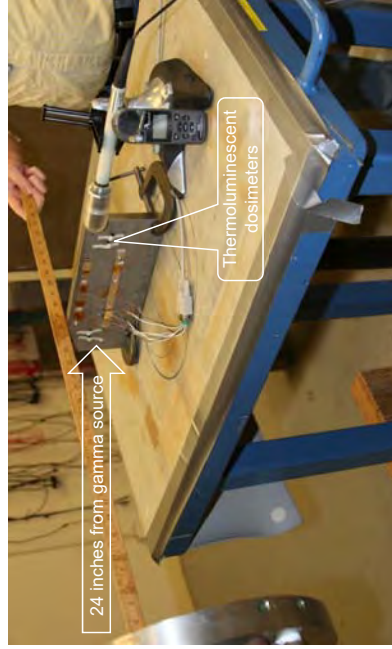


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White Sands Gamma Facility Test



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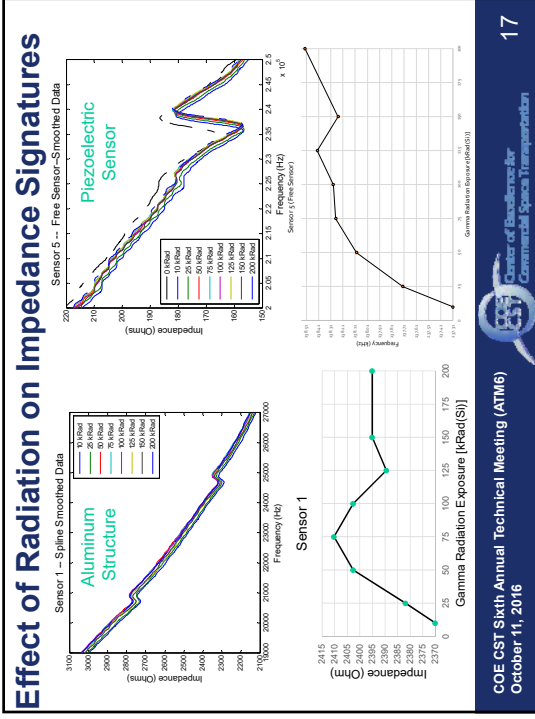
Irradiation Plan for LEO Simulations

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

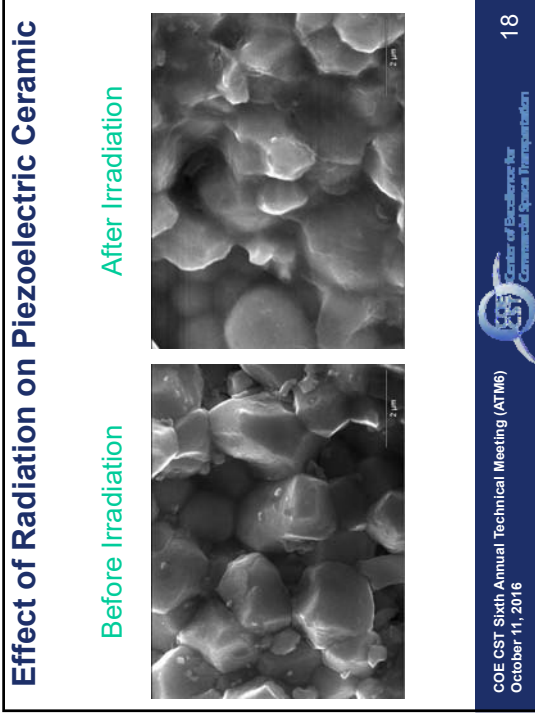
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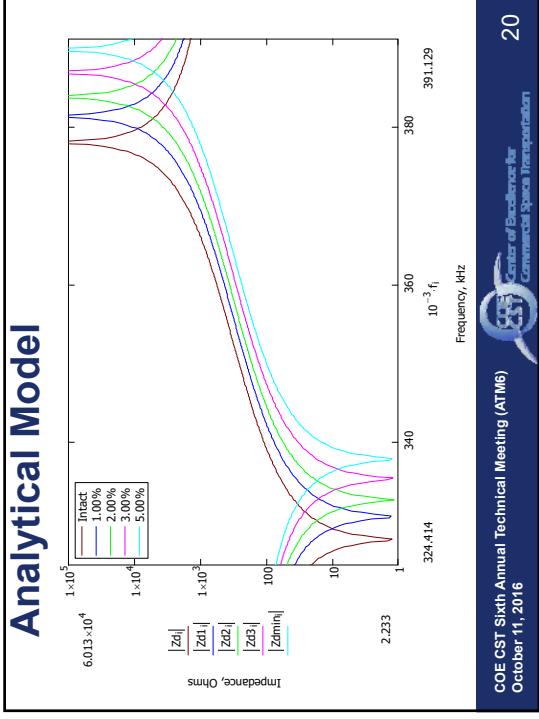
Analytical Model

In our modeling efforts, we propose that exposure to gamma radiation causes:

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

$$Y_{dmin} = i \omega_j C_a \left[1 - (k'_p)^2 \right] \left[1 + \frac{(k'_p)^2}{1 - (k'_p)^2} \left(\phi_{min} i \cdot J0(\phi_{min} i) - (1 - \sigma_{PZT}) \cdot J1(\phi_{min} i) \right) \right]$$

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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.

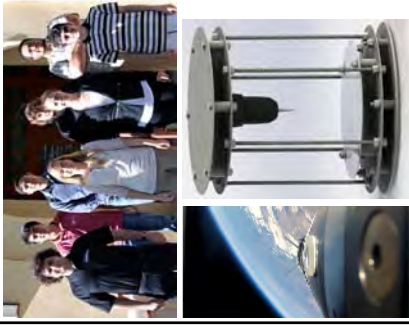
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Undergraduate SHM Team

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



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Acknowledgements

- Federal Aviation Administration (FAA) through Center of Excellence for Commercial Space Transportation,
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 - Jerome 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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References

- Giurgiutiu, V., Zagari, A.N. (2000). "The Use of Smart Materials Technologies in Radiation Environment and Nuclear Industry". SPIE's 7th Annual International Symposium on Smart Structures and Materials, Newport Beach, California, 5-9 March 2000. v. 3985, pp. 855-866.
- W. E. Price. "The Simulation of Space Radiation Damage to Spacecraft Systems." IEEE Transactions on Nuclear Science, vol. 12, no. 6, pp. 2-7, 1965.
- European Space Agency, "The Radiation Design Handbook," ESA Publications Division, Noordwijk, 1993.
- A. N. Zagari 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.
- National Aeronautics and Space Administration, "Nuclear and Space Radiation Effects on Materials," NASA, 1970.

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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.

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Task 325: Optical Measurements of Rocket Nozzle Thrust and Noise

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

FAA Technical Monitor:
Nick Demidovich



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Agenda

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

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Team Members

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












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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




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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.

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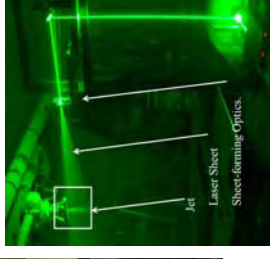
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Test Facilities



Nozzle
Ground Plate with
Transducer Block



Operational/Test Capabilities
 • Mach Number = 0.5 - 2.5
 • T_{ch} = 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

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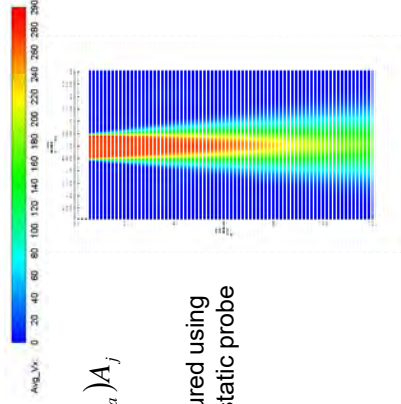
Thrust Measurements

$$F = F_m + F_p$$

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

Measured using PIV

Measured using Pitot-static probe



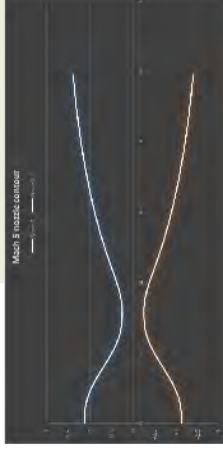
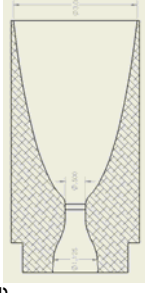
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Rocket Nozzle Design

Thrust optimized parabolic (TOP) contour nozzle



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Rocket Nozzle Fabrication



Design Mach #: 5.6
A/A* = 38




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Particle Image Velocimetry



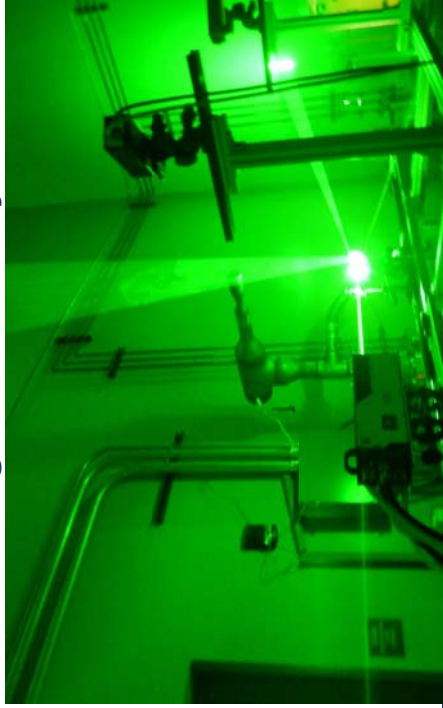
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Particle Image Velocimetry



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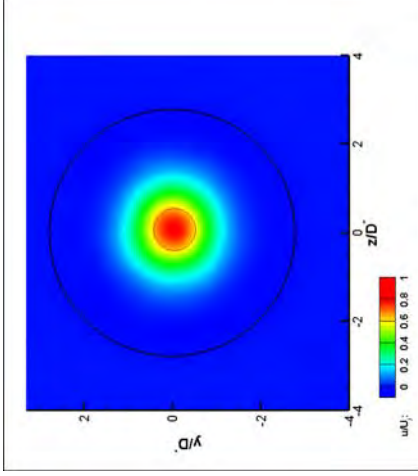


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Mean Velocity Field

Nozzle Pressure Ratio = 7
Temperature Ratio = 1.5



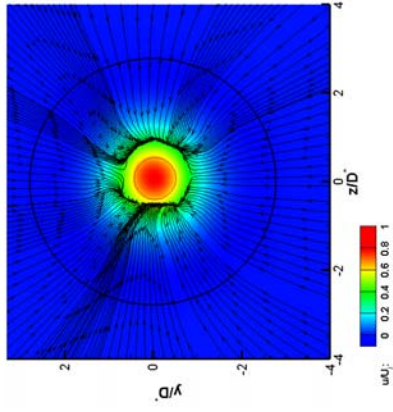
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Mean Velocity Field



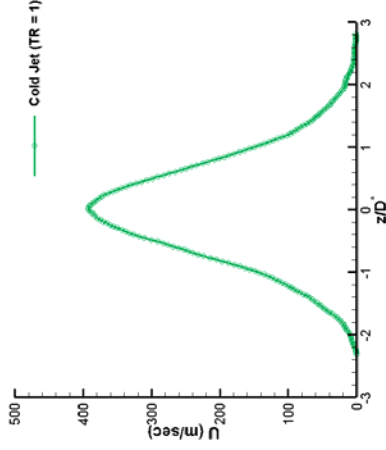
Nozzle Pressure Ratio = 7
 Temperature Ratio = 1.5

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Mean Velocity Profiles

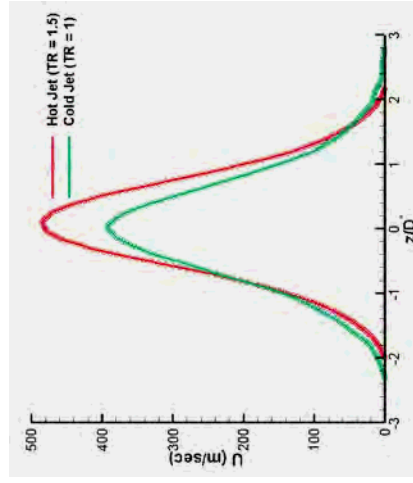


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Mean Velocity Profiles

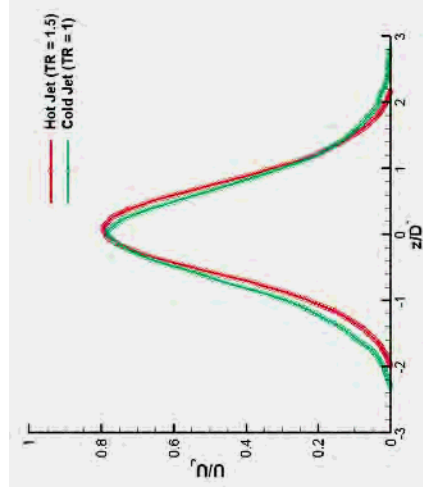


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Mean Velocity Profiles

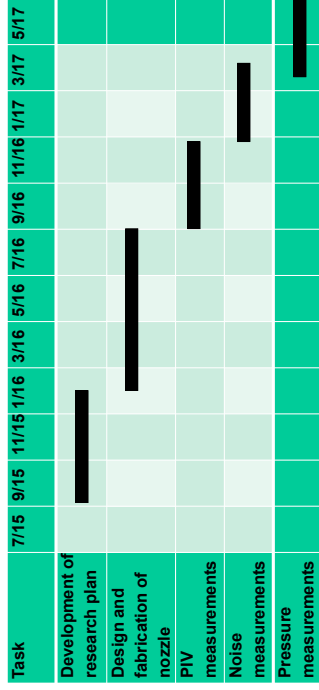


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Schedule and Milestones



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



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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



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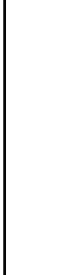
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Agenda

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



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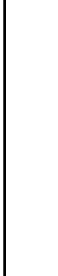
Team Members

- 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; Andreea 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





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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.



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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

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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

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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

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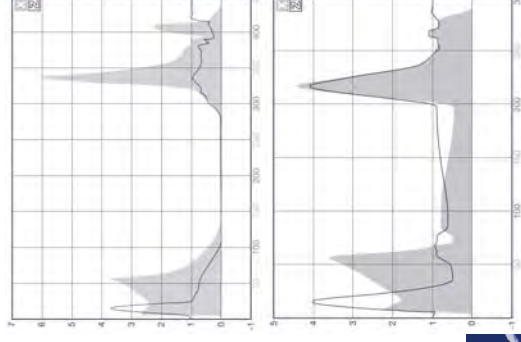


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Centrifuge Profiles

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



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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

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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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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 Casleberry, DO, MPH, Charles Mathers, MD, MPH
- Residents: Ranul Suresh, MD

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

Psychological stressors can be significant challenges in the operational environment, and hypersons 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
- 29 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
Alejandro 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
- Extrication Workshop – *tentative Spring 2017*
 - IndyCar
 - USAF 17th Test Squadron
 - NASA
 - Commercial Space Operators

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Goals

- Dedicated efforts towards the enhanced safety of crew extrication 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

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Results

- Pending

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Conclusions and Future Work

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

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

PROJECT LEADERSHIP

- 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
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STATUS

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- 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




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Publications, Presentations & Awards

PUBLICATIONS

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

Garbino A, Nuebaum DM, Buckland DM, Meron AS, Clark JB, Antonson 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)*

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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*
- Neils, 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*

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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

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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'**



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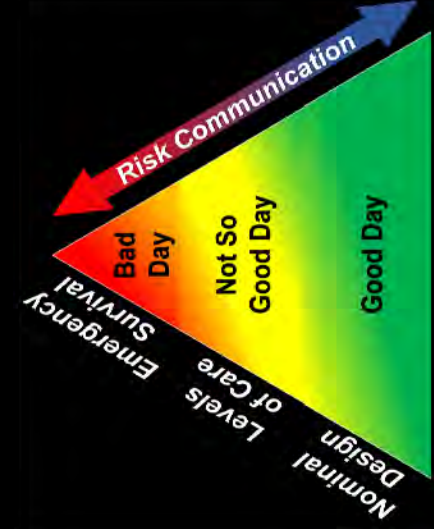
Task Description

- **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, work-around 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

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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

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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, TC-14-003
- FAA Environmental Control and Life Support Systems for Flight Crew and Space Flight Participants in Suborbital Space Flight, Version 1.0, April 2010

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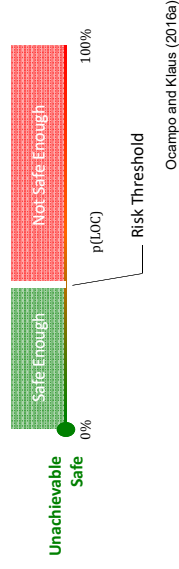


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Results: Risk Assessment

- **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 87.15.3C (2008) NASA General Safety Program Requirements (w/Change 9 dated 2/08/13), Washington DC



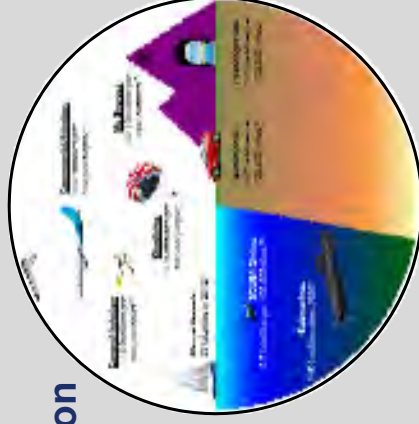
Ocampo and Klaus (2016a)

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Results: Risk Communication

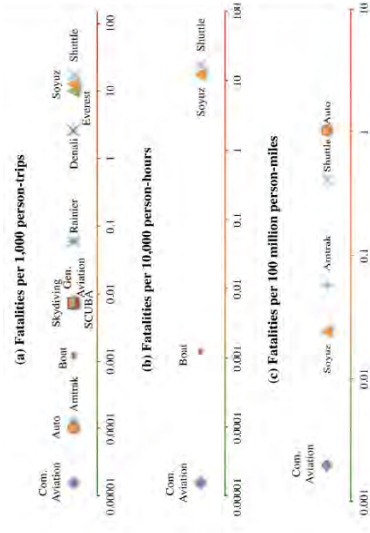


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Results: person-centric



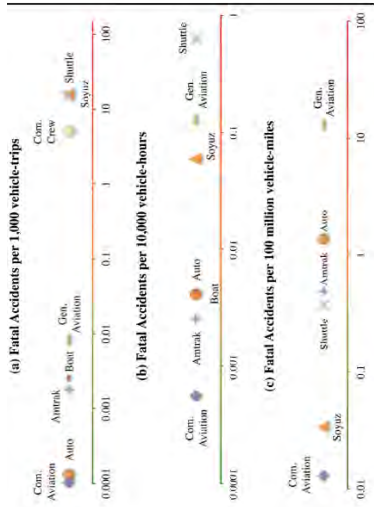
Ocampo, RP and Klaus, DM (2016b)

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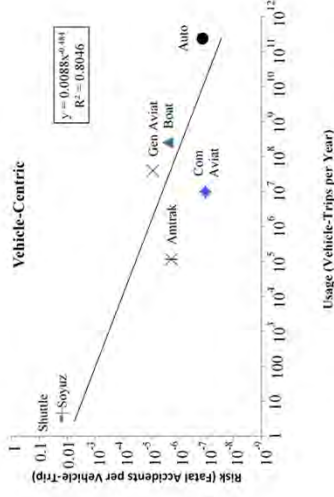
Results: vehicle-centric



Ocampo, RP and Klaus, DM (2016b)

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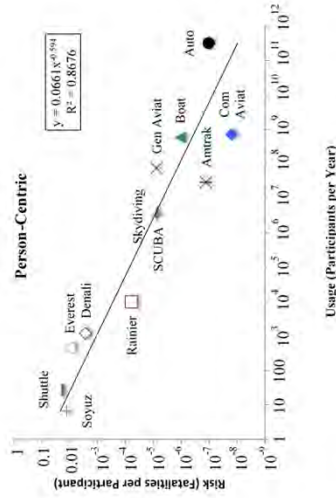
Results: vehicle-centric



Ocampo (2016)

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Results: person-centric



Ocampo (2016)

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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

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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

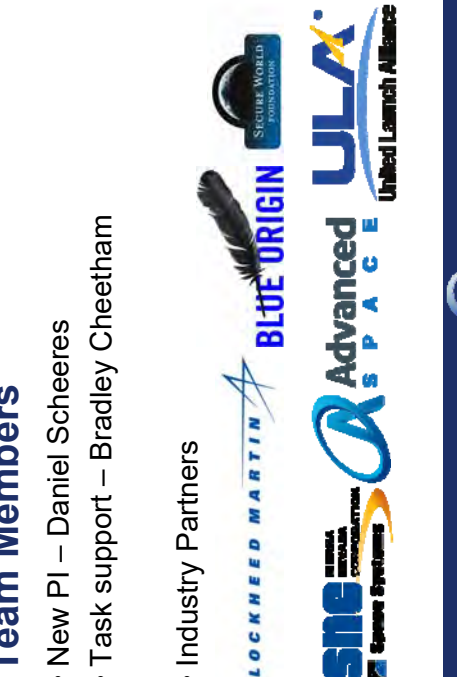
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Team Members

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



LOCKHEED MARTIN
BLUE ORIGIN
SINCERA CONSULTING
Advanced SPACE
United Launch Alliance

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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

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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

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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

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Results – ESIL-08



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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

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Results – ESIL-09



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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

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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

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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



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Agenda

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

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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
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McGill University



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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?

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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

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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?

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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?

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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?

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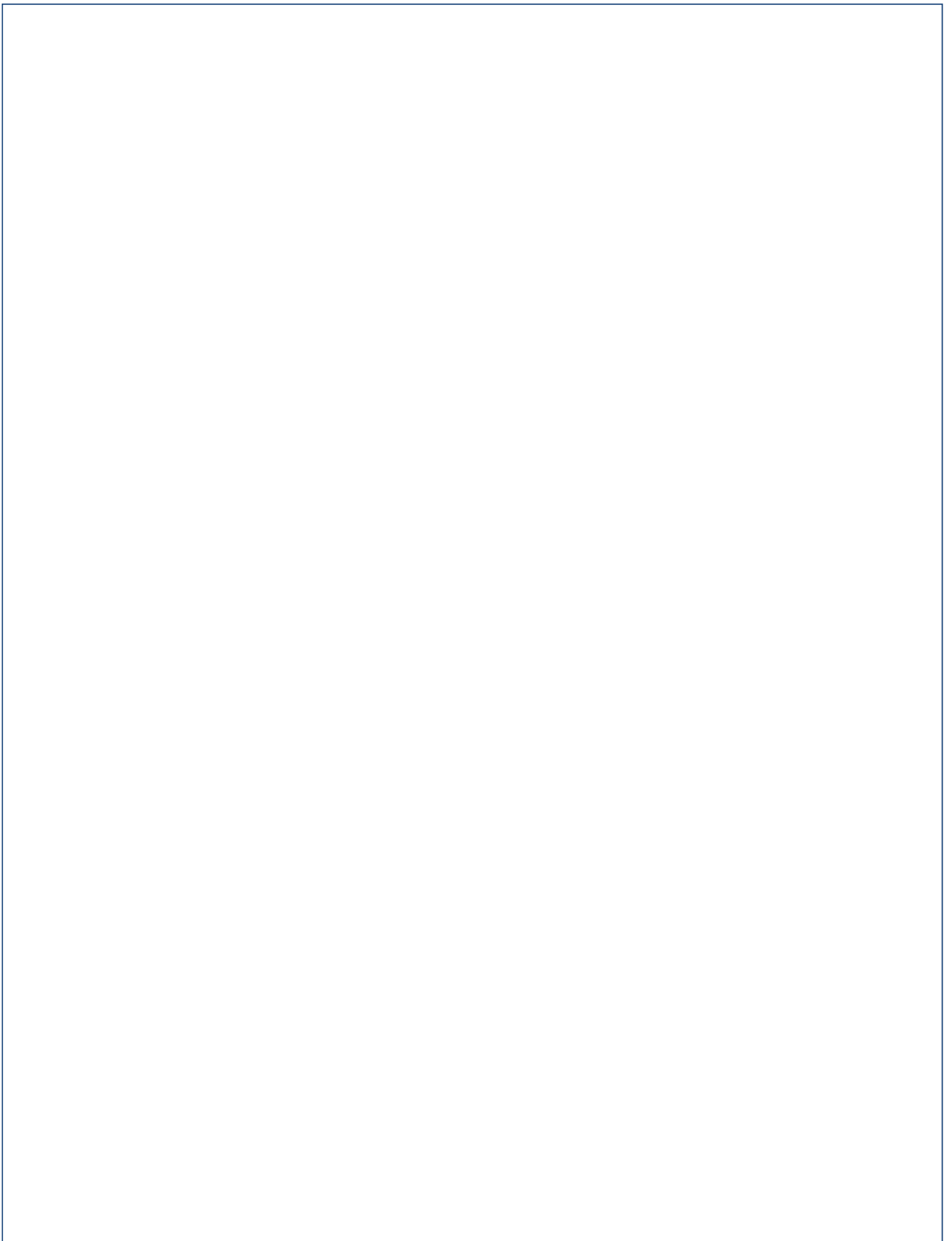
Conclusions and Future Work

- 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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