Florida Institute of Technology

Florida State University

NM State University

New Mexico Tech

Science • Engineering • Research • University

Leland Stanford Junior University

CU

University of Central Florida

UF University of Florida

utmb Health

www.coe-cst.org

COE CST Center of Excellence for Commercial Space Transportation

Federal Aviation Administration Center of Excellence for Commercial Space Transportation

Year 3 Annual Report

Volume 2. Annual Technical Meeting Presentations

December 31, 2013

COE CST YEAR 3 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 second year of operation. The document ends with a listing of the Year 2 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 third Annual Technical Meeting in October 2013 held on Capitol Hill in Washington, DC.
- 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 third Annual Technical Meeting in October 2013 held on Capitol Hill in Washington, DC.

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

- "COE CST Third Annual Technical Meeting: Welcome" presented by Ken Davidian from the Federal Aviation Administration (FAA) Office of Commercial Space Transportation (AST).
- "Strategic Technology Investment Plan and Technology Roadmaps" presented by Faith Chandler from NASA's Office of the Chief Technologist.
- "FAA Air Transportation Center of Excellence: Overview-Government/Academic/Industry Strategic Partnerships" presented by Dr. Patricia Watts from the FAA Centers of Excellence.
- "Embry Riddle Aeronautic University: Overview" (Affiliate Member)
- "NASTAR Center: Overview" (Affiliate Member) presented by Brienna Henwood from the NASTAR Center.
- "FAA COE CST Affiliate Member Overview" presented by Ken Davidian from the FAA AST.
- Florida Congressman Bill Posey
- "Bigelow Aerospace"
- "CESTAC Feedback" presented by Carissa Christensen

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

- Task 184 "Human Rating of Commercial Spacecraft" presented by Professor David Klaus of University of Colorado, Boulder (CU).
- Task 185 "Unified 4D Trajectory Approach for Integrated Traffic Management" presented by Tom Colvin and Juan Alonso of Stanford University (SU).
- Task 186 "Mitigating Threats Through Space Environment Modeling Prediction" presented by Tim Fuller-Rowell of the University of Colorado, Boulder (CU).
- Task 186 "Space Environment MOD Modeling and Prediction" presented by Alan Li and Sigrid Close of Stanford University (SU).
- Task 187 "Space Situational Awareness" presented by D.J. Scheeres of University of Colorado, Boulder (CU).
- Task 193 "Role of COE in EFT" presented by George H. Born of University of Colorado, Boulder (CU).
- Task 193 "Opportunities for Secondary and Hosted Payloads on NASA Missions" presented by Professor Scott Hubbard of Stanford University (SU).
- Task 220 "Develop Framework for Commercial Spaceport Operations that Creates a Body of Knowledge that Captures Best Practices" presented by Patricia C. Hynes, Ph.D. of New Mexico State University (NMSU).
- Task 228 "Magneto-Elastic Sensing for Structural Health Monitoring" presented Andrei Zagrai and Warren Ostergren of New Mexico Institute of Mining & Technology (NMT).
- Task 241 "Fracture Mechanics of Sapphire for High Temperature Pressure Transducers " presented by William Oates of Florida State University (FSU).

- Task 241 “High-Temperature Pressure Sensors for Hypersonic Vehicles” presented by David Mills and Mark Sheplak of University of Florida (UF).
- Task 244 “Autonomous Rendezvous and Docking” presented by Penina Axelrad of University of Colorado, Boulder (CU).
- Task 244 “Autonomous Rendezvous and Docking: Rapid Trajectory Generation” presented by Griffin Francis and Emmanuel Collins of Florida State University (FSU).
- Task 244 “Autonomous Rendezvous and Docking: Using Nano-Satellites for Inspection and Proximity Operations” presented by Steve Rock of Stanford University (SU).
- Task 244 “Autonomous Rendezvous and Docking for Space Debris Mitigation” presented by Norman Fitz-Coy of University of Florida (UF).
- Task 247 “Air and Space Traffic Considerations for CST” presented by Dr. Nathaniel E. Villaire and Professor Emeritus of Florida Institute of Technology (Florida Tech).
- Task 253 “ Ultrahigh Temperature Composites for Thermal Protection Systems (TPS)” presented by Dr. Jan Gou of University of Central Florida (UCF).
- Task 255 “Validation of Non-Invasive Biomedical Monitoring in Centrifuge-Simulated Suborbital Spaceflight” presented by Richard Jennings, MD, MS and Tarah Castleberry, DO, MPH of University of Texas Medical Branch (UTMB).
- Task 256 “Tolerance of Centrifuge-Induced G-Force by Disease State” presented by James M. Vanderploeg, MD, MPH of University of Texas Medical Branch (UTMB).
- Task 257 “Commercial Spaceflight Operations Curriculum Development” presented by George H. Born of University of Colorado, Boulder (CU).
- Task 258 “Analysis Environment for Safety of Launch and Re-Entry Vehicles” presented by Juan Alonso and Francisco Capristan of Stanford University (SU).
- Task 293 “Nonlinear Structural Models” presented by Dr. A. Keith Miller and Dr. Warren Ostergren of New Mexico Institute of Mining & Technology (NMT).
- Task 294 “Development of Minor Injury Severity Scale for Orbital Human Space Flight” presented by Richard T. Jennings, MD, MS of University of Texas Medical Branch (UTMB).
- Task 295 “Effects of EMI and Ionizing Radiation on Implantable Medical Devices” presented by James M. Vanderploeg, MD, MPH of University of Texas Medical Branch (UTMB).
- Task 298 “Integration and Evaluation of ADS-B Payloads” presented by Patricia C. Hynes, Ph.D. of New Mexico State University (NMSU).
- Task 299 “Nitrous Oxide Composite Case Testing” presented by Warren Ostergren, Michael Hargather, Robert Abernathy, and Andrei Zagrai of New Mexico Institute of Mining & Technology (NMT).

COE CST Third Annual Technical Meeting: Welcome!

Ken Davidian
COE CST ATM3 in Washington, DC
Tuesday, October 29, 2013

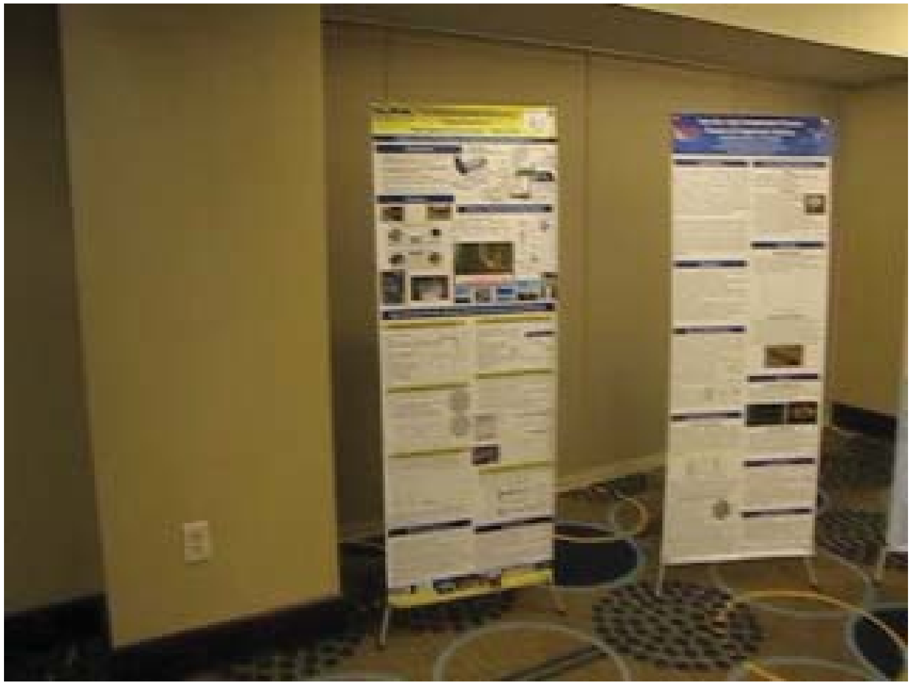
Overview

- Welcome!
  - PIs
  - Students
  - CESTAC
  - Affiliate Members
  - FAA Employees
  - Others!
- Safety & Logistics
- Meals & Network Breaks
- Agenda & Schedule
- Banner Competition

Agenda & Schedule

Time	Day 1	Time	Day 2	Time
9:00 AM	OPENING REMARKS WELCOME (K. Davidian, FAA AST) FAA OPENING KEYNOTE SPEAKER (G. Nield, FAA AST) NASA OPENING SPEAKER (F. Chandler, NASA HQ OCT)	9:00 AM	DAY 2 OPENING REMARKS	9:00 AM
9:15 AM		9:15 AM	3: HUMAN SPACEFLIGHT RESEARCH 184. Comm'l Spacecraft Human Rating (CU-Klaus) 255. Wearable Biomedical Equip (UTMB-Castleberry) 256. Centrifuge Testing (UTMB-Vanderploeg) 294. Minor Injury Severity Scale (UTMB-Castleberry) 295. EMF Effects on Implantable Devices (UTMB-Vanderploeg)	9:15 AM
9:30 AM		9:30 AM		9:30 AM
9:45 AM	PROGRAMMATIC OVERVIEWS - FAA COE Welcome & Overview (P. Watts, FAA COE) - COE CST Status Report (K. Davidian, FAA AST)	9:45 AM		9:45 AM
10:00 AM		10:00 AM		10:00 AM
10:15 AM		10:15 AM		10:15 AM
10:30 AM	Keynote Speaker Congressman Bill Posey	10:30 AM	Networking Break	10:30 AM
10:45 AM	Networking Break	10:45 AM		10:45 AM
11:00 AM	COE CST AFFILIATE AND ASSOCIATE MEMBERS - Overview (K. Davidian), McGill (Y. Nyampong), NASTAR (B. Henwood), ERAU (M. Hickey), DLR (J. Drescher) - Not in attendance: SatWest (B. Barnett), UN Lincoln (M. Schaeffer), NASA ARC (M. Dudley)	11:00 AM	2c: SPACE TRANSPORTATION OPS, TECH & PAYLOADS 244. Autonomous RDV & Docking for Space Debris Mitigation (UF-Fitz-Coy), (FSU-Collins), (SU-Rock), (CU-Axelrad)	11:00 AM
11:15 AM		11:15 AM		11:15 AM
11:30 AM		11:30 AM		11:30 AM
11:45 AM		11:45 AM		11:45 AM
12:00 PM	Lunch Hyatt Regency Capitol Room A, (Lunch Included in your Registration)	12:00 PM	Lunch Hyatt Regency Capitol Room A, (Lunch Included in your Registration)	12:00 PM
12:15 PM		12:15 PM		12:15 PM
12:30 PM	Keynote Speaker: Joseph Rothenberg (Chairman CESTAC/JHR Consulting)	12:30 PM	Keynote Speaker: Dr. T. Dwayne McCay (Executive VP-COO, Florida Institute of Technology)	12:30 PM
12:45 PM		12:45 PM		12:45 PM
1:00 PM	1a: SPACE TRAFFIC MANAGEMENT AND OPERATIONS 186. Space Env MMOD Modeling & Prediction (SU-Close), (CU-Fuller-Rowell)	1:00 PM	4: SPACE TRANSPORTATION INDUSTRY VIABILITY 193. Role of COE CST in EFP (SU-Hubbard), (CU-Born)	1:00 PM
1:15 PM		1:15 PM		1:15 PM
1:30 PM	1b: SPACE TRAFFIC MANAGEMENT AND OPERATIONS 185. Unified 4D Trajectory (SU-Alonso) 258. Multi-disc Analysis of Safety Metrics (SU-Alonso) 247. Air & Space Traffic Considerations for CST (FIT-Villaire)	1:30 PM	Parallel Sessions Allied Organization Presentations and CESTAC Closed Meeting	1:30 PM
1:45 PM		1:45 PM		1:45 PM
2:00 PM		2:00 PM		2:00 PM
2:15 PM	1c: SPACE TRAFFIC MANAGEMENT AND OPERATIONS 257. Master's Launch & On-Orbit Ops Class (Cheetham) 187. Space Situational Awareness (CU-Scheeres) 220. Space Operational Framework (NMSU-Hynes)	2:15 PM		2:15 PM
2:30 PM		2:30 PM		2:30 PM
2:45 PM		2:45 PM		2:45 PM
3:00 PM	Networking Break	3:00 PM	Networking Break	3:00 PM
3:15 PM		3:15 PM		3:15 PM
3:30 PM	2a: SPACE TRANSPORTATION OPS, TECH & PAYLOADS 228. Magneto-Elastic Sensing for SHM (NMT-Zagrai, Ostergren) 253. Ultra High Temp Composites (UCF-Gou, Kapat) 293. Reduced Order Non-Linear Dynamic System Models (NMT-Miller)	3:30 PM	CESTAC OUTBRIEF - Joe Rothenberg (CESTAC) CLOSING KEYNOTE Mike Gold (Bigelow Aerospace/COMSTAC) CLOSING REMARKS - P. Watts (FAA COE), K. Davidian (FAA AST), T. Fiedler (FIT)	3:30 PM
3:45 PM		3:45 PM		3:45 PM
4:00 PM		4:00 PM		4:00 PM
4:15 PM	2b: SPACE TRANSPORTATION OPS, TECH & PAYLOADS 241. High Temp Pressure Transducers (UF-Sheplak), (FSU-Oates) 298. Integration & Evaluation of Payloads (NMSU-Hynes) 299. Nitrous Oxide Composite Tank Testing (NMT-Ostergren, Dr. Robert Abernathy and Dr. Michael Hargather)	4:15 PM		4:15 PM
4:30 PM		4:30 PM		4:30 PM
4:45 PM		4:45 PM	Adjournment	4:45 PM
5:00 PM		5:00 PM		5:00 PM
5:15 PM	Adjournment	5:15 PM		5:15 PM

Banner Competition



National Aeronautics and Space Administration

Strategic Technology Investment Plan And Technology Roadmaps

FAA COE AST Briefing

October 29, 2013

Faith Chandler
Office of the Chief Technologist

Discussion Topics

- Overview – Office of the Chief Technologist
- Strategic Space Technology Investment Plan (SSTIP)
  - Relates to Technology Portfolio
  - SSTIP Development
  - SSTIP Content Overview
  - SSTIP Governance – NASA Technology Executive
- Opportunities
- What's Next?

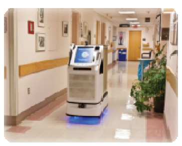
NASA - Building Upon Past Excellence….
Creating the Path For the Future

Office of Chief Technologist

- **Technology Strategic Planning, Policy and Requirements**
  - Develop and implement the NASA technology policies, requirements, roadmaps, and strategic technology investment plan to guide Agency technology and innovation activities.
- **Technology Coordination, Councils and Partnerships**
  - Coordinate technology needs across the NASA Mission Directorates and communicate with other Government agencies and the commercial sector to leverage shared priorities, encourage partnerships, and enable the broad use of NASA-developed technologies.
  - Manage NASA Technology Executive Council (NTEC) and Center Technology Council (CTC) to provide Agency-level decisions that address technology priorities & gaps, anticipate future needs, and avoid duplication of effort.
- **TechPort Development and Operation**
  - Provide the capability to make information about NASA's technology investments openly available and accessible to the Agency and the public.
- **Portfolio Tracking and Analysis**
  - Track NASA's technology investments, comparing the portfolio against the strategic technology investment plan and work with stakeholders to make appropriate adjustments.

Office of Chief Technologist

- OCT provides the strategy, leadership, and coordination that guides NASA's technology transfer and commercialization activities
- Managed by OCT, NASA's **Technology Transfer Program** is focused on extending the benefits of NASA's technology investments to have a direct and measurable impact on daily life and provide the greatest benefit to the Nation



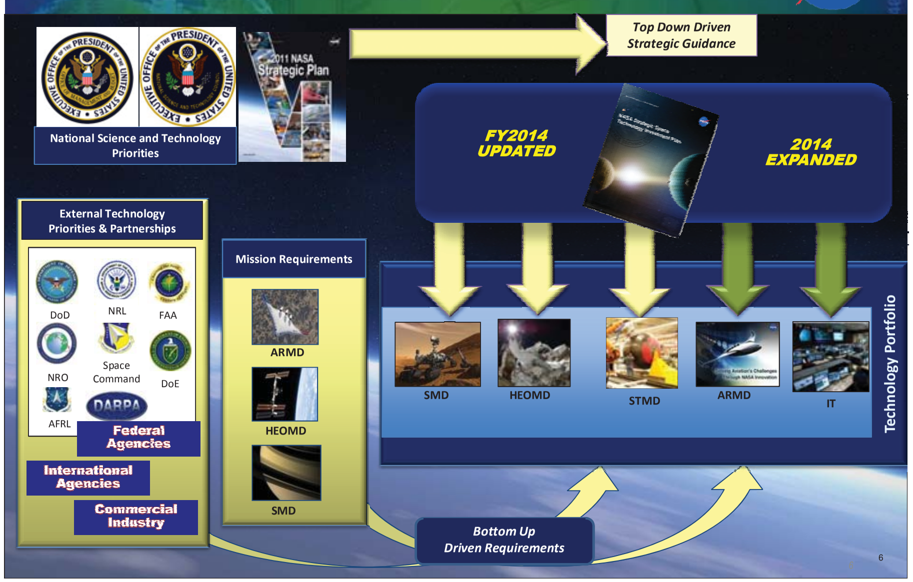
Companies featured in recent issues of NASA's *Spinoff* report have used NASA technology to:

- Create more than 14,000 jobs
- Save more than 444,000 lives
- Generate more than $5 billion in revenue
- Save $6.2 billion in costs

Active NASA-Patents	1034
Active NASA–Funded Patents (Non-Govt owned)	1132
All time Total Patents	8345
Technologies available for Licensing	831
Recorded Spinoffs	1,800+

Challenges Working In Space

NASA's Technology Portfolio



What is Technology?

***NASA Technology Definition**:*
A solution that arises from applying the disciplines of engineering science to synthesize a device, process, or subsystem to enable a specific capability.

Government-Wide OMB Circular No. A-11 **Conduct of R&D****	
6.1 Basic Research:	A study directed toward fuller knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications toward processes or products.
6.2 Applied Research:	Systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met.
6.3 Development:	Is directed toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements.

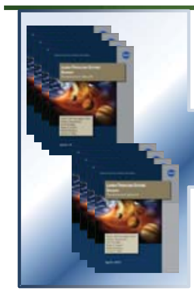
Strategic Space Technology Investment Plan (SSTIP)

Strategic Space Technology Investment Plan (SSTIP)

- NASA is moving forward with prioritized technology investments that will support NASA's exploration and science missions, while benefiting other Government agencies and the U.S. aerospace enterprise.
- The plan provides the guidance for NASA's space technology investments during the next four years, within the context of a 20-year horizon.
- This plan will help ensure that NASA develops technologies that enable its 4 goals to:
  - sustain and extend human activities in space,
  - explore the structure, origin, and evolution of the solar system, and search for life past and present,
  - expand our understanding of the Earth and the universe and have a direct and measurable impact on how we work and live, and
  - energize domestic space enterprise and extend benefits of space for the Nation.

"Sparking the imagination and creativity of our people, unleashing new discoveries—that's what America does better than any other country on Earth. That's what we do. We need you to seek breakthroughs and new technologies that we can't even imagine yet." -President Obama.

Roadmap and SSTIP Development



FY 2010

Space Technology Roadmaps

- *140 challenges (10 per roadmap)*
- *320 technologies*
- *20-year horizon*
- *Revised every 4 years*

FY 2011

National Research Council (NRC) Study

Prioritization:
- *100 top technical challenges*
- *83 high-priority technologies (roadmap-specific)*
- *16 highest of high technologies (looking across all roadmaps)*
- *Requested every 4 years*

FY 2012

SSTIP Development

Updated ST Roadmaps:
- *Incorporate NRC Study Results*

Developing a Strategic Space Technology Investment Plan:
- *current investments*
- *current MD/Office priorities*
- *opportunities for partnership*
- *gaps vs. current budget and capabilities*
- *20-Year horizon with 4-year implementation cadence*
- *Revised every 2 years*

FY 2013

Execution

Investment Portfolio
- *Technology Developments (across full Technology Readiness Level (TRL) spectrum)*
- *Flight Demonstrations*
- *Must accommodate:*
  - *Mission Needs & Commitments*
  - *Push Opportunities*
  - *Affordability*
  - *Technical Progress*
  - *Programmatic Performance*
- *Budgeted annually*

SSTIP Content

Framework
- Goals with capability objectives and technical challenges

4-year Investment Approach
- Three levels of investment
  1. Core
  2. Adjacent
  3. Complementary
- Together these investments:
  - Span the four goals
  - Include pioneering, crosscutting and mission specific technology development
  - Guide future technology expenditures
  - Rapidly produce critical capabilities
  - Seed future innovation

Governance – NASA Technology Executive Council (NTEC)

Principles of Investment and Execution

Core:
- *70% investment*
- *Represent the majority of the NRC's top priority recommendations*
- *Focus on mission specific technologies and 8 critical pioneering and crosscutting areas*
- *Near-term investments necessary to accomplish demanding science and exploration missions*

Adjacent:
- *20% investment*
- *Not part of the Core technologies, but part of NRC's 83 high priorities*
- *Development may take more time*

Complementary:
- *10% investment*
- *Does not include core or adjacent*
- *Does include the remaining technology capabilities in the goals and corresponding Space Technology Roadmaps*
- *Seeds innovation providing some early development in technologies that are not needed immediately*
- *Provide technologies relevant within the 20-year horizon of this strategic plan*

SSTIP found at: http://www.nasa.gov/pdf/726166main_SSTIP_02_06_13_FINAL_hires=TAGGED.pdf

SSTIP Content
Technology Investment Framework

- Four goals of Agency Space Technology Investment
- Each comprises:
  - Strategic investment goal
  - Capability objectives
  - Technical challenges
- Built upon:
  - NASA Space Technology Roadmaps
  - NRC recommendations
  - NASA technology portfolio assessments
  - → Survey of stakeholder needs
  - U.S. National Space Policy

GOAL: EXTEND AND SUSTAIN HUMAN PRESENCE AND ACTIVITIES IN SPACE	GOAL: EXPLORE THE STRUCTURE, ORIGIN, AND EVOLUTION OF THE SOLAR SYSTEM, AND SEARCH FOR LIFE PAST AND PRESENT	GOAL: EXPAND UNDERSTANDING OF THE EARTH AND THE UNIVERSE (REMOTE MEASUREMENTS)	GOAL: ENERGIZE DOMESTIC SPACE ENTERPRISE AND EXTEND BENEFITS OF SPACE FOR THE NATION
CAPABILITY OBJECTIVES	CAPABILITY OBJECTIVES	CAPABILITY OBJECTIVES	CAPABILITY OBJECTIVES
1. Achieve improved spacecraft system reliability and performance 2. Enable transportation to, from, and on planetary bodies 3. Sustain human health and performance 4. Enable payload delivery and human exploration of destinations and planetary bodies	1. Achieve improved spacecraft system reliability and performance 2. Enable transportation to, from, and on planetary bodies 3. Enable advanced in-situ measurement and exploration	1. Achieve improved spacecraft system reliability and performance 2. Enable transportation to space 3. Enable space-based and earth-based observation and analysis 4. Enable large-volume, efficient flight and ground computing and data management	1. Achieve improved spacecraft system reliability and performance 2. Enable transportation to and from space 3. Sustain human health and performance 4. Meet the robotic and autonomous navigation needs of space missions 5. Enable large-volume, efficient flight and ground computing and data management

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SSTIP Content
Core Technology Investments

- Core technologies represent 8 focus areas of technology investment that are indispensable for NASA's present and planned future missions
- Core technologies are the central focus of technology investment and will comprise approximately **70%** of the Agency's technology investment of the next 4 years (★ = highest investments now)

Launch and In-space Propulsion ★

Environmental Control and Life Support Systems

High Data-Rate Communications

Space Radiation

Lightweight Space Structures and Materials

Scientific Instruments and Sensors ★

Robotics and Autonomous Systems ★

Entry, Descent, and Landing ★

13

Evolving Paradigm for Rapid Development of World Class Robots

- Software, Robotics and Simulation Division uses a rapid development model that leverages core technologies
- Typical build cycle lasts 1 year

Potential Uses

- Assisted Walking on Earth
- Strength Augmentation
- Rehabilitation
- On Orbit Countermeasures
- On Orbit Dynamometry
  - Assessing muscle strength in space
- Assisted Walking on the Moon or Mars

The Possibilities are Endless!

SSTIP Content
Adjacent Technology Investments

- Adjacent technologies are a significant focus and will comprise __20%__ of the Agency's technology investment over the next 4 years
- Though not part of the Core, these technologies are still high-priority and integral to supporting the 4 goals of investment

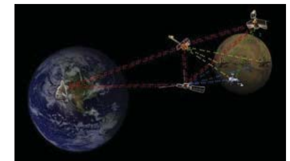
Example Adjacent technologies:

Technology Investment Classification	Associated SSTIP Technical Challenge Area	TABS	Associated NRC High Priorities
Adjacent	Advanced Power Generation, Storage and Transmission; Increased Available Power	3.2	Batteries
Adjacent	Efficient Accurate Navigation, Positioning and Timing	5.4	Timekeeping and Time Distribution
Adjacent	Long Duration Health Effects	6.3	Long Duration Crew Health
Adjacent	Surface Systems	7.4	Smart Habitats; Habitation Evolution
Adjacent	Improved Flight Computers	11.1	Flight Computing; Ground Computing

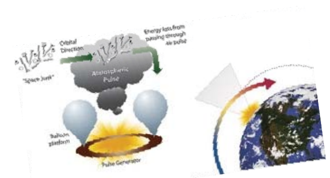
SSTIP Content
Complementary Technology Investments

- Opportunities to invest in future technologies beyond nearer term needs
- Will comprise __10%__ of the Agency's technology investment over the next 4 years

- Examples include:
  - Concepts for mitigating orbital debris
  - Innovative propulsion concepts
  - Ground processing technologies
  - New information technologies



Information Technologies support space exploration
Source: NASA



Space Debris Elimination (SpaDE)
Source: NASA

Antimatter Propulsion
Source: NASA

SSTIP Governance and Decision Making

- **NASA Technology Executive Council (NTEC) is the governing body for the SSTIP**.
- NTEC:
  - Evaluates the content and progress of NASA's space technology programs
  - Evaluates the Agency technology portfolio, balance the portfolio, or concur on a variation from the 70% - 20% - 10% approach
  - Makes recommendations on technology gaps, overlaps, and synergies

The Deep Space Atomic Clock
Source: NASA

Hypersonic Inflatable Aerodynamic Decelerator
Source: NASA

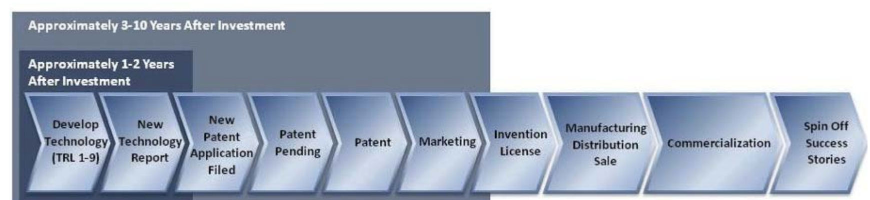
Computer simulations derived from data from years of Hubble observations indicate the Andromeda and Milky Way galaxies will collide in 4 billion years, depicted in this artist's rendering.
Source: NASA

SSTIP
Principles of Investment and Execution

Principles optimize investments, maintain a balanced portfolio, use developed technologies, and provide transparency to the American public

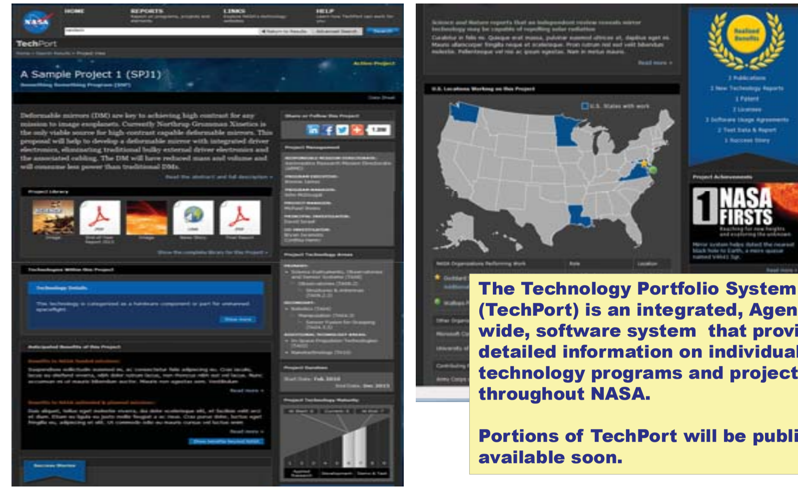
__Principles Guide Future Portfolio Investment and Execution__

- Achieve the agreed upon balance among investments:
  - Across all 14 Space Technology Areas in the Roadmaps
  - Across all levels of technology readiness
- Ensure developed technologies are infused into Agency missions
- Develop technologies through partnerships and ensure developed technologies are infused throughout the domestic enterprise
- Use a systems engineering approach when planning technology investments
- Reach out to the public and share information about its technology investments



Opportunities

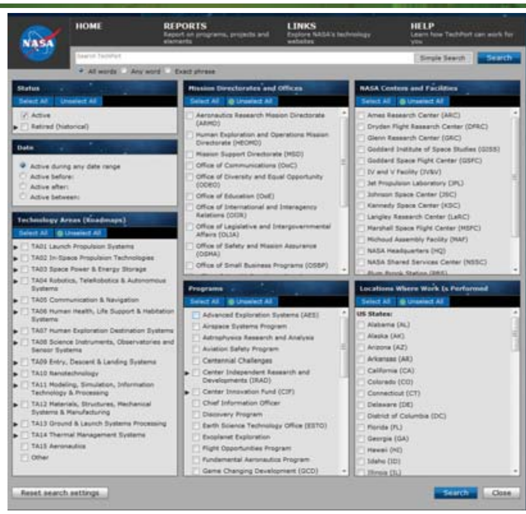
TechPort



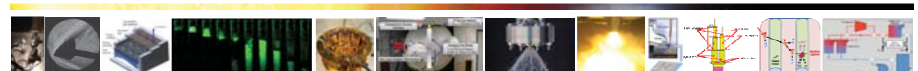
The Technology Portfolio System (TechPort) is an integrated, Agency-wide, software system that provides detailed information on individual technology programs and projects throughout NASA.

Portions of TechPort will be publically available soon.

TechPort



Space Technology Research Grants



- Invest in innovative, groundbreaking, high-risk/high-payoff, low TRL space technology research
- Reinvigorate the pipeline of low TRL technologies and future technological leaders

STRO *Space Technology Research Opportunities*

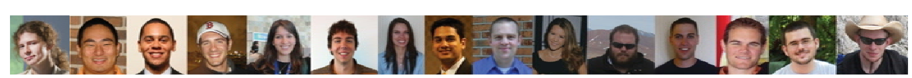
- One or more NRAs expected annually. Awards are typically grants
- Two workhorse solicitations
  - *Early Career Faculty (ECF)* – support for outstanding faculty early in their careers
  - *Early Stage Innovations (ESI)* – university-led efforts, multiple investigators possible
- Annual award value: ~$200 - $250K, awards initially one year with 1 or 2 renewals possible (depending on solicitation)

http://www.nasa.gov/directorates/spacetech/strg/index.html

NSTRF *NASA Space Technology Research Fellowships*

- Competitive selection of U.S. Citizen / permanent resident graduate students
- Annual solicitation consistent with academic calendar; awards are training grants to U.S. universities
- Selected candidates perform graduate student research on their respective campuses and at NASA Centers and not-for-profit R&D labs
- Annual award value: ~$68K, up to four years of support possible

http://www.nasa.gov/directorates/spacetech/strg/archives_nstrf.html



Center Innovation Fund

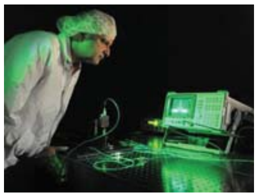
Goal: Stimulate and encourage creativity and innovation from within the NASA Centers.

CIF seed funds support:
- New technologies
- Innovative approaches
- Creative ideas
- Leveraging NASA Center talent and capabilities, as well as external partnerships

These funds allow Centers to support low TRL innovative technology initiatives.

HIGHLIGHTS
- In FY 2012, ~180 projects and studies were executed.
- Several of these were picked up by GCD (Woven TPS), or SBIR/STTR for further development.
- CIF is acting as a successful pipeline to the Space Technology programs focusing on higher TRL development.
- In FY 2013, all CIF selections of projects will be completed by the end of May

__FY 2014:__ Center Chief Technologists will select annual awards in alignment with Strategic Space Technology Investment Plan


GSFC: Atom Interferometry for Detection of Gravity Waves

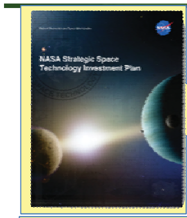
"This project was extremely exciting to be involved with and is just the kind of thing that NASA needs to be doing more of in regards to technology development. It is a good first step to changing the culture of innovation at the center and should definitely be continued."


GSFC: Electrically-controlled extinguishable solid propellant (ESP) thrusters

http://www.nasa.gov/directorates/spacetech/innovation_fund/index.html

What's Next In Technology?

FY2014 Update
Roadmaps and Investment Plan



SSTIP Update

__Will Consider__:
- New Priorities
- Current Investments
- Unmet Needs
- Partnerships & More

__Expanded Scope__:
- ✓ Aeronautics Technology
- ✓ Information Technology
- ✓ Other Technologies as influenced by other roadmap updates

Roadmap Update

__Will Consider__:
- Updates in Science Decadal Surveys
- Human Exploration Capability Work
- Advancements In Technology

__Will Include__:
- Capability Needs
- State-of-Art
- Performance Goals
- Technology Challenges & More

__Expanded Scope__:
- ✓ Aeronautics Technology
- ✓ Information Technology
- ✓ Radiation
- ✓ Space Weather
- ✓ Avionics
- ✓ Orbital Debris

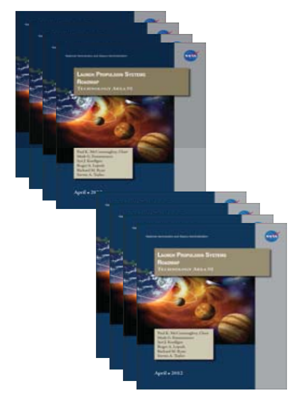
2010 Roadmaps

NASA Teams generated 14 Technical Area Roadmaps That Provided the Foundation for the Space Technology Investment Plan

Excellent products developed by some of NASA's most talented professionals.

__We are not starting over!__

__We are enhancing the existing roadmaps__ to be responsive to:
- Changing needs and priorities
- Advances in technology development
- Needed improvements that will increase the utility and ease of use by NASA and our external stakeholders.



Space Technology Roadmap
14 Technical Areas + Additional Areas

- TA01 • LAUNCH PROPULSION SYSTEMS
- TA02 • IN-SPACE PROPULSION TECHNOLOGIES
- TA03 • SPACE POWER & ENERGY STORAGE
- TA04 • ROBOTICS, TELE-ROBOTICS & AUTONOMOUS SYSTEMS
- TA05 • COMMUNICATION & NAVIGATION
- TA06 • HUMAN HEALTH, LIFE SUPPORT & HABITATION SYSTEMS
- TA07 • HUMAN EXPLORATION DESTINATION SYSTEMS
- TA08 • SCIENCE INSTRUMENTS, OBSERVATORIES & SENSOR SYSTEMS
- TA09 • ENTRY, DESCENT & LANDING SYSTEMS
- TA10 • NANOTECHNOLOGY
- TA11 • MODELING, SIMULATION, INFORMATION TECHNOLOGY & PROCESSING
- TA12 • MATERIALS, STRUCTURES, MECHANICAL SYSTEMS & MANUFACTURING
- TA13 • GROUND & LAUNCH SYSTEMS PROCESSING
- TA14 • THERMAL MANAGEMENT SYSTEMS
- TA15 AERONAUTICS

Autonomous Systems & AI Enhancements

Avionics Tech Enhancements

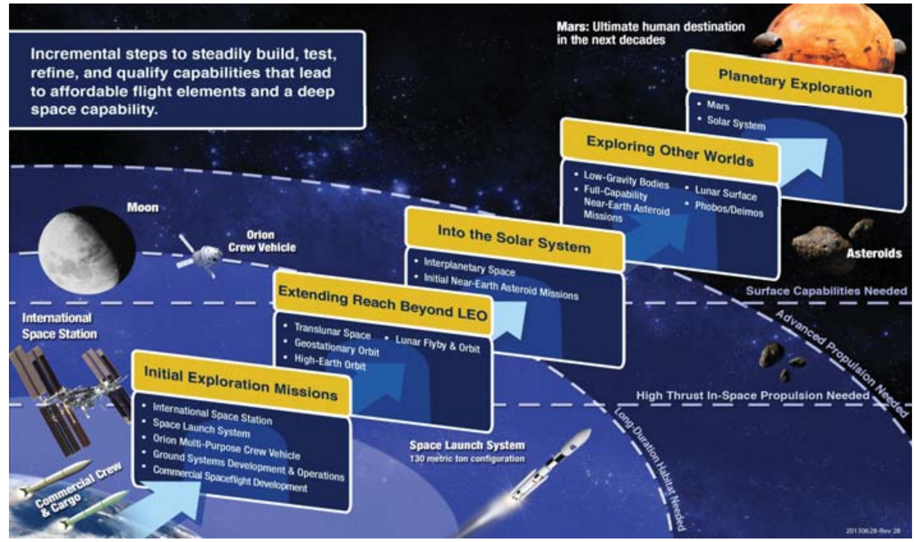
Radiation Tech Enhancements

Information Technology Section Expanded

Include NITRD and more

Space Weather Tech

Capability Driven Framework



Technology Investment Plan Update

New Data Collection	Gap Analysis	Criteria Setting	Ranking	Decision Making	Reviews
Collect Information: *NASA's Current Investments *National Priorities *NASA MD/Office Needs/Priorities *Other Government Partnership Priorities *Commercial Sector Partnership Priorities *International Partnership Priorities	Identify Unmet Capability Needs Compare funded investments with: * US Space Policy *National Priorities * NASA's Strategic Plan * NASA's Needs * MD/Office Priorities	Establish Criteria Consider the following: *All Priorities *Crosscutting Needs *NRC Recommendations *Potential Partnerships *Benefits *Capabilities & Facilities	Use Criteria to Rank Evaluate All Current Investments Technologies That Address Unmet Capability Needs	Establish Strategy for Core, Adjacent and Complementary: *Specific Goals *Top Capability Objectives * Technology Challenges * Investment Approach NTEC Approval	MD/Center Review NAC Review LRM Review A-Suite Review Final Report

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SSTIP - Impact to NASA's Future

Impact to achieving NASA's goals

- The SSTIP provides guidance on NASA's space technology investments
- Using TechPort and other tools, NASA conducts comprehensive data analysis enables understanding of the current technology portfolio
- NTEC uses SSTIP to make integrated Agency-level decisions
- NASA Implements actions that strengthen NASA's position for the future:
  - Optimizes technology investments to maximize technological breakthroughs:
    - Provides depth in key focus areas (core) - launch concepts, in-space propulsion, life seeking missions
    - Ensures breadth across far-term technology areas (adjacent and complementary)
    - **Increases strategic cooperation with other government agencies**
    - Builds stronger ties across industry (consider their priorities & develop crosscutting capabilities)

> *"Scientists discover the world that exists; Engineers create the world that never was."*
>
> *Theodore von Karman*

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National Aeronautics and Space Administration

Back Up

Office of the Chief Technologist

Asteroid Strategy

To protect our planet, advance exploration capabilities and technologies for human space flight, and learn how to best utilize space resources, the FY14 budget aligns relevant portions of NASA's science, space technology, and human exploration capabilities to cost-effectively meet the President's challenge to send astronauts to an asteroid by 2025 and to Mars in the 2030s.

The FY14 budget aligns relevant portions of NASA's science, space technology, and human exploration capabilities to plan for the mission.

NASA will build on a rich history of engaging citizen scientists, researchers and individual innovators in this quest.

Asteroid Mission Would Consist of Three Main Segments

Identify

Asteroid Identification Segment:

Ground and space based NEA target detection, characterization and selection

Redirect

Asteroid Redirection Segment:

Solar electric propulsion (SEP) based asteroid capture and maneuver to trans-lunar space

Explore

Asteroid Crewed Exploration Segment:

Orion and SLS based crewed rendezvous and sampling mission to the relocated asteroid

Goal 1: Extend and Sustain Human Presence and Activities in Space

Autonomous systems such as satellite servicing will advance technologies to achieve improved spacecraft system reliability and performance.

Transportation to planetary bodies will be enabled through entry, descent, and landing (EDL) technologies, such as low density supersonic decelerators.

Every human space mission requires a thorough radiation mitigation plan, using a wide variety of technologies and systems.

GOAL: EXTEND AND SUSTAIN HUMAN PRESENCE AND ACTIVITIES IN SPACE

CAPABILITY OBJECTIVES

1. Achieve improved spacecraft system reliability and performance
2. Enable transportation to, from, and on planetary bodies
3. Sustain human health and performance
4. Enable payload delivery and human exploration of destinations and planetary bodies

Goal 2: Explore the Structure, Origin, and Evolution of the Solar System, and Search for Life Past and Present

Exploring the solar system will require high-bandwidth communications to improve spacecraft performance. The Mars Science Laboratory will use high-bandwidth communication technologies as it searches for life past and present.

Deep space atomic clock technologies are necessary for efficient and accurate navigation and enable transportation to and from planetary bodies.

Autonomous robotic technologies allow for maneuvering and manipulation of samples on planetary surfaces, enabling in-situ measurement and exploration.

GOAL: EXPLORE THE STRUCTURE, ORIGIN, AND EVOLUTION OF THE SOLAR SYSTEM, AND SEARCH FOR LIFE PAST AND PRESENT

CAPABILITY OBJECTIVES

1. Achieve improved spacecraft system reliability and performance
2. Enable transportation to, from, and on planetary bodies
3. Enable advanced in-situ measurement and exploration

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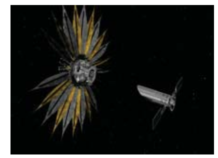
Goal 3: Expand Understanding of the Earth and the Universe (Remote Measurements)

Technologies such as those being advanced for solar electric in-space propulsion will help enable space transportation.



New techniques for using scientific instruments and sensors, like telescopes with a starshade, will enable future space-based observations.

Efficient computing and data management will be enabled by technologies for improving flight computers, such as low-power flight computers for cubesats.

GOAL: EXPAND UNDERSTANDING OF THE EARTH AND THE UNIVERSE (REMOTE MEASUREMENTS)

CAPABILITY OBJECTIVES

1. Achieve improved spacecraft system reliability and performance
2. Enable transportation to space
3. Enable space-based and earth-based observation and analysis
4. Enable large-volume, efficient flight and ground computing and data management

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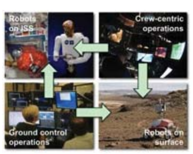
Goal 4: Energize Domestic Space Enterprise and Extend Benefits of Space for the Nation

Technologies for hazard detection and avoidance enable descent and landing on Earth and other planetary bodies.



Advancements in robotic and autonomous technologies will support future on-orbit assembly activities

Autonomous mission operations require high data rates. Technologies to improve computing will extend benefits to domestic space enterprises.

GOAL: ENERGIZE DOMESTIC SPACE ENTERPRISE AND EXTEND BENEFITS OF SPACE FOR THE NATION

CAPABILITY OBJECTIVES

1. Achieve improved spacecraft system reliability and performance
2. Enable transportation to and from space
3. Sustain human health and performance
4. Meet the robotic and autonomous navigation needs of space missions
5. Enable large-volume, efficient flight and ground computing and data management

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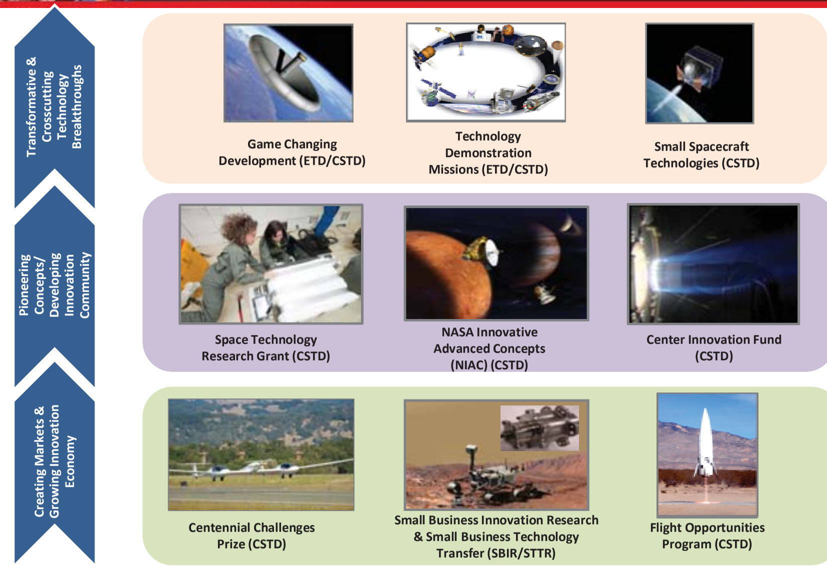
Space Technology Portfolio



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Roadmap Development
Comparison Architecture to Capability Driven

Content Development

2010 Roadmap Development Process

1. Design Reference Missions
2. Architectures
3. Mission Directorate Priorities
4. 14 Technical Areas
5. Technical Challenges
6. Potential Technologies / Paths (Roadmaps)

2014 Roadmap Development Process — Mission Directorates - Decadals

1. Mission Class (Aero Thrust Area) ☆
2. Design Reference Missions (Type)
3. Capability
4. Function
5. Parameter
6. Performance Goal ☆
7. State of Art (SOA) ☆
8. Performance Gap ☆
9. Technical Challenges
10. Potential Technologies/ Paths (Roadmaps)

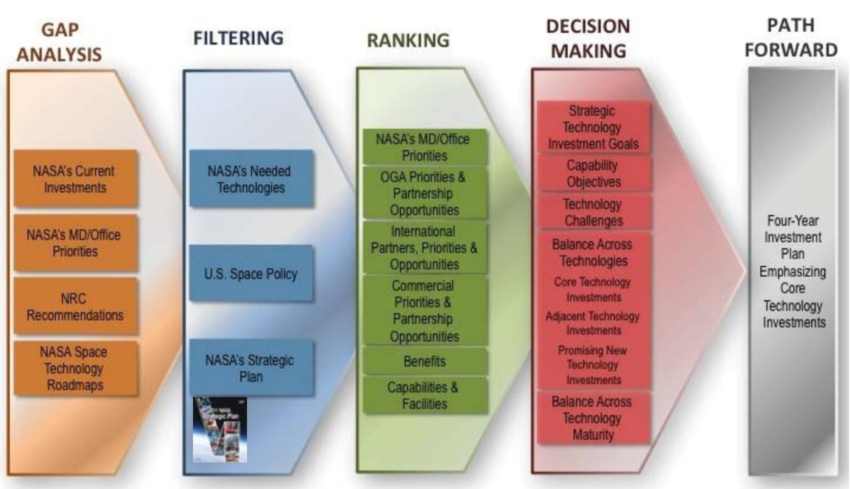
☆ = New Content For Some or All of TAs

Capability Driven Helps Align Priorities

Mission Directorates - Decadals / 2014 Roadmap Development Process / Technology Roadmap & Prioritization

1	Mission Class	Extending Reach Beyond LEO
2	Design Reference Missions (Type)	Crewed Mission to Surface
3	Capability	Entry, Descent and Landing
4	Function	Perform Entry
5	Parameter	Entry Location and Velocity
6	Performance Goal	Earth; 10.99 km/s; Mars, 14 km/s
7	State of Art (SOA)	
8	Performance Gap	
9	Technical Challenges	
10	Potential Technologies/ Paths (Roadmaps)	
11	Current Investments	
12	Unmet Needs (Investment Gap)	
13	Stakeholder Priorities / Possible Partnerships	
14	NASA Priorities	

Change From
2012 SSTIP Development Process



Science Decadal Surveys

- NASA relies on the science community to identify and prioritize leading-edge scientific questions and the observations required to answer them. One principal means by which NASA's Science Mission Directorate engages the science community in this task is through the National Research Council (NRC).

2013 – Visions and Voyages for Planetary Science*

2012 – Solar and Space Physics: A Science for a Technological Society*

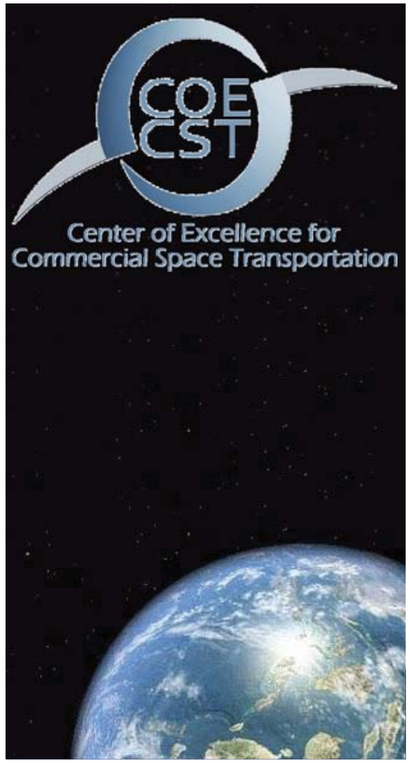
2010 – New Worlds, New Horizons in Astronomy and Astrophysics*

2007 – Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond

* **3 of the Decadal surveys are new and can influence the Technology Roadmap updates**

COE CST Third Annual Technical Meeting: COE CST Overview & Status

Ken Davidian
COE CST ATM3 in Washington, DC
Tuesday, October 29, 2013



Agenda

- Overview
- Team Members
- Organizational Highlights
- Funding Status
- Summary - Metrics At-A-Glance

Center of Excellence for Commercial Space Transportation

Created by the Omnibus Budget Reconciliation Act of 1990, Public Law 101-508, Title IX, Aviation Safety and Capacity Expansion Act.

- **What**: A 10-year partnership of academia, industry, and government to create a world-class consortium.
  - August 2010 - August 2020
- **3 Goals**: Research, Training, Outreach/STEM
- **Purpose**: **Improve National Competitiveness…**
  … through the development of advanced, specialized *human, physical, and knowledge resources* to address commercial space industry challenges.
- **Origins**: Openly-competed and selected by the FAA Administrator.
- **Matching Requirement:** 1:1 for All USG Funds

COE CST Research Areas & Tasks

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

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

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

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

COE CST “Team” Members

- Principal Investigators
- Students
- University Support Personnel
- Industry/CESTAC Members*
- Affiliate Members (Universities, Industry)
- Associate Members (Fed and State Gov’t Orgs)
- FAA AST Technical Monitors
- FAA Management (COE, Tech Ctr, AST)

Organizational Highlights

- **Previous Affiliate Member**: McGill University
- **New Affiliate, Associate Members!**
  - Affiliate Members: BCM, ERAU, NASTAR, Satwest, UN Lincoln
  - Associate Members: DLR, NASA ARC*
- **Third Annual Administrative Meeting (AAM3)** at FAA Tech Center on June 11-13, 2013
- **Transition of Administration Duties** to the Coordinating Committee Lead (FL TECH)

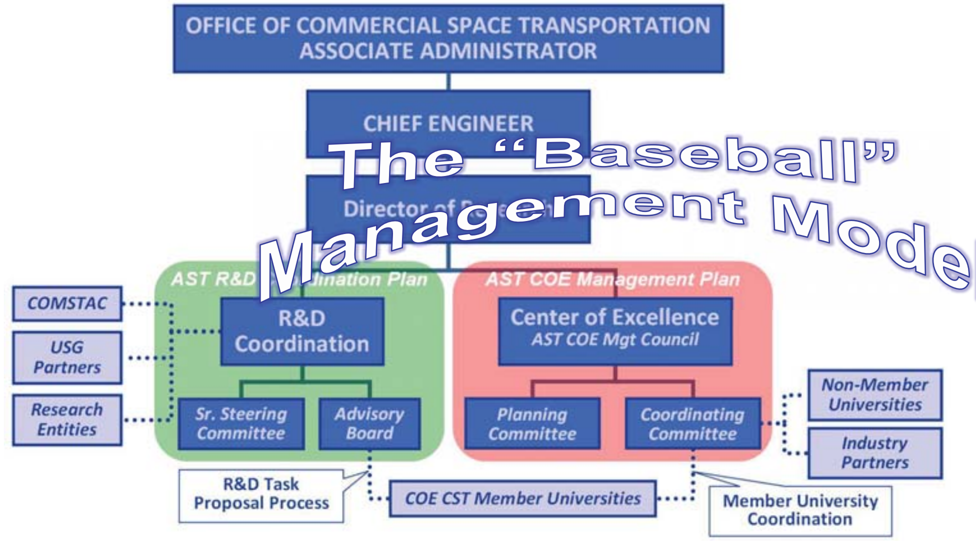
FAA Center of Excellence for Commercial Space Transportation

COE CST @ NSRC

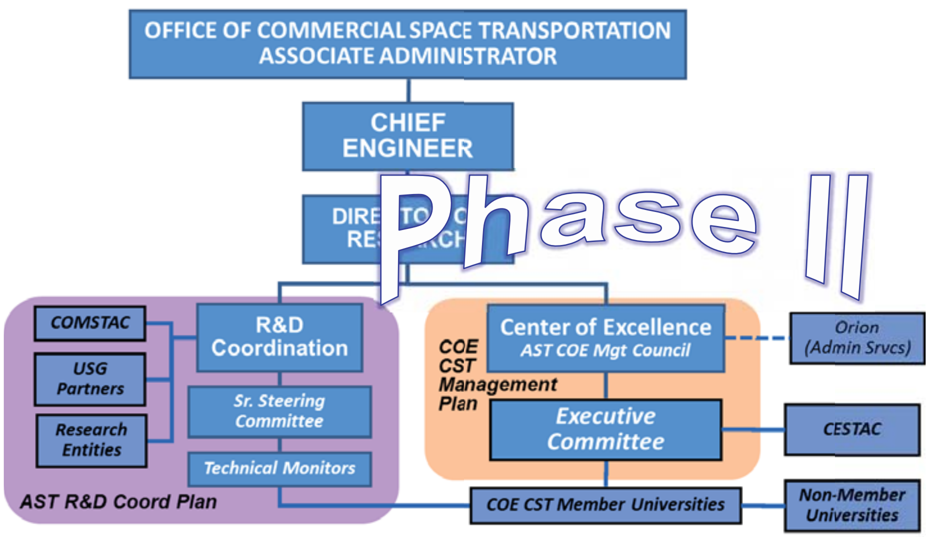
COE CST Milestones Since ATM2

- June 11-13, AAM3, Egg Harbor Twp, NJ (not far from the FAA Tech Center)

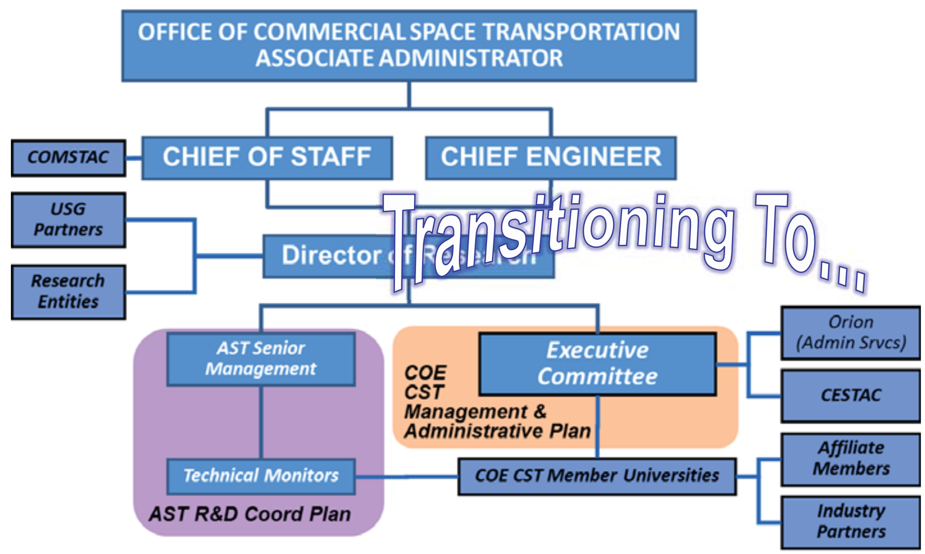
COE CST Org Chart - Year 1



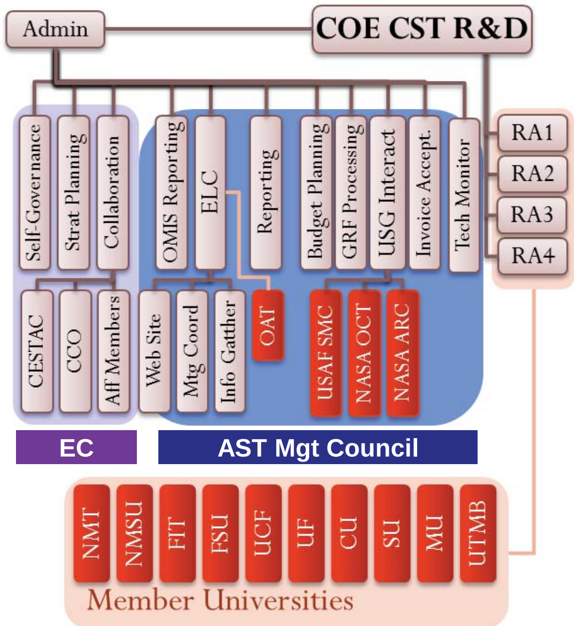
COE CST Org Chart - Year 2



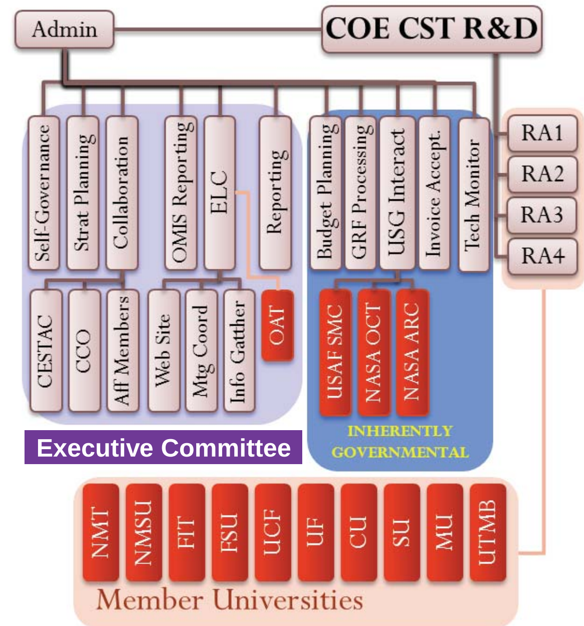
COE CST Org Chart - Year 3



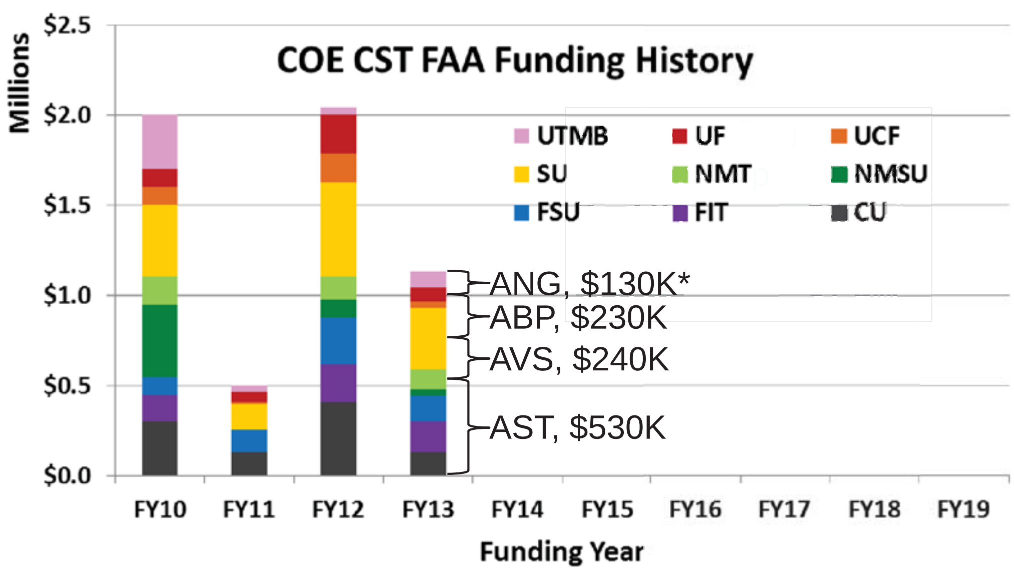
Year 2 COE CST Admin. Functional Diagram (with Orgs)



Year 3 COE CST Admin. Functional Diagram (with Orgs)



COE CST Funding Story, FY10-13



COE CST Metrics At-A-Glance

	Year 1	Year 2	Year 3
# Tasks	25	33	26
# PIs	27	24	24
# Students	31	~29	~29
# Reports	0	~9	TBD
# Affil/Assoc Members	0/0	1/0	6/1*
Funding	$2M (FY10)	$0.5M (FY11) $1.9M (FY12)	$1.13M (FY13)

Conclusions - First the Bad News…

- Funding Situation Unchanged
  - Unstable, Last Minute Allocations Leads to Loss of Students, Stress on System/People
  - Funding Goal: Sustained, Adequate Levels

… Now the Good News!

- Funding Situation Unchanged
  - Unstable, Last Minute Allocations Leads to Loss of Students, Stress on System/People
  - Funding Goal: Sustained, Adequate Levels
- R&D Activities and Results In Full Stride.
- Affiliate/Associate Membership Growing.
- Administrative Management In Transition from FAA Control to Center Control.

COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013
Center of Excellence for Commercial Space Transportation

FAA Air Transportation Centers of Excellence

FAA COE Overview

Government/Academic/Industry Strategic Partnerships

COE – Commercial Space Transportation
ATM3

Presented by:
Patricia Watts
FAA Centers of Excellence

October 29, 2013

COE Program Overview

- ❑ Legislation
- ❑ Funding Combinations
- ❑ COE Benefits
- ❑ FAA COEs
- ❑ University Members and Co-Sponsors
- ❑ Role of Gov't and other Sponsors
- ❑ Oversight & Streamlined Administration
- ❑ Oversight Teams & Control

Legislation

Omnibus Budget Reconciliation Act of 1990
<u>Public Law 101-508</u>

Title IX – Aviation Safety and Capacity Expansion Act

"The Administrator may make grants to one or more colleges or universities to establish and operate several regional centers of air transportation excellence, whose locations shall be geographically equitable. The responsibilities of each regional center shall include, but not be limited to, the conduct of research concerning airspace and airport planning and design, the air transportation environment, aviation safety and security, the supply of trained air transportation personnel including pilots and mechanics, and other aviation issues pertinent to developing and maintaining a safe and efficient air transportation system.…each center may make contracts with nonprofit research organizations and other appropriate persons.…"

Legislation (Selection Criteria)

"(d) ***Selection Criteria:*** *The Administrator shall select recipients of grants under this section on the basis of the following criteria:*

(1) ***the extent to which the needs of the State in which the applicant is located are representative of the needs of the region*** *for improved air transportation services and facilities.*

(2) ***the demonstrated research and extension resources*** *available to the applicant to carry out this section.*

(3) ***the ability of the applicant to provide leadership in making national and regional contributions*** *to the solution of both long-range and immediate air transportation problems.*

(4) ***the extent to which the applicant has an established air transportation program.***

(5) ***the demonstrated ability of the applicant to disseminate results of air transportation research and educational programs through a statewide or regionwide continuing education*** *program.*

(6) ***the projects*** *the applicant proposes to carry out under the grant."*

Legislation (Geographic Equity)

Airliner Cabin Environment-Intermodal Research
Auburn Un.- Admin Lead
Kansas State Un.
Harvard Un.
Purdue Un.
Boise State Un.
Un. of Med & Dentistry of NJ

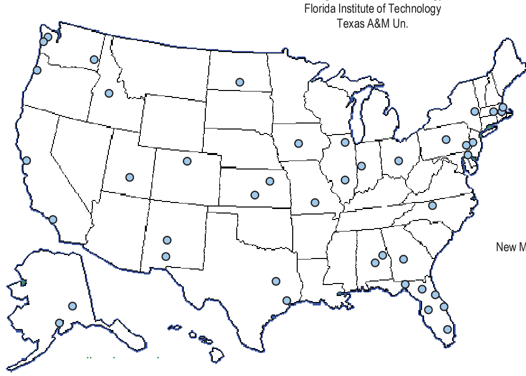
Noise and Emissions Mitigation
MIT (Lead)
Boston Un.
Georgia Tech
Harvard Un.
Penn State
Purdue Un.
Stanford
Un. of Illinois
Un. of Missouri-Rolla
Un. of Pennsylvania
Un. of North Carolina - Chapel Hill

General Aviation
Embry Riddle Aeronautical Un. (Lead)
Un. of Alaska
Un. of North Dakota
Wichita State

General Aviation - 2012
Purdue Un. (Lead)
The Ohio State Un.
Iowa State Un.
Georgia Institute of Technology
Florida Institute of Technology
Texas A&M Un.

Advanced Materials
Un. of Washington (Co-Lead)
Wichita State Un. (Co-Lead)
Edmonds Community College
Florida Internal Un.
Northwestern Un.
Purdue Un.
Oregon State Un.
Tuskegee Un.
Un. of California at LA
Un. of Delaware
Un. of Utah
Washington State Un.

Commercial Space Transportation
New Mexico State Un.
Stanford Un.
Florida Institute of Technology
New Mexico Inst. of Mining & Technology
Florida State Un.
Un. of Florida
Un. of Central Florida
Un. of Colorado at Boulder
Un. of Texas Medical Branch

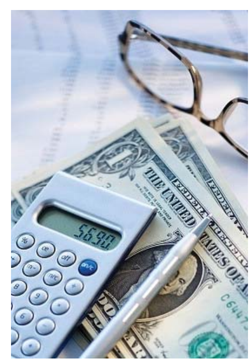


Operations Research (1996-Present)
UC-B, MIT, UMD, VPI, Geo. Mason

Airworthiness Assurance (1997-2007)
31 Equal University Partners

Airport Technology (1995-2013)
Un. of Illinois, RPI

Funding Combinations



- **COE Grants** for Public Purpose - require matching funds to establish, operate and conduct research. **Mandated by Congress** (PL. 101-508).
- **Cost-share Contracts** for FAA Purpose - awarded following competitive establishment. Authorized by the **White House Reinvention Lab**
- Centers receive funding from any public or private source.
- **Each core university receives direct grant awards from FAA.**
- As set forth in PL. 101-508: *Centers **may contract with others** as appropriate*

Center of Excellence Benefits

- **Promote** academic, government & industry scientific networks prepared to enhance the safety, security & efficiency of the national airspace system
- **Augment** government resources ($:$) and leverage funds through flexible and responsive public/private partnerships
- **Expand** the U.S. math & science pipeline, support STEM goals, and facilitate aerospace recruitment opportunities
- **Provide** a formal strategy & trusted structure to coordinate a national research agenda and related education, and training
- **Advance** U.S. technology and expertise while satisfying Congressional mandate

The nation must immediately reverse the decline in and promote the growth of a scientifically and technologically trained U.S. aerospace workforce.

Final Report of the Commission on the Future of the United States Aerospace Industry

FAA COEs (Historical Overview)

Year	Center of Excellence (Topic Areas)	Sponsor	LOE
2013 – 2023	Alternative Jet Fuels & Environment	AEE / HQ	$
2012 – 2022	General Aviation - 2012 (PEGASAS) (*)	ANG / TC	$ 1 M
2010 – 2015	Commercial Space Transportation (CST)	AST / HQ	$ 10 M
2004 – present	Research in the Intermodal Transport Environment (ACER/RITE)	AAM / HQ	$ 45 M
2004 – 2015	Joint COE Advanced Materials (JAMS)	ANG / TC	$ 47 M
2003 – 2014	Aircraft Noise and Emissions Mitigation (PARTNER) *	AEE / HQ	$ 100 M
2001 – 2014	General Aviation (CGAR) *	ANG / TC	$ 39 M
1997 – 2007	Airworthiness Assurance (AACE) *	AAR/ANG / TC	$ 135 M
1996 – (2007)	Operations Research (NEXTOR – National Resource) *	ARA / HQ	$ 47 M
1995 – 2013	Airport Technology (CEAT – National Resource)	AAR/AIP / TC	$ 42 M
1992 - 1996	Computational Modeling of Aircraft Structures	AAR / TC	$ 10 M
	*NOTE: Includes Grants & Matching Contributions; Interagency Agreements, and * Contracts*		~ $ 485 M

University Members and Co-Sponsors (1 of 3)

Andrew Leonard, UND
COE for General Aviation

2010 DOT FAA COE
Student of the Year

John Porcari
Deputy Sec. of Transportation
Chelsea He, MIT
COE for Noise & Emissions

2011 DOT FAA COE
Student of the Year

Auburn University
Boise State University
Boston University
Edmonds Community College
Embry-Riddle Aeronautical University
Florida Institute of Technology
Florida International University
Florida State University
Georgia Institute of Technology
Harvard University
Iowa State University
Kansas State University
Massachusetts Institute of Technology
New Mexico Inst. of Mining & Tech
New Mexico State University
Northwestern University
Ohio State University
Oregon State University
Pennsylvania State University
Purdue University
Rensselaer Polytechnic Institute
Stanford University
Texas A&M

University Members and Co-Sponsors (2 of 3)

Phillip Donovan, UIUC
COE for Airport Technology

2009 DOT FAA COE
Student of the Year

Gregory D. Winfree
Deputy Administrator, RITA
Bradley Cheetham, Un. of Colorado at Boulder
COE for Commercial Space Transportation
2012 DOT FAA COE
Student of the Year

The Ohio State University
Tuskegee University
University of Alaska at Anchorage
University of Alaska at Fairbanks
University of California at Los Angeles
University of Central Florida
University of Colorado at Boulder
University of Dayton
University of Delaware
University of Florida
University of Hawaii
University of Illinois at Urbana Champaign
Un. of Medicine & Dentistry of NJ
University of Missouri at Rolla
University of North Dakota
University of Oregon
University of North Carolina at Chapel Hill
University of Pennsylvania
University of Texas Medical Branch
University of Tennessee
University of Utah
University of Washington
Washington State University
Wichita State University

University Members and Co-Sponsors (3 of 3)

Advanced Transportation R&E Laboratory (ATREL)
Aero Shell
AeroClave
Aerodyne Research Inc.
Air Force Research Laboratory
Air Tran Airways
Air Transport Association of America (ATA)
Airborne Express
Airbus Industries
Aircraft Owners & Pilots Association (AOPA)
Airline Pilots Association (APA)
Airports Council International – North America
Alaska Airmen's Association
Alaska Airways
Alaska Science and Technology
Alcoa Technical Center
AlliedSignal
Allison Engine Company
Aloha Airlines
American Airlines
American Eagle Airlines, Inc.
American Institute of Aeronautics and Astronautics (AIAA)
ARINC Dayton
Battelle

Bell Helicopter TEXTRON
BF Goodrich R&D Center
Boeing Company
Bombardier Aerospace-Learjet
Brookhaven National Lab
California DOT
Cape Air
Cessna Aircraft
Chicago O'Hare International Airport
Cirrus Aviation
Comair, Inc.
Continental Airlines
Delta Airlines
Donaldson Company, Inc.
Draper Laboratory
Elite Air Center
Executive Jet Aviation
Experimental Aircraft Assoc. (EAA)
FedEx Corporation
General Electric Company
General Aviation Mfg. Assn. (GAMA)
Goodrich
Gulfstream Aerospace Corporation
Harris Corporation
Honeywell
Illinois Department of Aeronautics

Indiana Department of Transportation
International Centre for Indoor Environment & Energy, Technical University of Denmark
JENTEK Sensors, Inc.
Livermore Software Technology Corp.
Lockheed Martin Aeronautics Co.
Los Angeles World Airports
Lufthansa
Maryland Aviation Administration
Massachusetts Port Authority
McDonnell Douglas Aerospace
Metron Aviation, Inc.
Metropolitan Washington Airport Authority
NASA
National Business Aviation Assn. (NBAA)
NMS Bio-Defense
Northrop Grumman Corporation
Northwest Airlines
Northwest Composites
O'Hare Modernization Program (OMP)
O'Hare Noise Compatibility Commission
Ohio Department of Development
Ohio Department of Transportation
Pratt & Whitney

Professional Flight Attendants Association
Raytheon Aircraft Company
Regional Airport Authority of Louisville and Jefferson County
Rockwell International
Rolls Royce
SAE International
San Francisco Inter.
Airport/Community Roundtable
Sandia National Laboratories
Seagull Technology
Sikorsky Aircraft
Southern Air Transport
Southern California Association of Governments
Southwest Research Institute
Spitfire Aviation Partners
SRI International
Illinois Dept. of Transportation
STERIS Corporation
Sun Microsystems
Transport Canada
United Airlines
United Parcel Service
US Airways
US DOT Volpe National Trans. Systems Center
US EPA
Virginia Department of Transportation
Wyle Laboratories

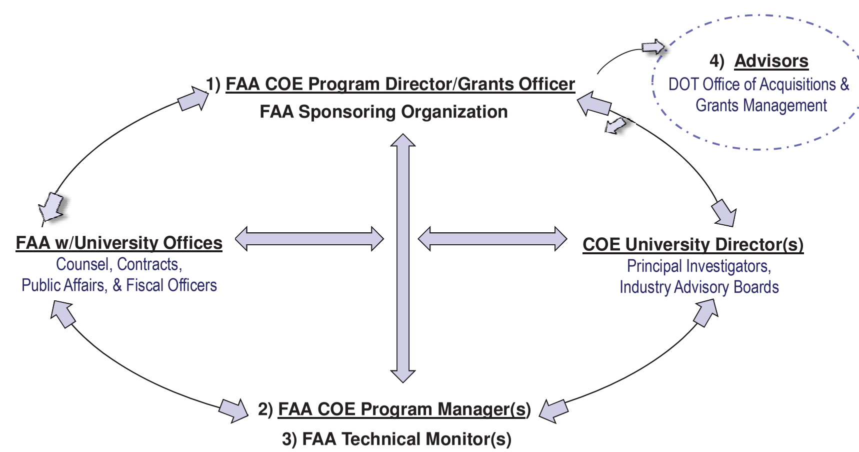
Role of Gov't and Sponsors

- **Federal Government:**
  Commits funds for research, education, tech transfer and related activities **over a period of 5 - 10 years**.
- **Universities, Other Public and Private Entities:**
  – Serve on COE Advisory Boards and related committees
  – **Provide matching contributions** in accordance with OMB guidance, cash or in-kind such as:
    - **Labor**
    - **Materials**
    - **Lab space**
    - **Host meetings**
    - **etc.**

Oversight & Streamlined Administration

- The FAA sponsoring organization assigns a COE Program Manager to each Center. **The funding source assigns a Task Monitor to each task.**
- **The Gov't funds COE projects on an on-going basis** following proposal submission and technical evaluations conducted by the funding organization.
- **Following competitive process/AOA selection, projects are funded:**
  - For public purpose – via grants, or
  - For FAA purpose to obtain deliverables – via IDIQ contract.
- **Members meet quarterly during first year, semi-annually thereafter.** Universities and industry affiliates host meetings to enhance partnership opportunities and seek matching contributions.
- **FAA reassesses COE management, projects, and progress within each Phase; requests official audit of matching funds.**

Oversight Teams & Control



Discussion and Questions

FAA Air Transportation Centers of Excellence

Contact: Patricia Watts, Ph.D.
FAA Centers of Excellence
National Program Director
FAA William J. Hughes Technical Center, ANG-A12
Atlantic City International Airport, NJ 08405
Phone: (609) 485-5043
Email: patricia.watts@faa.gov
Website: http://www.faa.gov/go/coe

FAA AIR TRANSPORTATION CENTERS OF EXCELLENCE
Government • Academia • Industry Partnerships

ERAU Overview

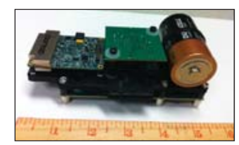
- World's oldest and largest Aerospace/Aviation focused university
  - Recently established BS in Commercial Space Operations
- Applied for Affiliate Status of the COE CST under NMSU as host
- Some potential research areas:
  - ADS-B for CST applications (previous AST funding)
  - Rocket Plume Analysis related to Electrical Fields and Triggered Lightening Strikes (previous AST funding)
  - NextGen integration / coordination
  - Human factors issues (from situational displays to space suit design)

ERAU ADS-B Prototype for Suborbital Reusable Launch Vehicles

- **PROJECT AT-A-GLANCE**
- AST POC: Nick Demidovich
- UNIVERSITY: Embry-Riddle Aeronautical University
- PRINCIPAL INVESTIGATOR: Dr. Richard S. Stansbury
- STUDENT RESEARCHER: Dominic Tournour

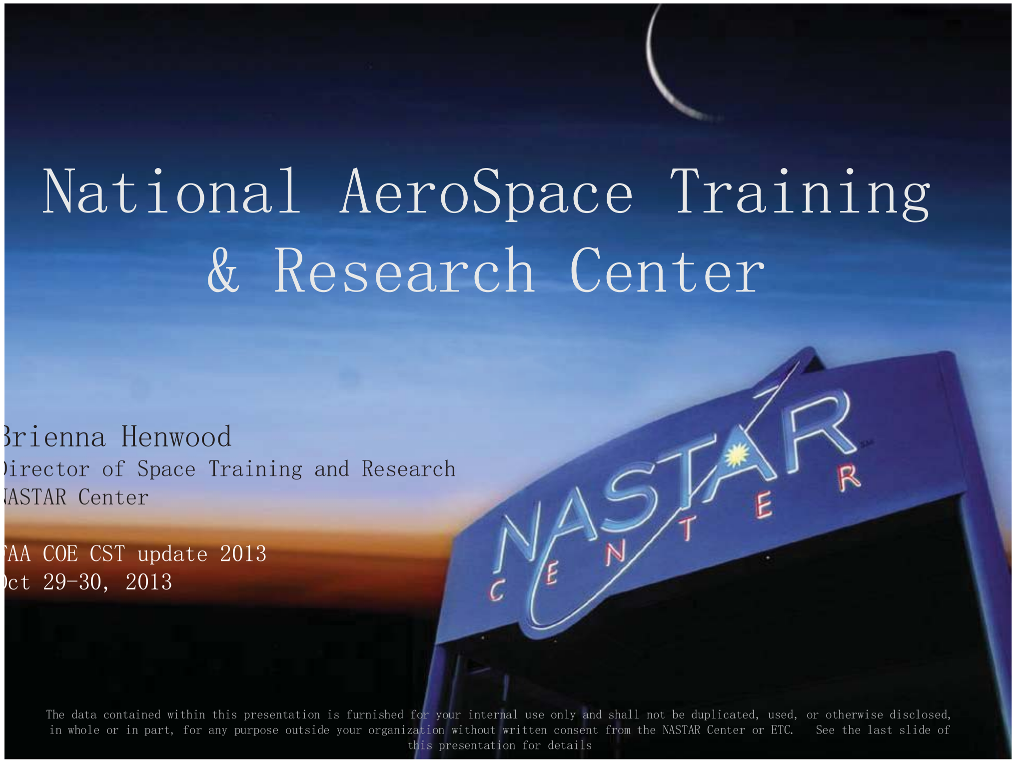
RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- ADS-B technology provides a means of tracking suborbital reusable launch vehicles both during the ascent and descent providing details including: position, altitude (geodetic and pressure), and velocity. It reduces the footprint of airspace sanitization required for commercial space operations.

STATEMENT OF WORK
- Develop a prototype ADS-B receiver based upon the MITRE UBR-TX capable of supporting space velocities, accelerations, and altitudes (COMPLETED)
- Verification and demonstration of prototype onboard high altitude balloon (COMPLETED)
- Verification, validation, and demonstration of prototype onboard sounding rocket to reach TRL 7 or higher (INPROGRESS).



STATUS
- Prototype design completed
- Demonstration on two Near Space Corporation Nano Balloon System Flights (59kft and near 100kft), February 2013
- Demonstration on Near Space Corporation High Altitude Shuttle System (105kft), July 2013

FUTURE WORK
- Demonstration onboard Up Aerospace SpaceLoft-8 and SpaceLoft-9
- Develop research plan to expand capabilities of ADS-B for CST including refining UAT and 1090ES message set to accommodate space altitudes and velocities


National AeroSpace Training
& Research Center
Brienna Henwood
Director of Space Training and Research
NASTAR Center
FAA COE CST update 2013
Oct 29-30, 2013
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NASTAR CENTER
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Students | Teachers


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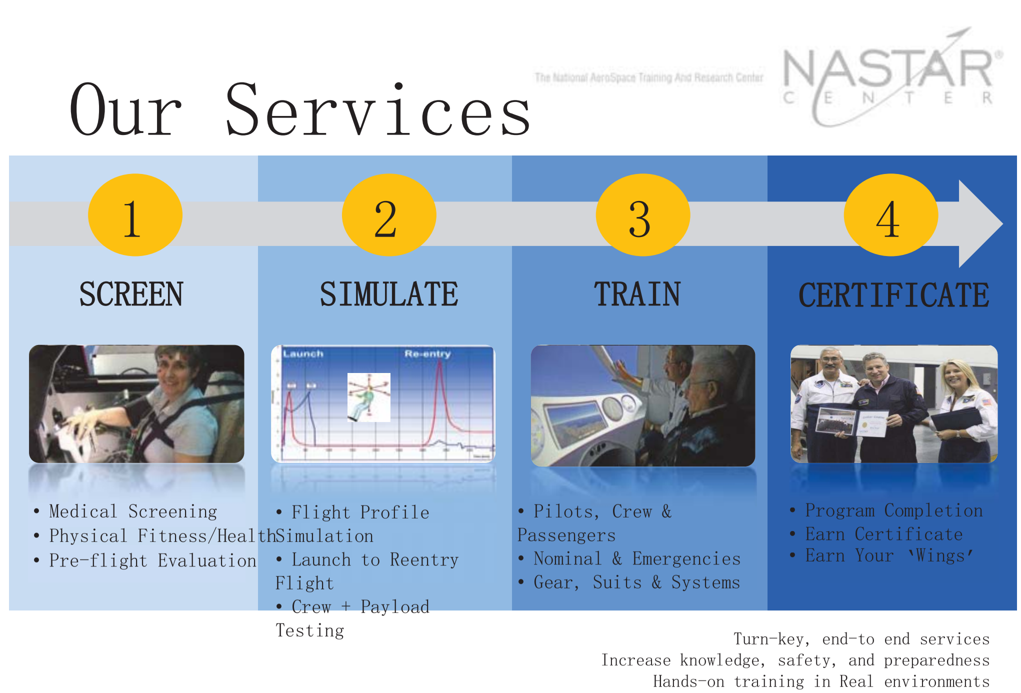
Unlike Any Other Experience.
Pilot
Astronaut

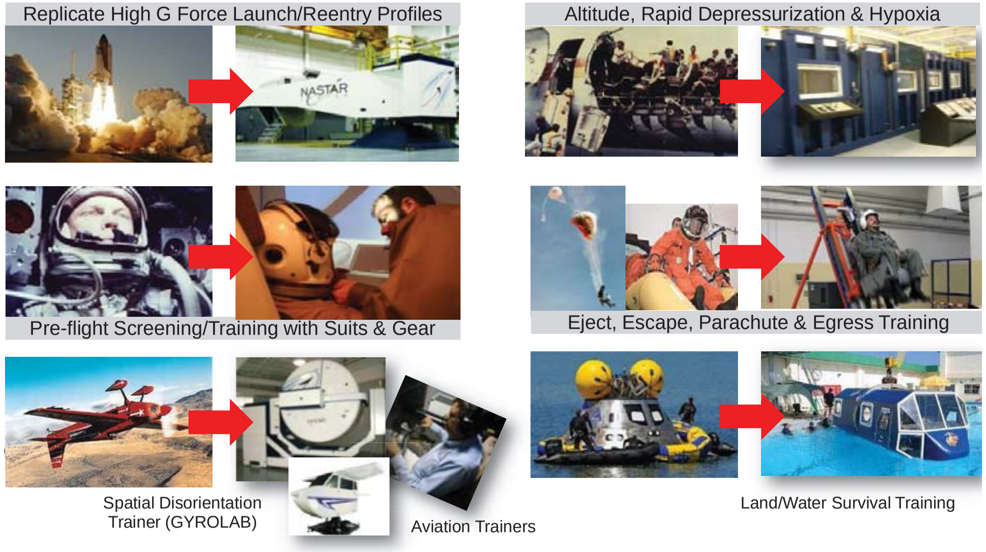

Our Services
The National AeroSpace Training And Research Center
NASTAR CENTER
1 SCREEN
• Medical Screening
• Physical Fitness/Health
• Pre-flight Evaluation
2 SIMULATE
• Flight Profile Simulation
• Launch to Reentry Flight
• Crew + Payload Testing
3 TRAIN
• Pilots, Crew & Passengers
• Nominal & Emergencies
• Gear, Suits & Systems
4 CERTIFICATE
• Program Completion
• Earn Certificate
• Earn Your 'Wings'
Turn-key, end-to end services
Increase knowledge, safety, and preparedness
Hands-on training in Real environments

Our Equipment

We Simulate REAL Situations

The National AeroSpace Training And Research Center

NASTAR® CENTER



VIDEO

The National AeroSpace Training And Research Center

NASTAR® CENTER

Contact Info:

Brienna L. Henwood
Director of Space and Research

NASTAR Center
125 James Way
Southampton, PA 18966 USA
(215) 355-9100 x1504
BHenwood@NASTARCenter.com

FAA COE CST Affiliate Member Overview

Ken Davidian
COE CST ATM2 in Socorro, NM
October 31, 2012

Federal Aviation Administration

Overview

- What is an Affiliate Member
- Who is Involved
- "Gives & Gets"
- New Affiliate Members
- New Associate Member
- Future Plans

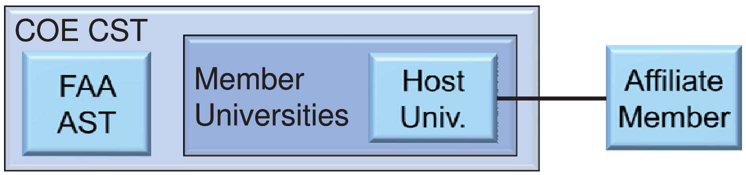
FAA Center of Excellence for Commercial Space Transportation

What Is An Affiliate Member?

- Any University not currently a COE CST Member University
- Domestic (US) or Foreign (non-US)
- Provide diverse and complementary capabilities to benefit research projects related to the COE CST

Involved Parties

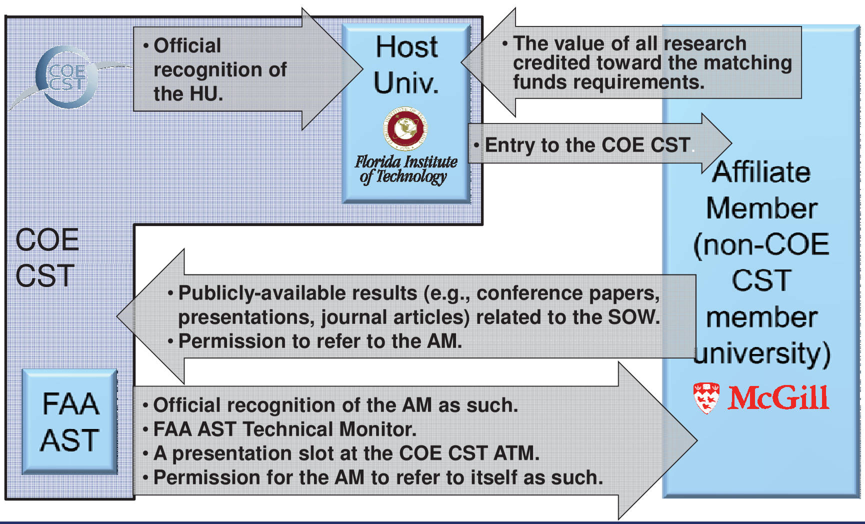
- FAA Office of Commercial Space Transportation (AST)
- Member University (MU), one of the current nine member universities
- COE CST, comprised of the FAA AST and the MUs.
- Host University (HU), an MU acting as the liaison between the COE CST and the AM.
- Affiliate Member (AM)



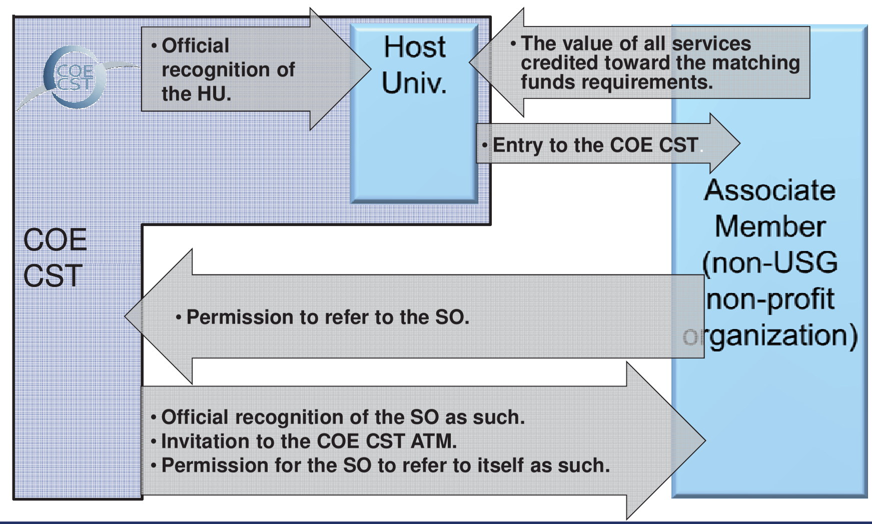
General Terms

- The AM and AST will work together to develop a research task Statement of Work (SOW) that is satisfactory to both the AM and the COE CST.
- There will be no exchange of funds between any of the Involved Parties.
- The AM will be responsible for all costs associated with the research being conducted, including but not limited to: oversight, guidance, execution, training, travel and per diem.

Affiliate Members "Gives & Gets"



Associate Members "Gives & Gets"



1st Affiliate Member: McGill University

- Principal Investigator: Prof. Dr. Ram Jakhu
  - Institute of Air and Space Law
  - Faculty of Law, McGill University
  - Montréal, Canada - 1st International Member
- Ph.D. Students
  - Ms. D. Howard - World-Wide Spaceport Regs
  - Mr. P. Fitzgerald - ICAO Role in ETO Regs
- Host University: Florida Institute of Technology
- Research Area: 4.4 Industry Viability - Regulation

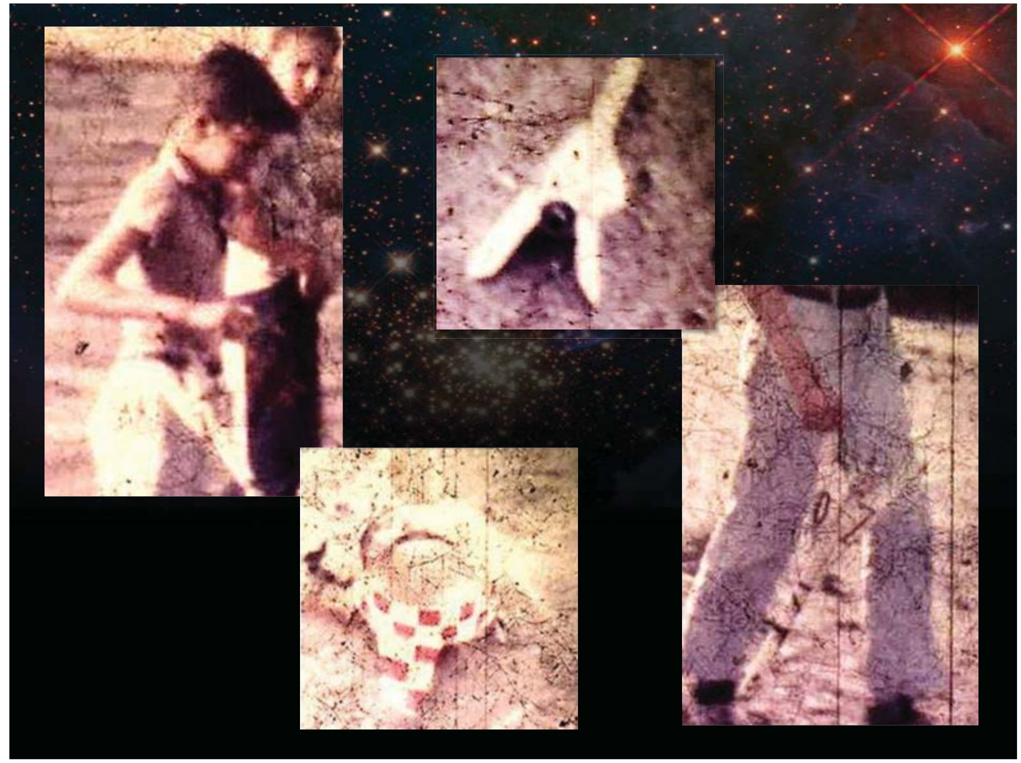
Future Plans

- FAA AST is interested in increasing the number of Affiliate Members
- Three Affiliate Member candidates
  - All US Universities
- Consideration of a Solicitation Announcement in the Federal Register.

Summary

- COE CST Growing with Affiliate Members
- Mutual Benefits for COE CST, Host University and Affiliate Members
- First Affiliate Member: McGill University
  - Also First International Member!
- Future Plans include:
  - Solicitation for more AM candidates
  - Supporting Organizations (???)
    - Currently Two Non-US Candidates


Federal Aviation Administration
Commercial Space Transportation
Annual Meeting
October 29, 2013




COURSE COMPLETION
POSEY, WILLIAM J.
OP-116
C-39 BLAST ESCAPE SYSTEM
JAN 24 1969
JOHN F. KENNEDY SPACE CENTER
THIS IS TO CERTIFY THAT
WILLIAM J. POSEY
HAS ATTENDED THE FOLLOWING COURSE:
OP-107-BEN, COMPLEX 39
SAFETY ORIENTATION (2 HRS)
OCT 23 1967
DATE
TRAINING SUPERVISOR
BENDIX LAUNCH SUPPORT DIV
JOHN F. KENNEDY SPACE CENTER
THIS IS TO CERTIFY THAT
WILLIAM J. POSEY
HAS ATTENDED THE FOLLOWING COURSE:
OP-108-BEN, COMPLEX 34/37
SAFETY ORIENTATION (2HRS)
OCT 2 1967
DATE
TRAINING SUPERVISOR
BENDIX LAUNCH SUPPORT DIV

Certificate of Participation

JOHN F. KENNEDY SPACE CENTER

ARMSTRONG COLLINS ALDRIN

W. J. POSEY

was a member of the KSC Government/Industry team that launched Apollo 11 which successfully accomplished mans first landing on the Moon July 20, 1969.

S. D. TRUHAN
DIRECTOR FLORIDA TEST CENTER
McDONNELL DOUGLAS ASTRONAUTICS COMPANY
McDONNELL DOUGLAS CORPORATION

KURT H. DEBUS
DIRECTOR, KENNEDY SPACE CENTER

IP PERFORMER

VIP

MCDONNELL-DOUGLAS MISSILE & SPACE SYSTEMS DIVISION

ORMANCE HONORS GIVEN TO VIPS

Conscientious Effort—W. J. Posey, A41-726, Inspection & Test has won VIP honors for his dedication in assisting Quality Engineering in eliminating a backlog of components being held for required documentation. He also completed the demanding task of verifying and reverifying all components in the Vehicle Countdown Kits. His diligence eliminated any possible delays in verification of flight critical items for the Vehicle Flight Readiness Review.

NASA needs its swagger back

JOHN KELLY
SPACE

NASA needs some of what Elon Musk, Jeff Bezos and Sir Richard Branson bring to the table: gutsy, all-in leadership.

Don't get me wrong. I like Charlie Bolden, the former Marine turned astronaut who heads the agency. He's a good man who served his country with honor. He can tell you what's special about NASA and sell the virtues of exploration. But Bolden, and some of his senior leaders, seem stuck telling yesterday's version of the NASA story rather than tomorrow's. They're not breaking out of a mold constructed in the Cold War, slightly modified through the shuttle and space station eras, and now terribly outdated.

NASA got big. The innovative, beat-the-odds space agency got bogged down by two forces: the politically charged bureaucracy of Washington and its commitments to big legacy contractors of the military-industrial complex.

Perhaps NASA could cut loose those anchors, but that's not going to happen with the kind of appointees typically put in charge. Sean O'Keefe and Mike Griffin, the two men before Bolden, were strong personalities. They couldn't break the

See KELLY, Page 2B

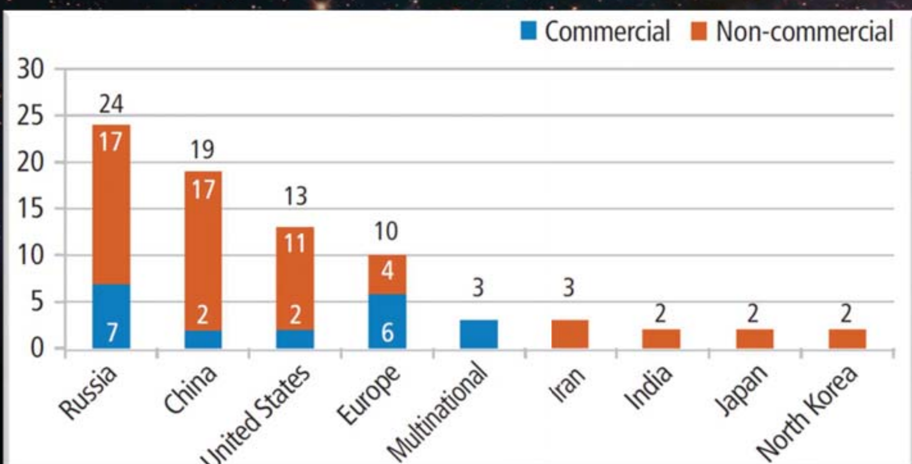
These are some of the results of ***The Harris Poll*** of 2,278 U.S. adults surveyed online between January 17 and 22, 2013 by Harris Interactive.

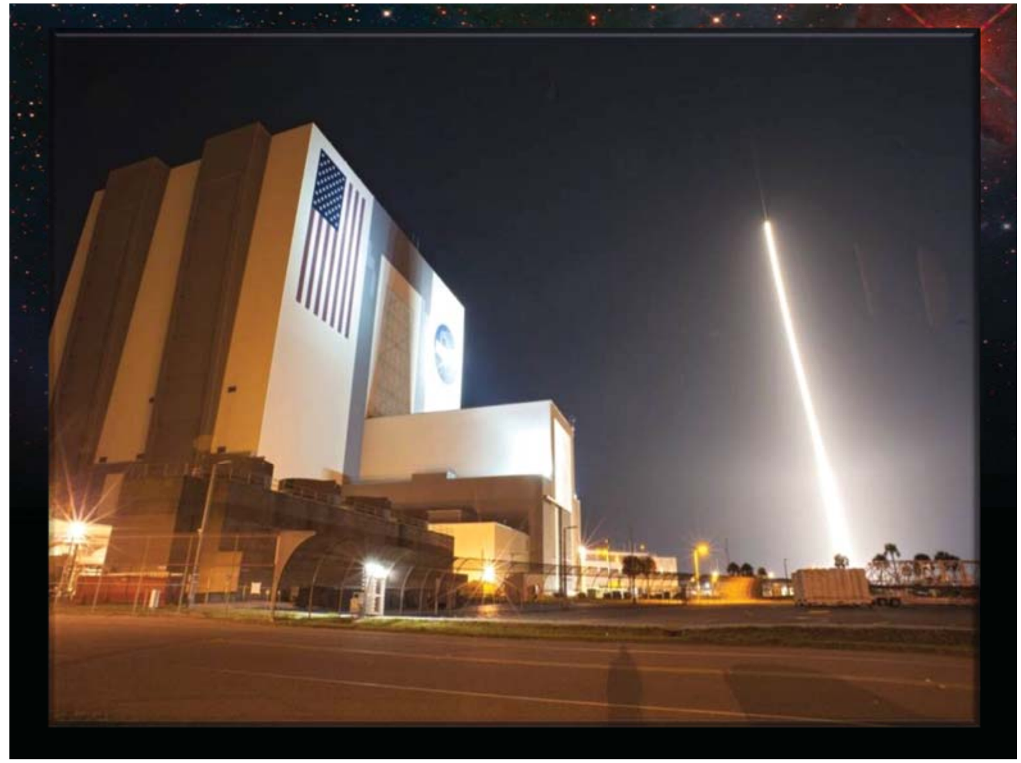
TABLE 1
CUTTING GOVERNMENT PROGRAMS

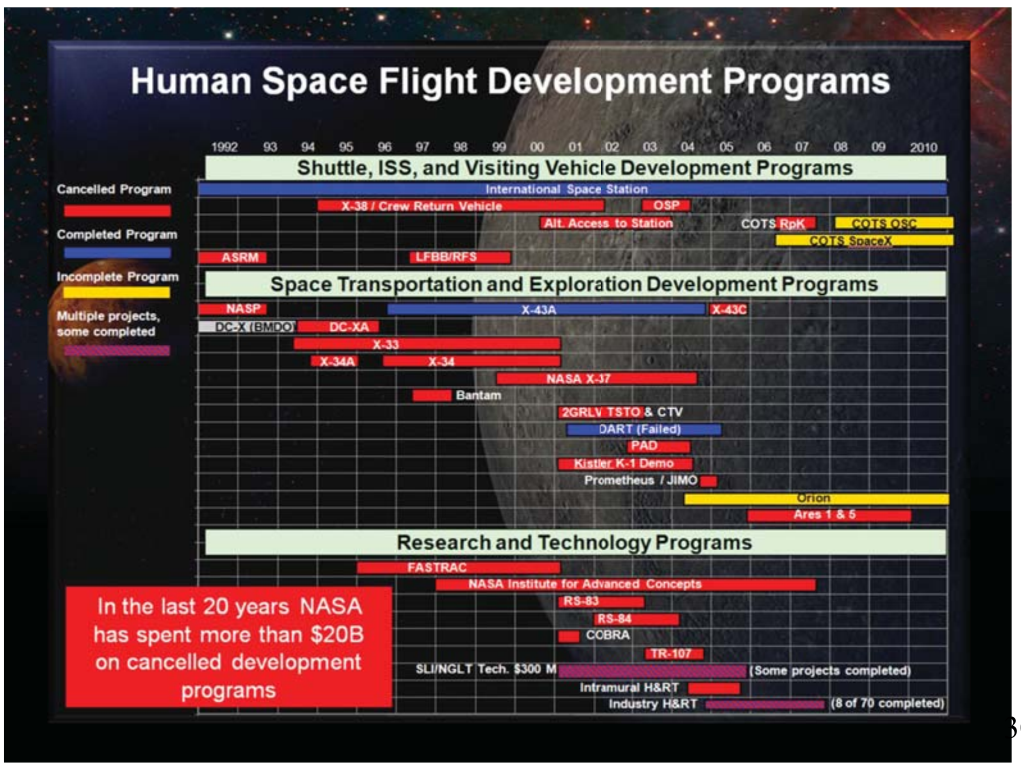
Below is a list of different areas of federal government spending. For each, please indicate if you would favor major cut in spending, a minor cut, no cut at all, or would you increase spending in this area?"

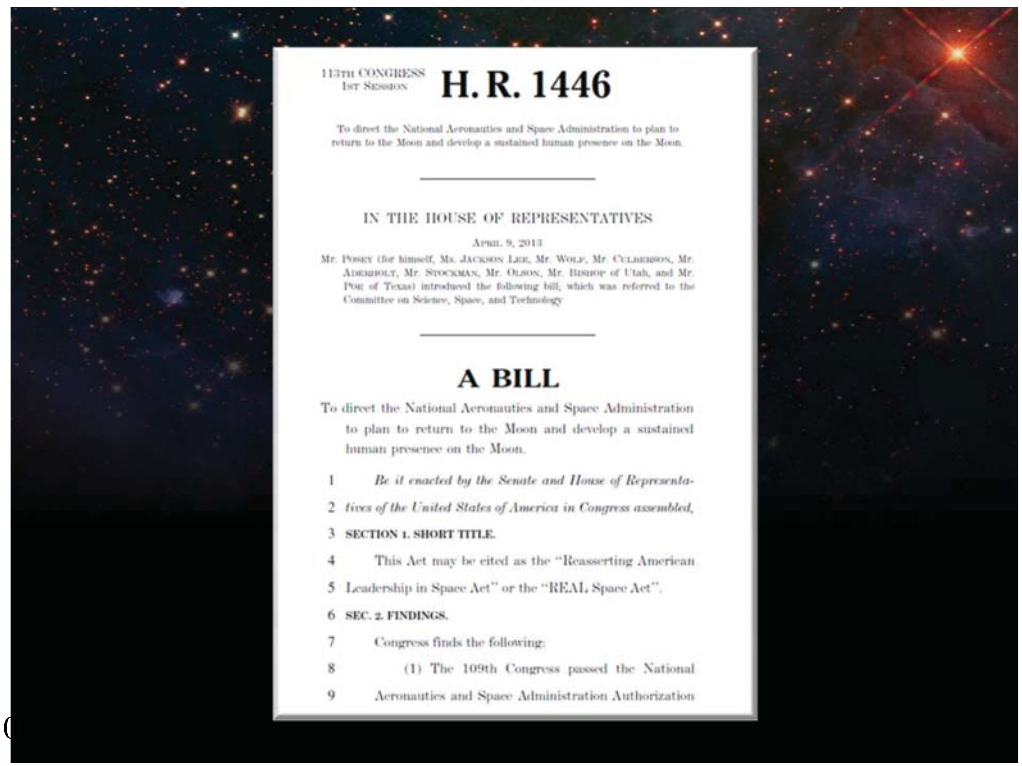
ıse: All Adults

	FAVOR CUT (NET)	Major cut	Minor cut	OPPOSE CUT (NET)	No cut in Spending	Increase in spending	Not at all sure
	%	%	%	%	%	%	%
Foreign economic aid	**77**	49	28	**15**	12	3	8
Foreign military aid	**74**	45	30	**17**	14	3	9
Spending by the regulatory agencies generally	**55**	25	29	**30**	24	5	16
Subsidies to business	**54**	25	29	**36**	30	6	10
Federal welfare spending	**51**	26	24	**42**	34	8	7
Space programs	**50**	23	27	**41**	28	14	9
Defense spending	**46**	19	26	**46**	33	13	8
The food stamp program	**44**	21	23	**49**	36	12	7
Federal housing programs	**40**	16	25	**51**	37	14	9
Farm subsidies	**40**	17	23	**50**	37	13	11
Federally funded scientific research programs	**37**	13	24	**53**	36	17	9
Spending for mass transportation	**34**	12	23	**56**	36	20	10
Pollution control	**33**	12	21	**58**	41	17	9
Federal aid to cities	**31**	8	23	**59**	46	14	10
Federal job training programs	**31**	10	20	**61**	40	21	8
Federal highway financing	**26**	4	22	**65**	44	21	9
Revenue sharing with states and cities	**25**	8	17	**59**	47	12	16
Health care	**23**	11	12	**69**	38	31	8
Federal aid to education	**19**	7	11	**73**	36	37	8
Social security payments	**12**	4	9	**80**	52	28	8









113TH CONGRESS 1ST SESSION

H. R. 1446

To direct the National Aeronautics and Space Administration to plan to return to the Moon and develop a sustained human presence on the Moon.

IN THE HOUSE OF REPRESENTATIVES

APRIL 9, 2013

Mr. POSEY (for himself, Ms. JACKSON LEE, Mr. WOLF, Mr. CULBERSON, Mr. ADERHOLT, Mr. STOCKMAN, Mr. OLSON, Mr. BISHOP of Utah, and Mr. POE of Texas) introduced the following bill; which was referred to the Committee on Science, Space, and Technology

A BILL

To direct the National Aeronautics and Space Administration to plan to return to the Moon and develop a sustained human presence on the Moon.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

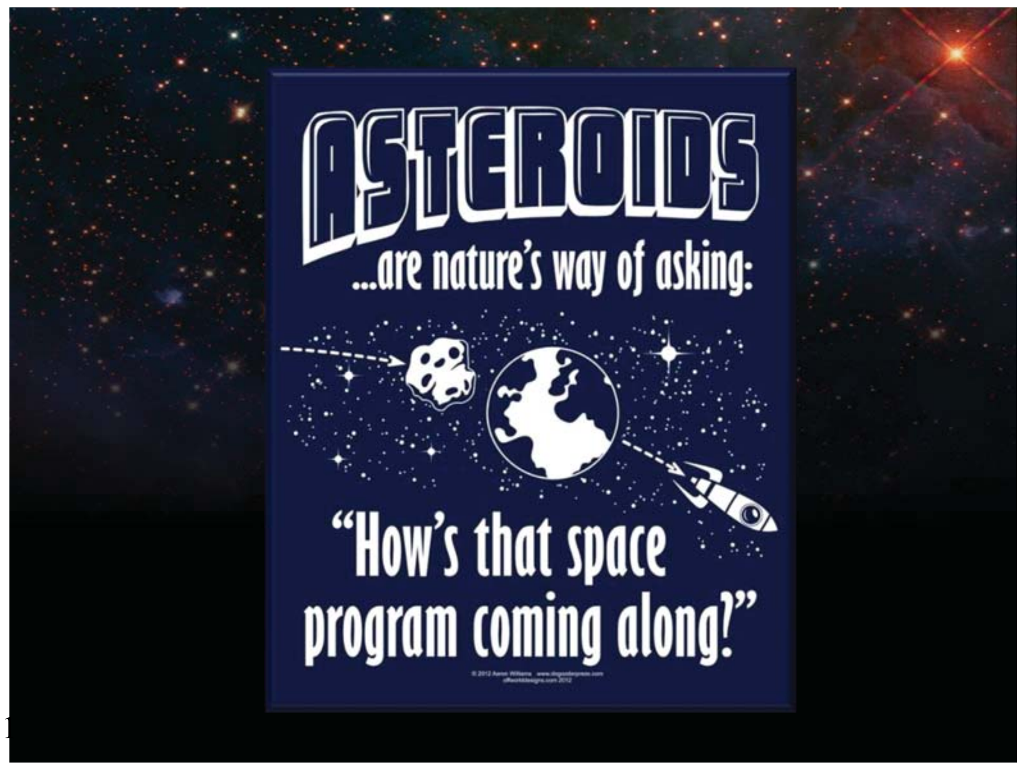
This Act may be cited as the "Reasserting American Leadership in Space Act" or the "REAL Space Act".

SEC. 2. FINDINGS.

Congress finds the following:

(1) The 109th Congress passed the National Aeronautics and Space Administration Authorization


The Competition For Space
Blue Origin
LOCKHEED MARTIN
BOEING
ULA
United Launch Alliance
Virgin Galactic
Bigelow Aerospace
Orbital
SPACEX


ASTEROIDS
...are nature's way of asking:
"How's that space
program coming along?"

BIGELOW AEROSPACE®

FAA COE CST
Annual Tech Meeting

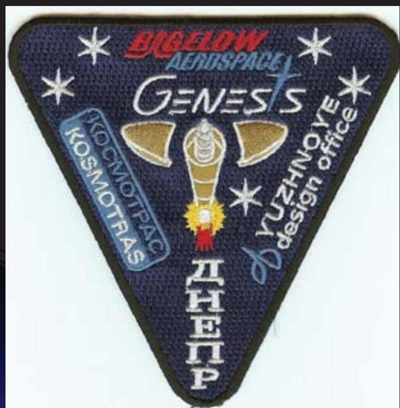
NASA's Inflatable Beginning

2

An Old Idea Made New Again

3

The Genesis Missions



4

5

Genesis I

- Launched on July 12, 2006 by ISC Kosmotras from the new Yasny Launch Base in the Orenburg Region of Russia
- Genesis I validated BA's fundamental engineering concepts and proved the deployment process
- Genesis I demonstrated expandable habitats' long-term durability and provided BA flight controllers with invaluable experience in on-orbit operations

6

Genesis I Firsts

- First launch by Bigelow Aerospace
- First launch of an expandable space habitat prototype into orbit
- First launch of a single, large payload aboard the Dnepr
- First launch from the new Yasny Cosmodrome in Russia

7

Genesis I

8

Bringing Red Sox Nation to Russia

9

11

Launch of Genesis II on Dnepr LV from Yasny Launch Base

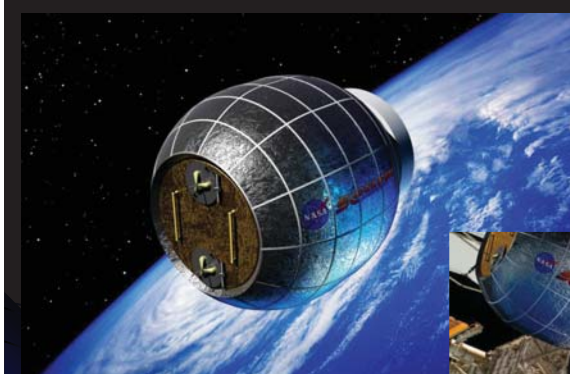
Genesis II

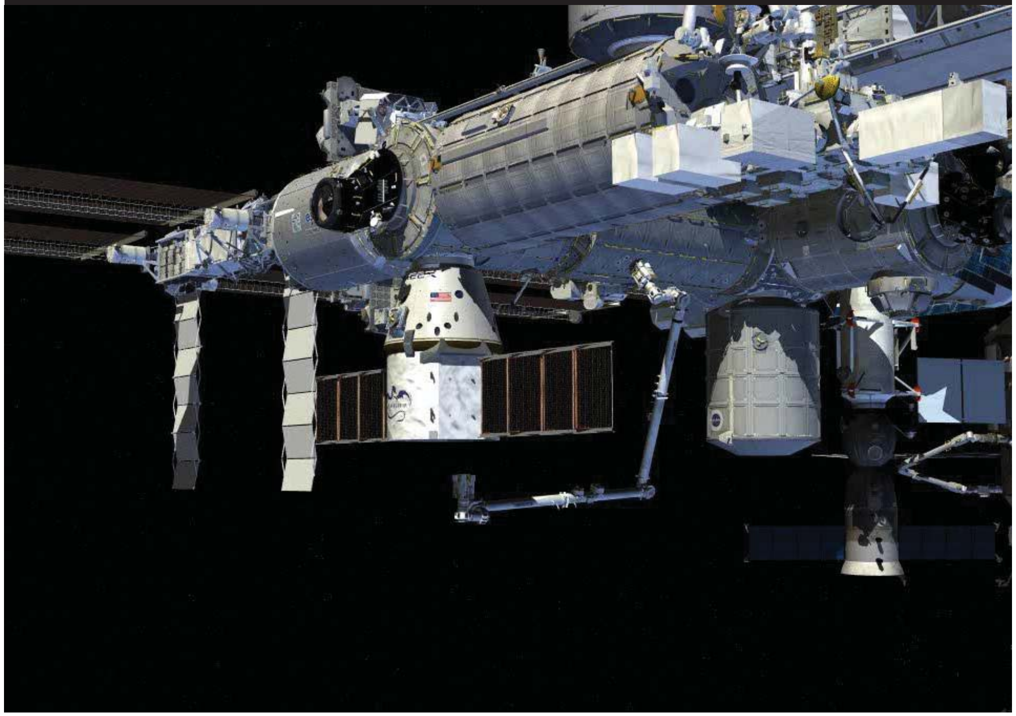
13

Genesis II Surprise

14

BEAM Me Up





BA 330

17

Future

- Leverage the COTS Model
- Expedite Commercial Crew
- The Moon

18

Entrepreneurial Spirit

19

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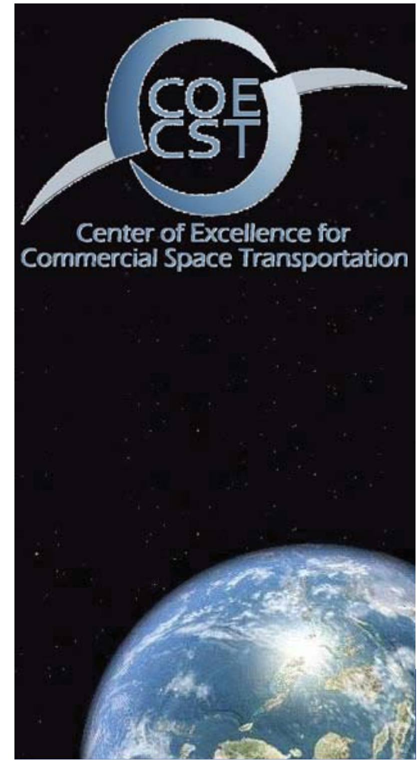
CESTAC Feedback



Carissa Christensen
COE CST ATM3 in Washington, DC
Wednesday, October 30, 2013

Purpose

- CESTAC is the Center of Excellence Space Transportation Advisory Committee
- Consists of industry representatives from across the industry
- Intended to provide COE CST with insight into the relevance of its research agenda to industry needs

Industry Review Process

- Members of CESTAC attending the meeting evaluated each project presented
- Industry review considered 3 parameters
  - Research area important to meet an industry need?
  - Likelihood of FAA role in potential regulations resulting from the research area
  - Planned product or result directly relevant to the industry need?
- This presentation represents preliminary findings in real time

Findings

- Projects in Research Area 3, Human Spaceflight Research, were typically
  - Relevant
  - Important
  - Well executed
- More of a mix in other research areas
- Will provide more detail in report

Four Standout Projects: Highly Relevant to Industry Need and FAA Role

184 Commercial Human Spacecraft Rating (CU-Klaus) [Research Area 3]

220 Space Ops Framework (NMSU-Hynes) [Research Area 1]

255 Wearable Biomedical Monitoring Equipment (UTMB-Castleberry) [Research Area 3]

256 Centrifuge Testing (UTMB-Vanderploeg) [Research Area 3]

Observations

- Research agenda matches more tightly to industry needs than last year
- Presentations were strong and showed progress from last year
- Projects appear to be generating real value by leveraging academic capability
- While commending the work that was done and presented, CESTAC continues to question FAA and COE role in
  - Debris mitigation
  - Education process
  - Defining policy for other agencies

Preliminary Recommendations

- Include project funding and milestones in evaluation process
- Increase participation by industry reviewers
- Ask presenters to specifically address evaluation criteria
  - Industry need
  - FAA role
  - Relevance of project
- Incorporate evaluation criteria into project proposal process
- ASSIGN EACH PROJECT A UNIQUE NUMBER

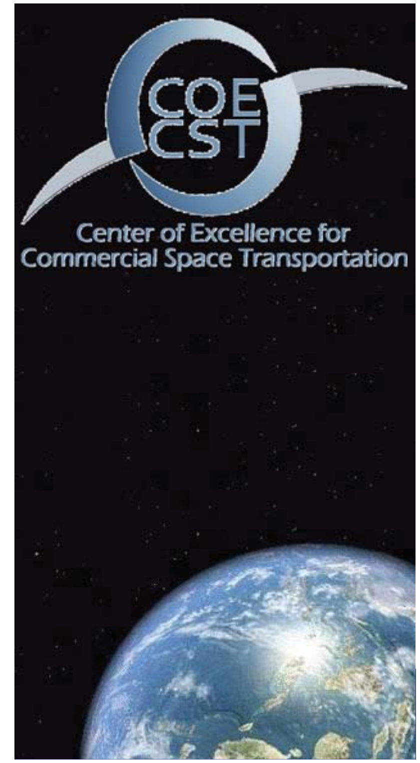
Thank you for the opportunity to comment

COE CST Third Annual Technical Meeting (ATM3)

Task 184
Human-Rating of Commercial Spacecraft

Prof. David Klaus
University of Colorado Boulder

October 30, 2013



Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results or Schedule & Milestones
- Next Steps
- Contact Information

Team Members

- **David Klaus**, PI, University of Colorado Boulder
- **Christine Fanchiang**, PhD student, CU Aerospace (funded by COE)
- **Robert Ocampo**, PhD student, CU Aerospace (funded by SNC)
- **Henry Lampazzi, Jeff Sugar, Randy Repcheck**, (*Pam Melroy, Rene Rey*) FAA
- **Human-rating Working Group Participants**
  - Armadillo Aerospace
  - Boeing
  - Sierra Nevada Corporation
  - SpaceX
  - United Launch Alliance (ULA)
  - Draper Laboratory
  - Environmental Tectonics Corporation (ETC)-NASTAR Center
  - Metropolitan State College of Denver
  - Space Adventures
  - University of Texas Medical Branch (UTMB)
  - Wyle
  - Baylor
  - University of Colorado (Law)
  - University of Nebraska (Law)

Purpose of Task

- Purpose
  - The purpose of this task is to *define* and *assess* appropriate *criteria and protocols* for human-rating of commercial spacecraft to support development of certification needs and verification methods.
- Objectives - *year 3* (6/1/13 to 5/31/14)
  - Establish Industry-wide Consensus on Key Terms and Definitions
  - Analyze Considerations for Safety/Risk Classification
  - Review and Support 'FAA Established Practices for Human Spaceflight Occupant Safety' (draft)
- Goals
  - Develop report on 'Human-Rating Guidelines and Considerations for Commercial Space Transportation' addressing requirements, validation & verification, and regulatory practices

Research Methodology

What is Human-Rating?

"A human-rated system ***accommodates*** human needs, effectively ***utilizes*** human capabilities, controls hazards and ***manages safety*** risk associated with human spaceflight, and provides, to the maximum extent practical, the capability to safely recover the crew from hazardous situations.

NASA NPR 8705.2B. Human-Rating Requirements for Space Systems, 2012

Current research is focused on safety considerations for the spacecraft occupants & uninvolved public.

Human-Rating Perspectives

Review of 'Man/Human-Rating' Practices

- **X-Series (1940s-1950s)**
  - First reference found to 'man-rated' system
  - X-15 capable of suborbital spaceflight
- **Mercury (1961-1963) and Gemini (1965-1966)**
  - Redundancy, conservative design, reliability, and abort systems
- **Apollo (1968-1975)**
  - Extensive ground and flight tests
  - First launch vehicle specifically designed for humans
- **Skylab (1973-1974)**
  - Man-rating extended from just safety to include operability
- **Space Shuttle (1981-2011)**
  - First launch vehicle not tested in unmanned configuration

Review of 'Man/Human-Rating' Documents

- **NASA 410-24-13-1** Launch Vehicle Man-Rating, 1963
- **NHB 5300.4 (1D-2)** Safety, Reliability, Maintainability and Quality Provisions for the Space Shuttle Program, October, 1979
- **JSC-23211** Guidelines for Man Rating Space Systems, 1988
- **NASA SP 6104 A** Perspective on the Human-Rating Process of U.S. Spacecraft: Both Past and Present, 1995
- **NASA NPG 8705.2** Human-Rating Requirements and Guidelines for Space Flight Systems, 2003-2008
- **NASA NPR 8705.2A** Human-Rating Requirements for Space Systems, 2005-2010
- **NASA NPR 8705.2B** Human-Rating Requirements for Space Systems, 2008-2013
- **NASA CCT-1001** Commercial Human-Rating Plan (Draft), May 21, 2010

NASA Commercial Crew References

- **CCT-REQ-1130** *International Space Station (ISS) Crew Transportation Certification and Services Requirements Document*
  - NASA ISS crew transport certification and service requirements
- **CCT-STD-1140** *Commercial Crew Transportation Evaluation of Technical Standards*.
  - technical, safety, and crew health & medical processes
- **CCT-PLN-1100** *Commercial Crew Transportation Plan*
  - certification to transport NASA/NASA-sponsored crew members
- **CCT-DRM-1110** *Commercial Crew Transportation System Design Goals*
  - reference missions to transport humans to/from ISS & LEO destinations
- **CCT-STD-1150** *Commercial Crew Transportation Operations Standards*..
  - establishes the ground and flight operations processes
- **NASA SSP-50808** ISS to COTS Interface Requirements Document
- **AFSPCMAN-91-710** Range Safety User Requirements

Evaluating Safety / Risk

1) *Assessing Risk* –varying methods focus on quantification

Severity	Consequence
1	No Impact / Monitor
2	Degraded Performance
3	Loss of Mission (LOM)
4	Loss of Vehicle (LOV)
5	Loss of Crew (LOC)

Risk management process

1) Identify hazards.
2) Define the consequence if hazard is realized.
3) Assess the probability of realizing hazard.

Typical risk outcome assessment scheme

2) *Accepting Risk* –subjective, based on person's or society's judgement

- Overall LOC probability distribution for an ISS mission shall have a mean value no greater than… (NASA CCT-REQ-1130, 4.0)
  - **1 in 270**

Risk Acceptance Perception

Ocampo, R., Klaus, D. (2013). A Review of Spacecraft Safety: From Vostok to the International Space Station. New Space 1(2): 73-80

Comparison of Transportation System Fatalities				
Risk Metrics	Automotive	Railway	Commercial Aviation	Space Shuttle (~800 passengers)
Fatal Missions : Total Missions	N/A	N/A	1 : 334,247	1 : 68
Fatalities : Total Mission	N/A	N/A	1 : 192,835	1 : 10
Fatalities : Total Passengers	1 : 95	N/A	1: 14,800,000	1 : 58
Fatalities : Total Miles	1 : 87,719,298	1 : 34,333,333	1 : 19,746,153,846	1 : 38,802,507
Fatalities : Total Passenger-Miles	N/A	N/A	1 : 346,154	1 : 242,591,494

Soyuz 119 missions (Sept 2013): 2 fatal missions (1:60), 4 fatalities (1:30), 2 aborts

Utilization Metric Development

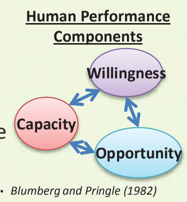
***Human-Rating* →** **Protect, Accommodate, and Utilize the Crew**
But how do you measure <u>utilization</u> of crew?

Problem
Crew Utilization (i.e. performance) not well-characterized and thus hard to monitor, maintain, and resolve throughout mission.

Literature Review

Currently over 300 different Human Performance Methods and Tools to choose from with different areas of applicability.

While human performance has been examined, it is still not well-quantified, nor are there standard metrics for its use.



Approach & Methodology

1) Characterize Crew Performance Metrics
2) Assess needs for different Mission Profiles
3) Quantify, evaluate and validate metrics

Duration \ Destination	Up to LEO	Beyond LEO
Short (< 2 weeks)	A Suborbital LEO	B Lunar Orbit Lunar Surface Surface Ascent/Descent
Long (> 2 weeks)	C ISS	D Lunar Surface Mars Orbit Mars Surface NEA

Christine Fanchiang, PhD student

Results or Schedule/Milestones

COE CST Task 184 Report Documentation

- Human Spaceflight Terminology and Definitions. Updated: 1 Oct 2013.
- Human Spaceflight Safety Terms and Definitions. Updated: 1 Oct 2013
- Human Spaceflight Safety Perspectives. Updated: 1 Oct 2013

- Review and Comments to the FAA Established Practices for Human Spaceflight Occupant Safety DRAFT July 31, 2013

Results or Schedule/Milestones

COE CST Task 184-Related Publications & Presentations

- Ocampo, R., Klaus, D. (2013). A Review of Spacecraft Safety: From Vostok to the International Space Station. *New Space* **1(2)**: 73-80
- Fanchiang, C. and Klaus, D.M. (2013) Defining a Crew Utilization Figure of Merit to Characterize Human Performance Influence on Spacecraft Design (*poster*) AIAA 43rd International Conference on Environmental Systems (ICES), Vail, CO, July 2013
- Klaus, D.M., Fanchiang, C. and Ocampo, R.P. (2012) Perspectives on Spacecraft Human-Rating. AIAA-2012-3419
- Fanchiang, C., Johnson, M. (2012) Evaluation of Commercial Human Space Flight Laws and Regulations in the United States. 63rd International Astronautical Congress, Naples, Italy, Oct 2012
- Fanchiang, C. (2012) Characterization and Evaluation of Manned Spacecraft Operability Factors. 63rd International Astronautical Congress, Naples, Italy, Oct 2012
- Fanchiang, C. and Klaus, D.M. (2012) Defining an Operability Index for Human Spacecraft Design (*poster*) AIAA 42nd ICES, San Diego, CA, July 2012
- Ocampo, R.P. and Klaus, D.M. (2012) Defining a Safety Index for Human Spacecraft Design (*poster*) AIAA 42nd ICES, San Diego, CA, July 2012

Next Steps

Assessment of risk mitigation implementation practices and strategies

BEST PRACTICES – A technique, method, process, activity, incentive, or reward that is believed to be more effective at delivering a particular outcome than any other technique, method, process, etc. when applied to a particular condition or circumstance.

PROTOCOL – A detailed plan for a scientific or medical experiment, treatment or procedure.

GUIDELINE – A statement by which to determine a course of action. [It] aims to streamline particular processes according to a set routine or sound practice. Guidelines are not binding and are not enforced.

CERTIFICATION – Designation that participants [or item being certified] have demonstrated the requisite, work-related knowledge, skills, or competencies and met other requirements established by the certification program provider (e.g., academic degree, specified number of years of occupational or professional experience).

LICESNSURE – A mandatory credentialing process established by a government entity. It is illegal for an individual to practice the profession without a license.

REQUIREMENT-BASED – Technique used in system engineering design in which specific functions are required for the system and each function must be verified for compliance.

Final Report: Considerations and Guidelines for Human-Rating of Commercial Space Transportation Systems

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Federal Aviation Administration

Unified 4D Trajectory Approach for Integrated Traffic Management

Tom Colvin & Juan Alonso
Stanford University

Oct 29 2013

Outline

- Brief overview of the aviation/space transportation conflict
- Research: Propose architectures for aircraft safety during launch and re-entry and analyze them using compact 4D envelopes
- Analysis Environment / Methodology
  - Propagate Uncertain Trajectories and Debris
  - Generate probabilistic compact 4D envelopes
  - Measure impact on NAS with FACET
- Example Scenario
- Concluding thoughts and directions

What's The Problem?

- Safely and fairly sharing the NAS
  - Need launch architectures to ensure NAS users are safe
  - Current method uses SUAs, NOTAMs, etc and cannot respond dynamically
  - No robust quantitative framework for creating SUAs, thus they are overly conservative
  - Commercial space traffic in rising volume and launching from new ranges requires new ATM architectures

Source: 45 SW Eastern Range: Special Use Airspace, PPT Presentation by Art Ladd

What's Needed?

- **Airspace Management Architectures For Launch / Re-entry**
  - **Procedures governing how the airspace will be handled / partitioned to keep planes and rockets safe**
  - **Specific to each vehicle's mission and quantifiably safe**
- **Examples**
  - **Proactive: No-fly zone is established encompassing entire potential danger area for launch until successful staging**
  - **Reactive: No-fly zone bounds nominal trajectory only. In the event of off-nominal event, SUA is dynamically created and enforced**

Purpose of Task 185

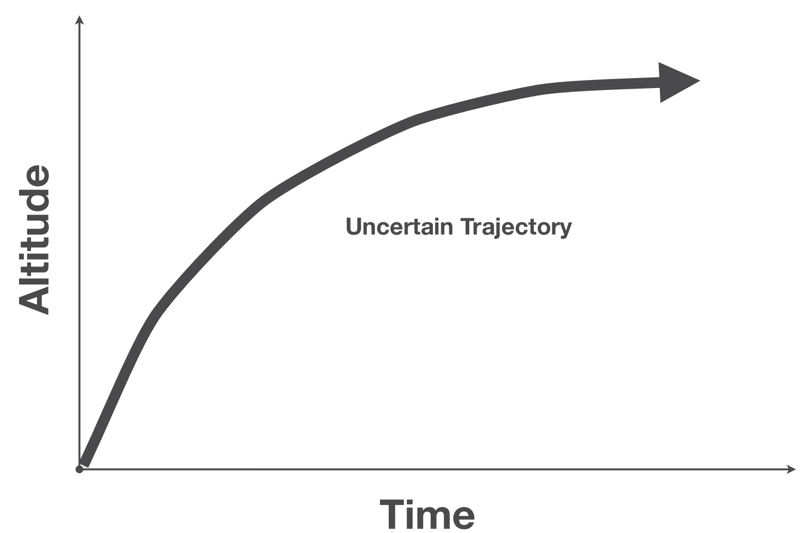
- **Development of requirements, architecture and prototype implementations of simultaneous air/space traffic management procedures for commercial space transportation. Leverage projected improvements derived from NextGen.**

Photo Credit: (NASA/Robert Markowitz)

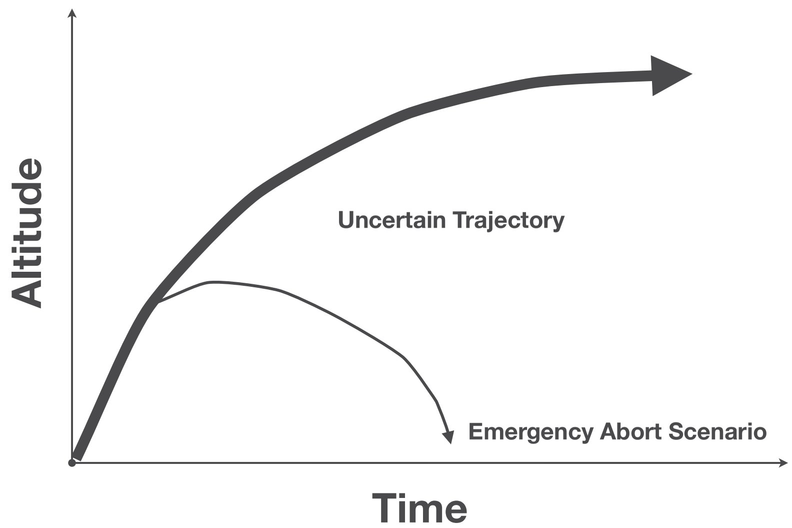
- **Research, develop, analyze and optimize plausible architectures for an Integrated Airspace Management System based on 4D, time-space probabilistic trajectories and safety assessments**

Compact Envelope Concept

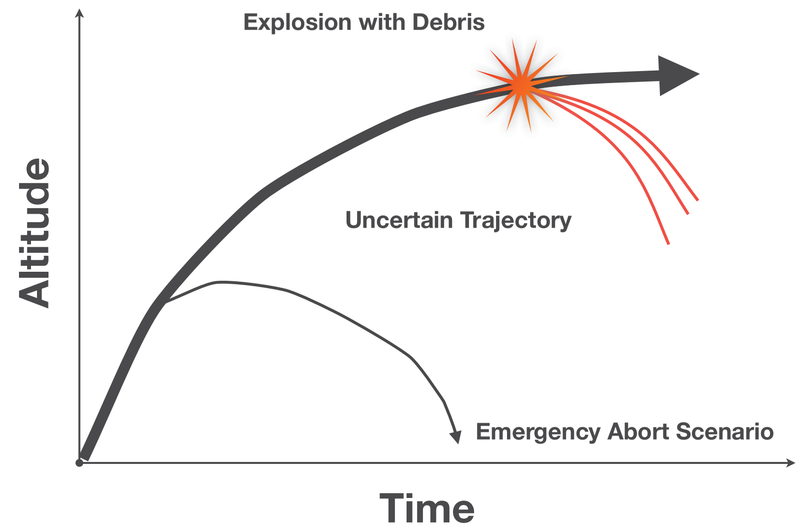
Compact Envelope Concept



Compact Envelope Concept



Compact Envelope Concept



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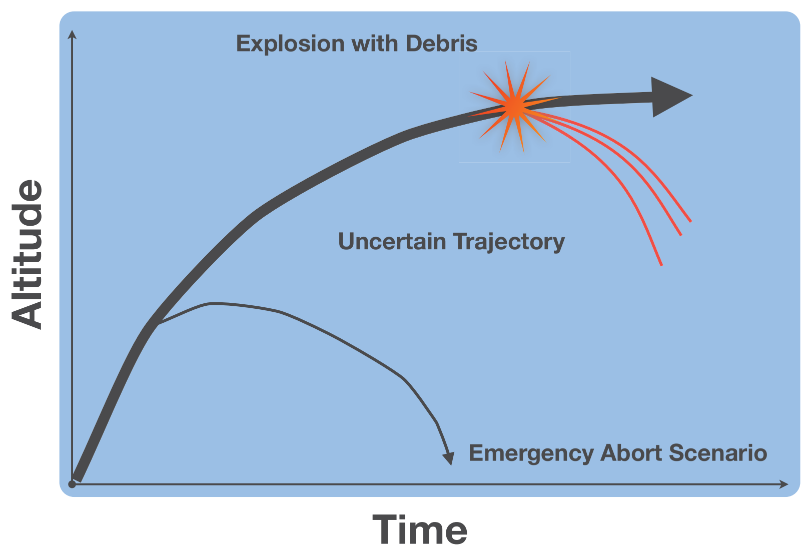

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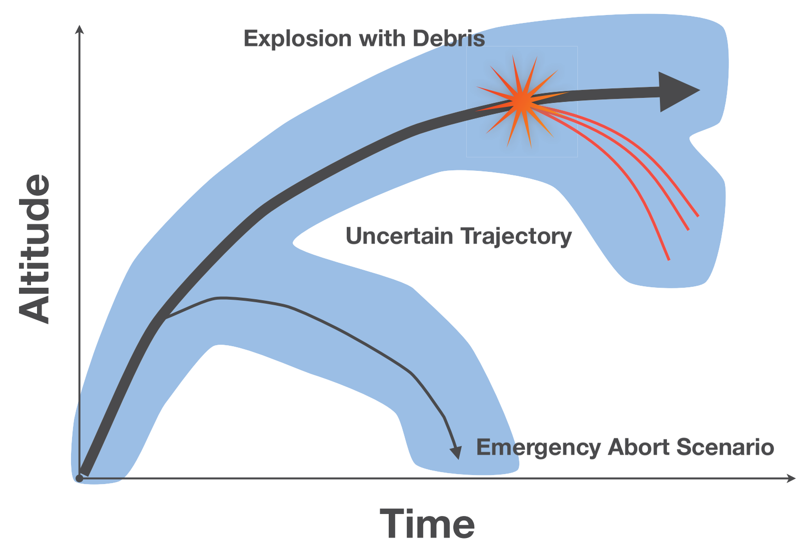
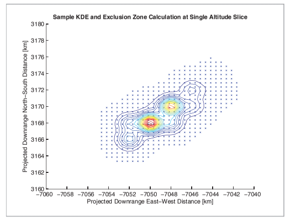
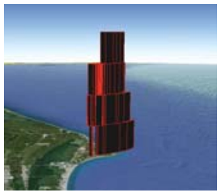


Methodology - Individual Scenario

Run a Monte Carlo simulation that accounts for variation in thrust profiles, weather and time-of-launch uncertainties, and distributions for time of failure.

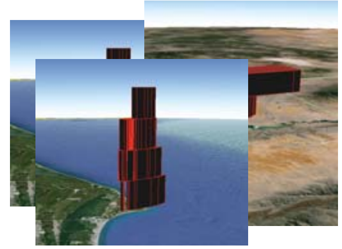
Bin the results of the simulation. Estimate the pdf of the debris / rocket locations via Kernel Density Estimation and find exclusion zone based on probability of aircraft strike prescribed from regulation or user-input.



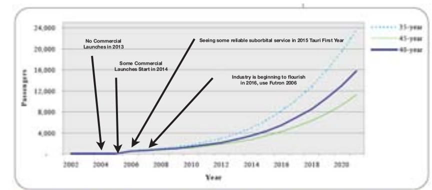


Create compact envelope around the exclusion points using the Swinging Arm Algorithm. Visualize the envelopes in Google Earth or analyze their impact on the National Airspace with FACET.

Methodology - System Level Scenario



Store envelopes from single scenario analysis and collect them into a compact envelope library.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Baseline (40-year)	503	642	820	1,045	1,330	1,692	2,150	2,726	3,448	4,350	5,468	6,842	8,517	10,532	12,923	15,712
35-year	611	798	1,042	1,358	1,768	2,298	2,980	3,853	4,962	6,359	8,100	10,241	12,829	15,895	19,443	23,437
45-year	489	608	756	939	1,166	1,447	1,794	2,222	2,747	3,390	4,174	5,125	6,273	7,646	9,277	11,192

Figure 45: Suborbital forecast ranges using a Fisher-Pry model

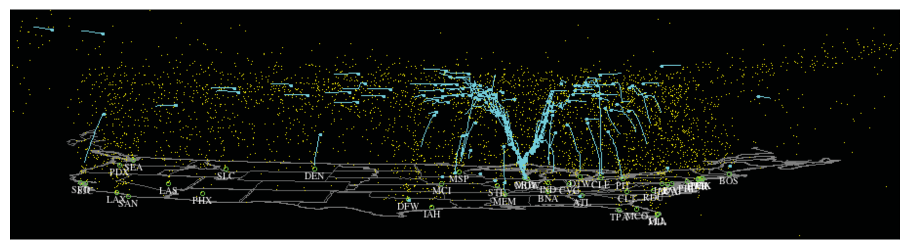
Estimate the volume of orbital and suborbital launch and reentry traffic in the future. Collaborated with FAA (SVO and Advanced Op Concepts) to produce estimates for years 2018 and 2025.

Approximate new missions within estimated space traffic scenarios by using previously calculated envelopes. Rotate and translate as needed then analyze in FACET.

Measure NAS Impact With FACET

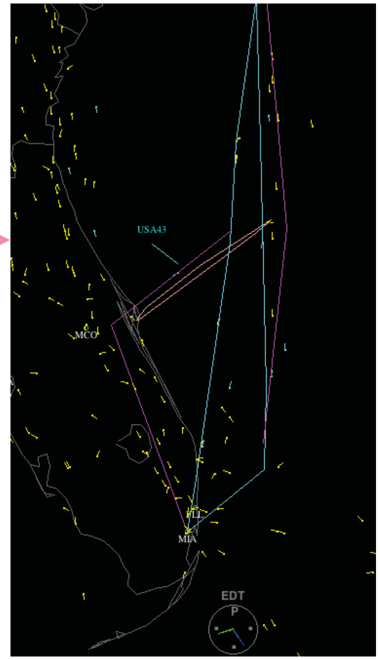
- Future ATM Concepts Evaluation Tool
- Simulation environment for preliminary testing of advanced ATM concepts over continental United States
- Award Winning
  - NASA's Software of the Year Award 2006
  - AIAA Software Engineering Award 2009
- Examples of advanced ATC concepts already implemented
  - Aircraft self-separation, prediction of aircraft demand and sector congestion, system-wide impact assessment of traffic flow management constraints, wind-optimal routing, etc.
- Massive amount of multi-threaded code in C and Java

How It Works (Bird's-Eye View)



- FACET 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 type of aircraft.
- Graphical interface displays the traffic patterns in two and three dimensions, under various current and projected conditions.

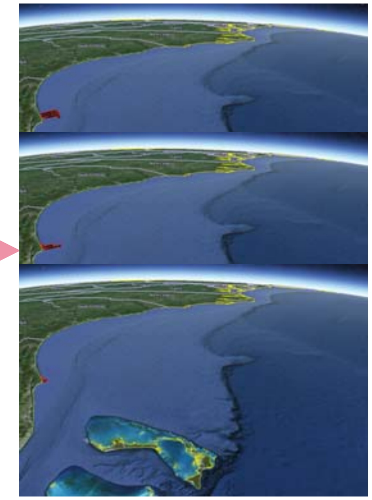
Example Scenarios



Falcon9-style launch from Cape Canaveral: Using a reactive architecture, we assume that the airspace needs five minutes to react to an off-nominal event; we create an envelope around the potential debris cloud to which the NAS would not have adequate time to react. In event of nominal operations, airspace is only blocked off for two minutes post-launch.

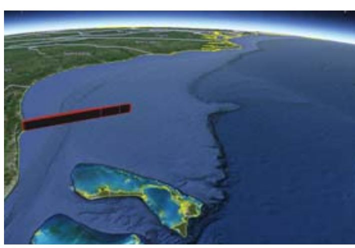
Example Scenarios

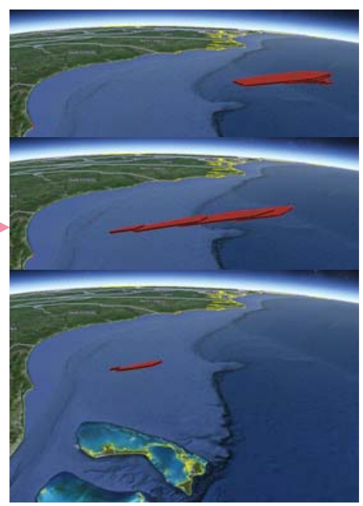
Failure at Maximum Q: The debris footprint from this type of failure is dramatically smaller than compact envelope that is already on. If this event occurs, switch to smaller envelope.



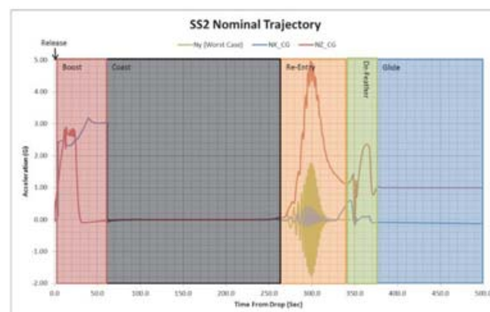
Example Scenarios

Failure at staging event: When this happens, it will be more than 5 minutes until debris reaches the NAS, so can be reactive.





Not Just Orbital: SpaceShipTwo



Source: Virgin Galactic SpaceShipTwo User Guide

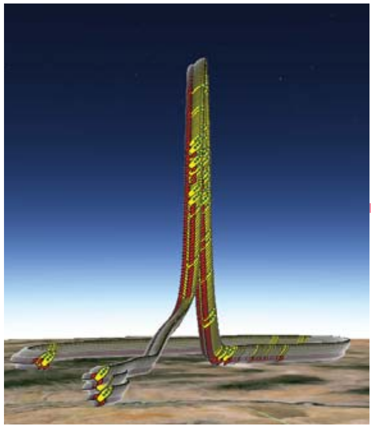
Table 2: Expected g-Loads for Flight and Crash Conditions

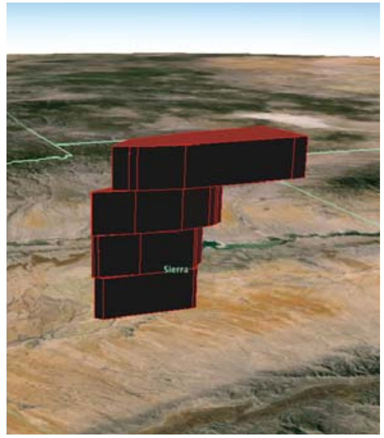
Direction	Maximum Boost Loads	Maximum Re-Entry Loads	Crash Loads
Front/Back (N_x)	+0.1 / -3.4	+ 1.4 / -1.5	+15.8 / -0.0
Left/Right (N_y)	+0.0 / -0.0	+1.8 / -1.8	+2.8 / -2.8
Down/Up (N_z)	+3.7 / -1.0	+8.4 / -0.1	+4.5 / -4.5

Source: Virgin Galactic SpaceShipTwo User Guide

- Used acceleration profile graph to back out thrust profile in body frame
- Estimated weight between 21k-30k lbs
- Made assumptions about pitching angle
- Propagated realistic suborbital trajectory for SS2

Suborbital Example





<u>SpaceshipTwo-style Launch:</u> We have the ability to create compact envelopes for multiple suborbital architectures (aircraft first stage, Lynx-style HTHL, VTHL, etc). This is an example trajectory and compact envelope for a vehicle modeled after SS2, dropped from a plane at 50kft, and climbs to 100km above the surface of the earth and explodes a few moments after launch.

Results

- We have an environment ready to begin analyzing ATM architectures for launching commercial space missions
  - Propagate Uncertain Trajectories and Debris
  - Probabilistically generate compact 4D envelopes
  - Automated interface with FACET
  - Counting aircraft / launch vehicle conflicts with FACET
  - Can simulate arbitrary day in the NAS, rerouting aircraft around compact envelopes
  - Outputs new flight plans, times, and difference in distance

Results

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Conclusion

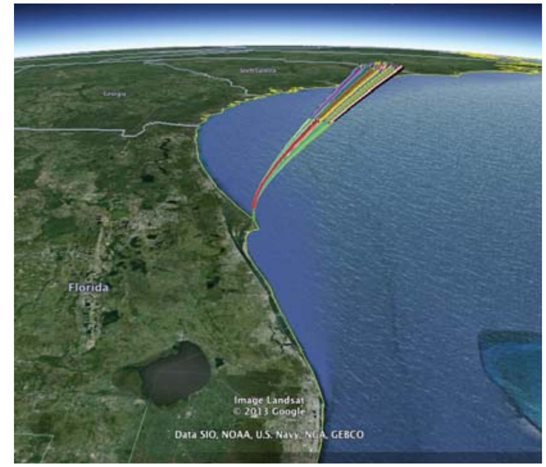
- Have suite of interfacing software environments that can simulate missions with uncertainty, bound the results probabilistically, and analyze their effect on the airspace.
- Have been collaborating closely with FAA to estimate launch / reentry traffic volumes for 2018 and 2025 in preparation for NAS-wide study.
- Beginning to validate FACET's results with FAA's AirTOp. Both have some odd rerouting behaviors which must first be investigated. Working with FAA's Kevin Hatton (SVO) to ensure rerouting algorithms produce realistic results for our scenarios.
- Will use FACET as part of an optimization to research launch architectures and air traffic routes that are optimal for the integrated space-and-air-traffic system.

The End

- return 0; }

Propagation Code

- Monte Carlo software framework that accepts arbitrary:
  - Thrust profiles (TVC, etc)
  - Weather profiles for wind and temperature, with uncertainty parameters for each
  - Failure parameters and distributions
  - Debris model
- Outputs:
  - Collection of (x,y,z,t) points which represent all places a vehicle or its debris may be found from a MC simulation



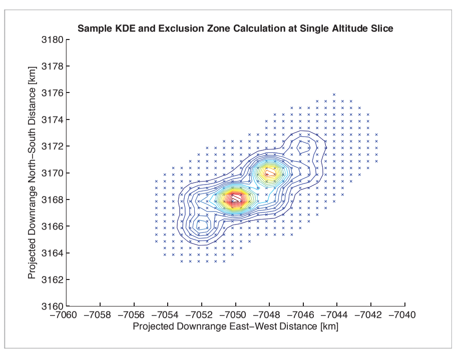
Kernel Density Estimation

Currently

- Create a histogram for debris locations at each altitude level
- Use bivariate gaussian kernel with naive bandwidth parameters
- Make assumptions about aircraft density
- Find exclusion points based on probability of aircraft strike

Coming Soon

- Improved aircraft density model
- More appropriate bandwidth matrix (e.g. UCV)



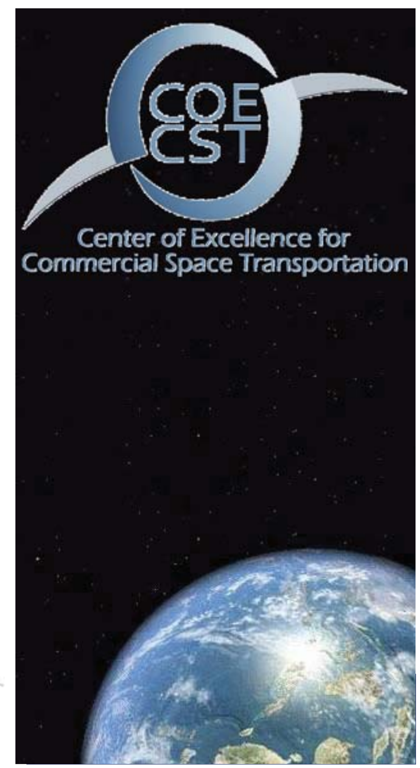
COE CST Third Annual Technical Meeting:

Mitigating threats through space environment modeling/prediction

PI: Tim Fuller-Rowell

University of Colorado Boulder

October 29th, 2013



Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results
- Conclusions and Next Steps
- Contact Information

COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013

Team Members

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

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Jeffrey Forbes
Aerospace Engineering Sciences, University of Colorado, Boulder

COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013

Purpose of Task

Purpose: *An integrated air and space traffic management system requires real-time access to:*

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 on-orbit collision avoidance and atmospheric re-entry, and forecast of near-surface weather conditions (winds, turbulence, storms, lightning, etc.),

3. Plasma density, total electron content, ionospheric irregularities, and radiation conditions for communications, navigation, and safety in flight

Objectives: *Develop a "weather" (terrestrial weather and space weather) prediction model extending from Earth's surface to the edge of space*

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

COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013

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

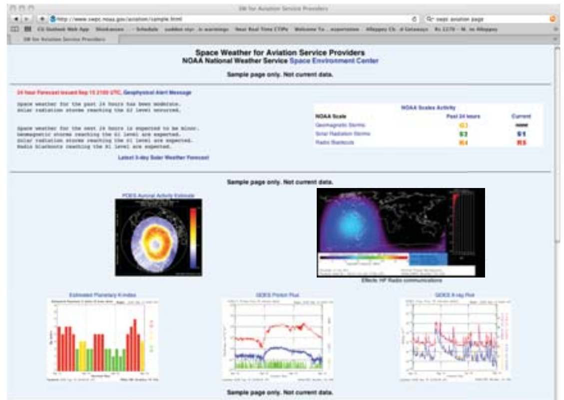
- Winds and temperature
- Turbulence
- Icing
- Analysis and Forecasts

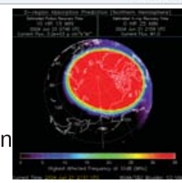
COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013

Current: Aviation Space Weather Support

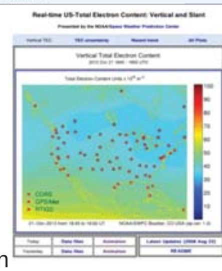
: conditions above 100 km from Space Weather Prediction Center impacting communications, navigation, and radiation hazard

- Solar flare prediction: D-region absorption, HF radio blackout
- Solar proton events: polar cap absorption, radiation hazard
- Coronal mass ejections: geomagnetic activity forecast, GPS/GNSS positioning error, etc.
- Empirical neutral density model for orbit prediction (Jacchia-Bowman 2008)





Polar cap absorption and radiation hazard



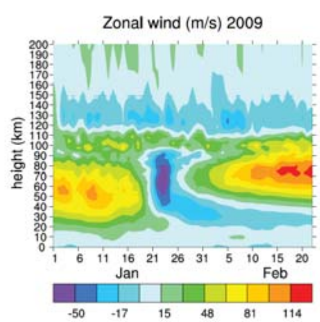
US-TEC for GPS positioning correction

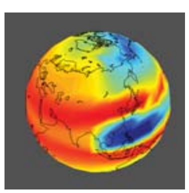
Research Methodology

- CST requires an integration of terrestrial and space weather conditions (from one coordinated source)
- Seamless model from the ground to 600 km altitude to fill gap between conventional weather and space weather for commercial space transportation
- Neutral atmosphere weather forecast for winds, temperature, density, turbulence, and satellite drag
- Ionospheric space weather forecast for plasma density and ionospheric irregularity conditions
- Radiation hazard (e.g., NAIRAS potential new start)

Research Methodology

- **Global seamless neutral whole atmosphere model (WAM) 0-600 km, 0.25 scale height, 2° x 2° lat/long, hydrostatic, 10-fold extension of Global Forecasting System (GFS) US weather model.**
- **O_3 chemistry and transport**
- **Radiative heating and cooling**
- **Cloud physics and hydrology**
- **Sea surface temperature field and surface 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**

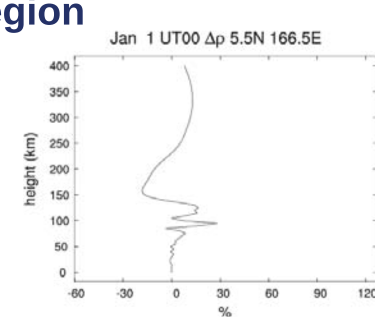


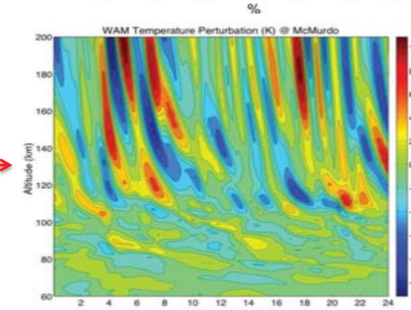


Coupled to a global ionosphere, plasmasphere, electrodynamics module (GIP) for plasma parameters

Variability in the re-entry region

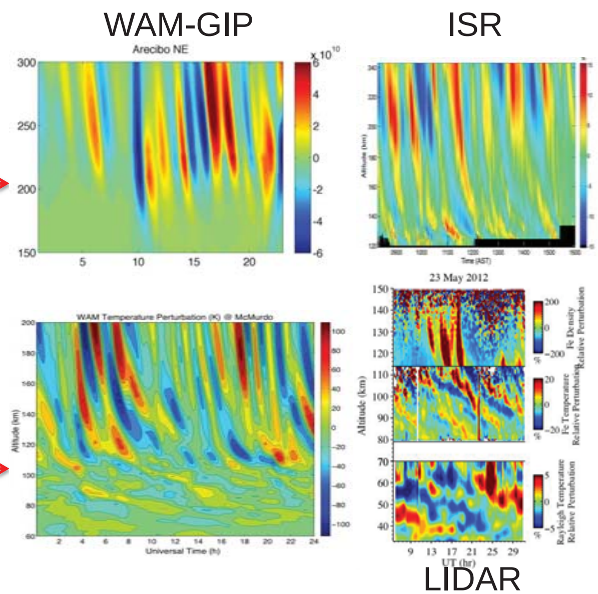
- Tropospheric weather drives localized and steep density gradients in the sub-orbital and re-entry region (80 to 150 km altitude).
- The whole atmosphere model (WAM) is able to simulate and hopefully predict this structure for situational awareness
- Efforts are under way to validate the WAM structure by comparing with ground-based LIDAR observations in the mesosphere and lower thermosphere, in collaboration with colleagues at CU (Xinzhao Chu and Xian Lu).



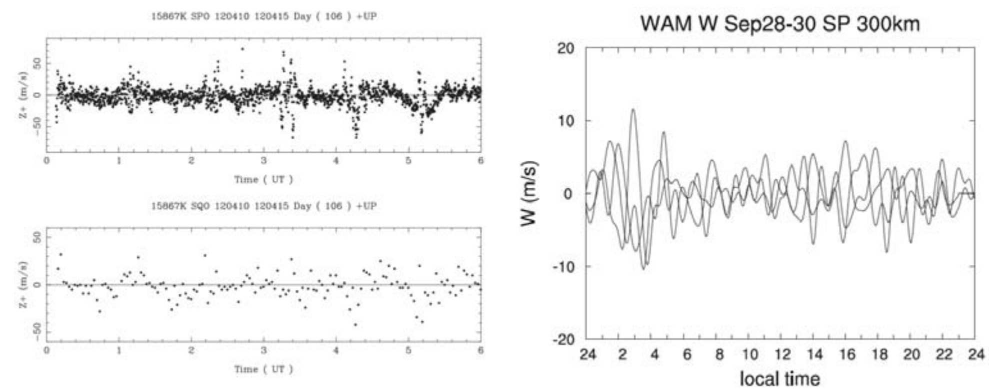


Validation: ionosphere and Fe LIDAR

- WAM fields drive ionospheric structure in good agreement with observations from incoherent scatter radar (ISR)
- WAM structure also agrees well with ground-based LIDAR observations in the mesosphere and lower thermosphere

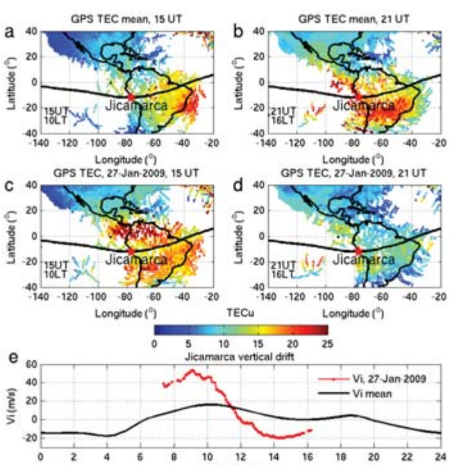


WAM Validation: Fabry-Perot tri-static south pole vertical winds (Gonzalez Hernandez)

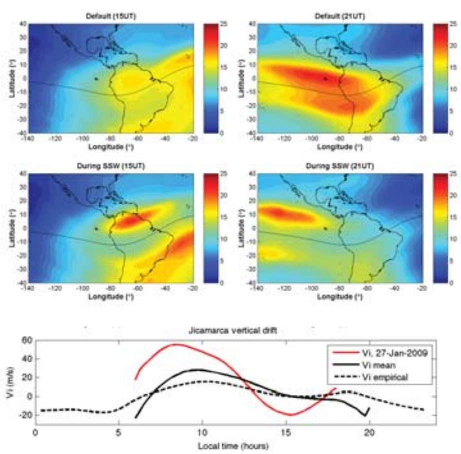


Simulation of January 2009 dynamics and impact on EIA

GPS-TEC and Jicamarca vertical plasma drift before and after SSW (Goncharenko/Chau



WAM-GIP before and after SSW



Reasonable agreement between GIP and observations on Jan 27th at 15 and 21 UT, equivalent to 10 and 16 LT over SA

Summary, Conclusions, and Next Steps:

- WAM and GIP are developed and are being validated to combine terrestrial and space weather conditions through the whole atmosphere-ionosphere
- WAM is being integrated into the NOAA Environmental Modeling System (NEMS) to be transitioned into operations in ~2015
- WAM predicts strong neutral density structure in the re-entry region ~50-100%
- WAM spectrum of variability agrees with ISR N_e, Fe LIDAR, and FPI winds

Next steps:

- **Continue to validate** WAM and GIP and explore impact on density, drag, and ionosphere structure
- Establish full **two-way coupling of WAM to the ionosphere** GIP module to determine balance between lower atmosphere and solar/magnetospheric space weather forcing
- **Extend WAM data assimilation** into the lower thermosphere (SABER, MLS temperatures, etc.)
- Test **higher resolution WAM T382** (35 km resolution) to resolve small-scale wave field penetrating to the thermosphere and impacting density and ionosphere structure
- Explore **assimilation of ionospheric data** for density prediction
- Whole atmosphere/ionosphere data assimilation at high resolution

Contact Information

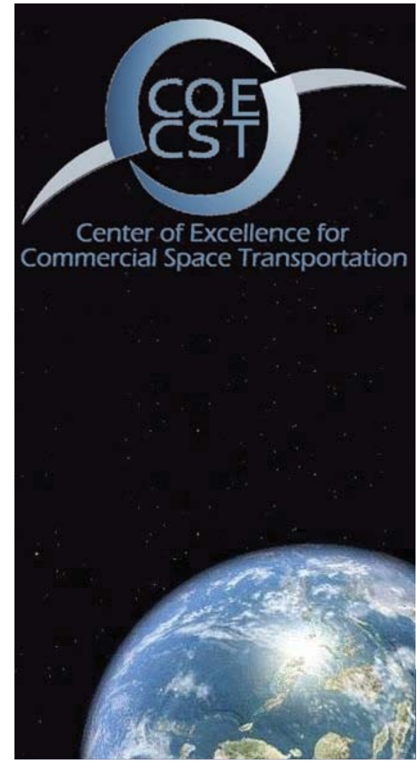
- **Dr. Tim Fuller-Rowell,** Physicist, Cooperative Institute for Research in Environmental Sciences, University of Colorado/Space Weather Prediction Center, Tim.Fuller-Rowell@noaa.gov
- **Dr. Tomoko Matsuo**, Physicist, Cooperative Institute for Research in Environmental Sciences, University of Colorado/Space Weather Prediction Center, Tomoko.Matsuo@noaa.gov
- **Dr. Houjun Wang**, Physicist, Cooperative Institute for Research in Environmental Sciences, University of Colorado/Space Weather Prediction Center, Houjun.Wang@noaa.gov
- **Dr. Fei Wu**, Physicist, Cooperative Institute for Research in Environmental Sciences, University of Colorado/Space Weather Prediction Center, Fei.Wu@noaa.gov
- **Catalin Negrea**, Student, CU Electrical, Computer, and Energy Engineering, Catalin.Negrea@noaa.gov
- **Dr. Mihail Codrescu**, Physicist, NOAA/Space Weather Prediction Center, Mihail.Codrescu@noaa.gov
- **Dr. Rodney Viereck**, Physicist, NOAA/Space Weather Prediction Center, Rodney.Viereck@noaa.gov
- **Dr. Jun Wang**, Physicist, NOAA/Environmental Modeling Center, Jun.Wang@noaa.gov
- **Professor Jeffrey M. Forbes**, Department Chair, Aerospace Engineering Sciences, University of Colorado, Forbes@Colorado.edu

COE CST Third Annual Technical Meeting:

Space Environment MOD Modeling and Prediction

Alan Li and Sigrid Close

October 29, 2013



Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results or Schedule & Milestones
- Next Steps
- Contact Information

Team Members

- **Sigrid Close, Stanford University (PI)**
- **Alan Li, Stanford University (graduate student)**
- **Steven Pifko, Ryan Volz and Jonathan Yee, Stanford University (graduate students supported by NSF)**

Purpose of Task

- **Spacecraft are routinely impacted by space debris and natural impactors**
  - Mechanical damage: "well-known", larger (> 120 microns), rare

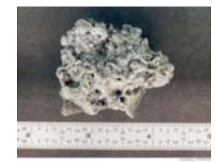
    Electrical damage: "unknown", smaller/fast, more numerous

- **Goal: Characterize impactor population and provide predictive threat assessment**

Impactors

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

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



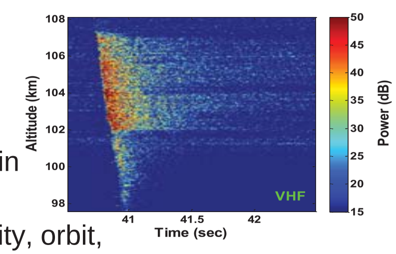
Methodology: Meteoroids

- **Atmospheric Plasma**

  Data: ground-based radar

  Models: Particle-In-Cell (PIC) for plasma development, Finite Difference Time Domain (FDTD) for EM interaction with plasma

  Deliverables: energy flux, mass, bulk density, orbit, prediction



- **Impact Plasma**

  Data: ground-based accelerators

  Models: Computational Fluid Dynamics (CFD) for initial conditions, PIC for plasma development and RF emission

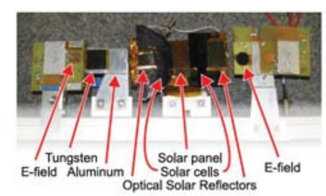
  Deliverables: plasma composition, temperature, RF spectra

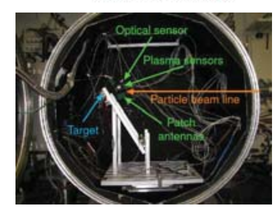
Meteoroid Data

- **Radars**
  - ALTAIR
  - Arecibo Observatory
  - MIT Millstone
  - MU

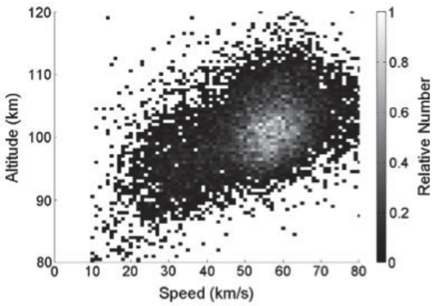
- **Accelerator**

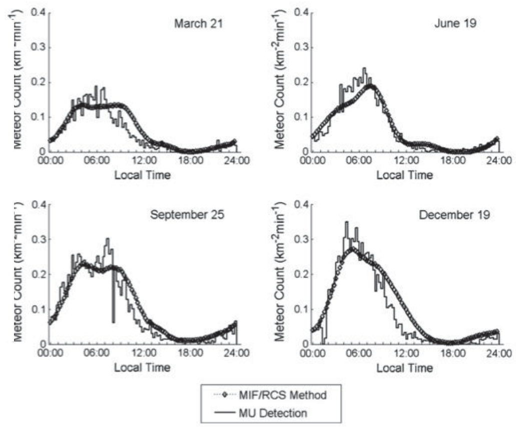
  Van de Graaff at Max Planck Institute



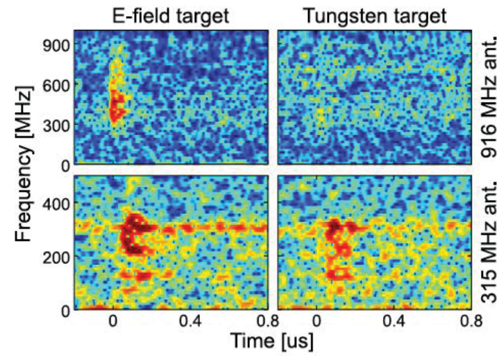


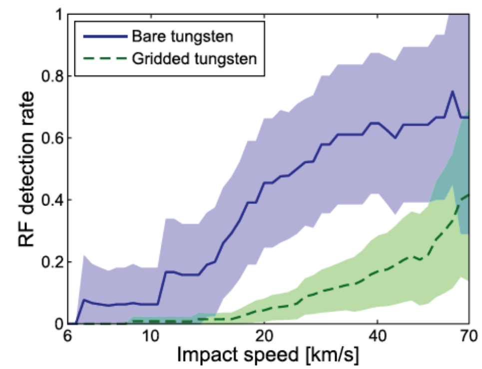
Meteoroid Atmospheric Plasma: Speed and Seasonal Dependence





Meteoroid Impact Plasma: RF Emission



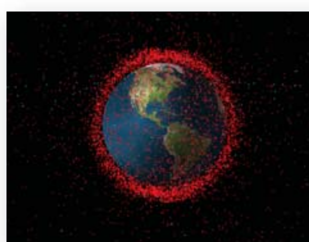


Methodology: Debris

- **Remote Sensing**
  - *Data*: ground-based radar

    Models: ORDEM for environment, LEGEND and MASTERS for collision and propagation

    Deliverables: shape factor, flux, orbit, prediction



- **Impact Experiments**

  Data: future light-gas gun tests

  Models: Computational Fluid Dynamics (CFD) for initial conditions, PIC for plasma development and RF emission

  Deliverables: plasma composition, temperature, RF spectra

Debris Data

- **EISCAT Svalbard radar**

  78.1°N, 16.0°E

  500 MHz, 32 m dish, 0.8 MW peak power

  Az 182.1°, El 81.6°

- **Data collection**

  Primarily during IPY (International Polar Year) from January 2007 to February 2008

Debris Modeling Results

- **ORDEM (NASA)**
  - Environment

    Data: SSN, HAX, Goldstone, LDEF, returned arrays from HST

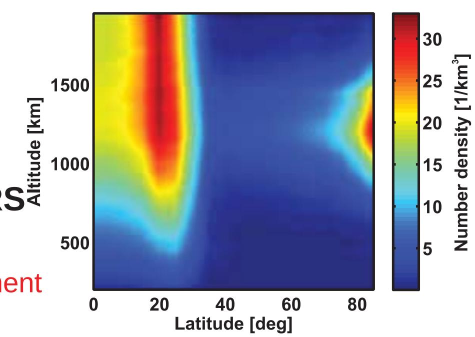
    Model: EVOLVE (used to extrapolate where data is scarce
- **LEGEND (NASA) and MASTERS (ESA)**

  Collision and propagation (environment evolution)

  Includes drag modeling

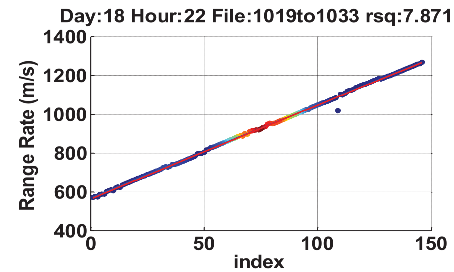
  MASTERS predicts lower amount of small debris

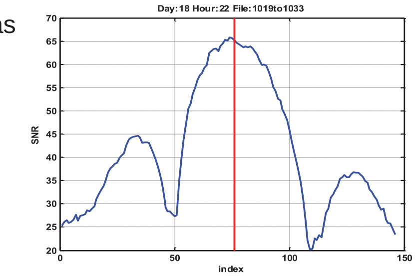
ORDEM 2000 for debris > 0.01 mm



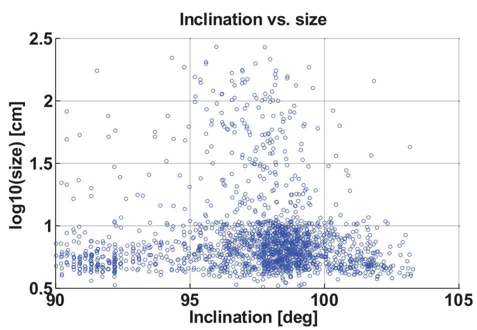
Orbital Parameter Estimation

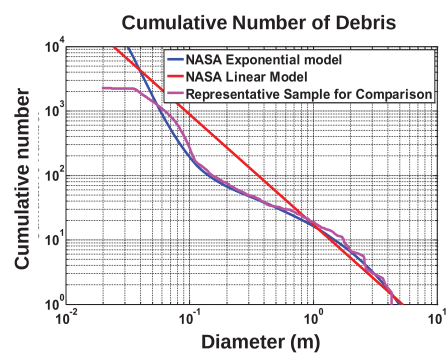
- Difficult to determine orbital parameters given lack of interferometry
- General description:
  - Fit range and range rate to parabolic and linear profiles
  - Point of symmetry within SNR pattern as initial starting point
  - Assume direction of v_{debris} (initially perpendicular to r_{debris})
  - Rotate v_{debris} by θ and φ (similar to azimuth and elevation angles)
  - Propagate orbit and fit with range and range rate data





Debris Results





Next Steps

- **Meteoroids**

  Energy flux model

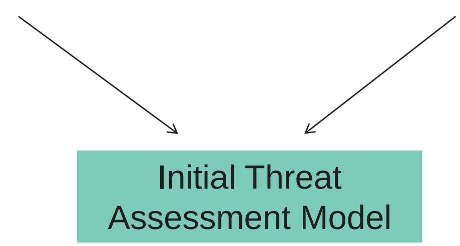
  Spectra of RF emission

  Effect of charging on electrical failure mechanism
- **Debris**

  Continue EISCAT analysis

  Comparison of EISCAT data with MASTERS/ORDEM

  Light-gas gun experiments



Publications

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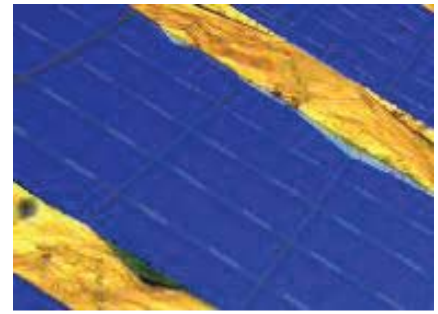
- Close, S., I. Linscott, N. Lee, T. Johnson, D. Strauss, A. Goel, D. Lauben, R. Srama, A. Mocker, and S. Bugiel (2013), Detection of electromagnetic pulses produced by hypervelocity micro particle impact plasmas, *Physics of Plasmas*, *20*, 092102, 1–8, doi:10.1063/1.4819777.
- Lee, N., S. Close, A. Goel, D. Lauben, I. Linscott, T. Johnson, D. Strauss, S. Bugiel, A. Mocker, and R. Srama (2013), Theory and experiments characterizing hypervelocity impact plasmas on biased spacecraft materials, *Physics of Plasmas*, *20*, 032901, 1–9, doi:10.1063/1.4794331.
- Lee, N., S. Close, and R. Srama (2013), Composition of plasmas formed from debris impacts on spacecraft surfaces, *Sixth European Conference on Space Debris*.
- Pifko, S., D. Janches, S. Close, J. J. Sparks, T. Nakamura, and D. Nesvorny (2013), The Meteoroid Input Function and predictions of mid-latitude meteor observations by the MU radar, *Icarus*, *223*, 444–459, doi:10.1016/j.icarus.2012.12.014.

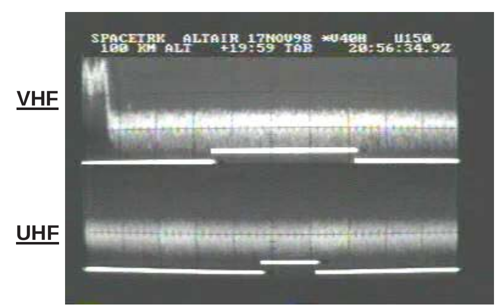
Thank You!

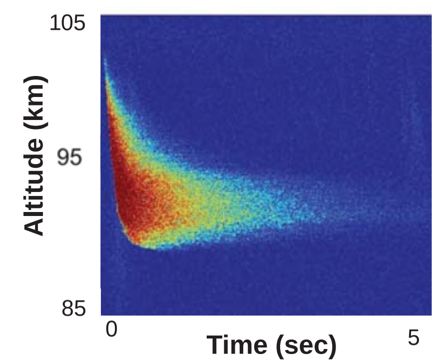
- **Alan Li (alanli@stanford.edu)**
- **Sigrid Close (sigridc@stanford.edu)**



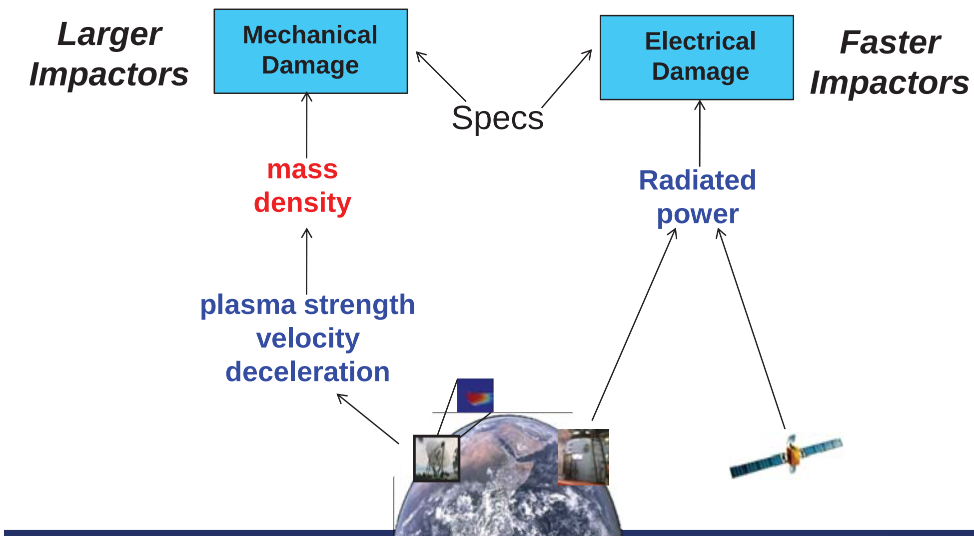
Backup

ALTAIR Radar Data

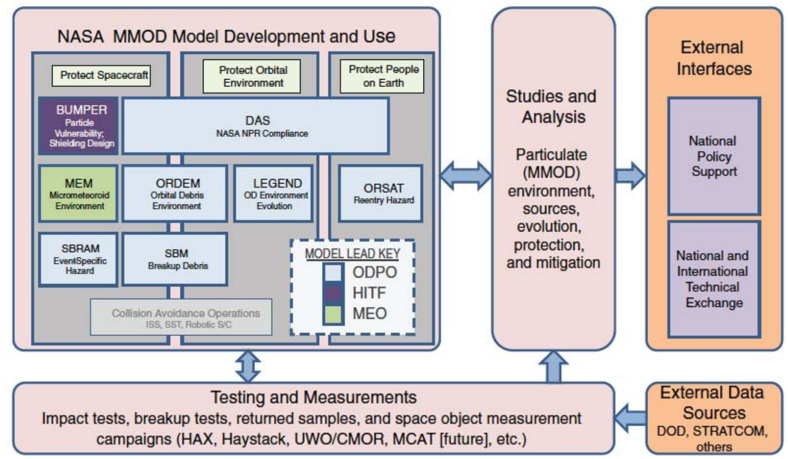




Mechanical and Electrical Damage



NASA Approach



COE CST Third Annual Technical Meeting (ATM3)
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Center of Excellence for Commercial Space Transportation

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Results or Schedule/Milestones

- 1-2 slides

Next Steps

Contact Information

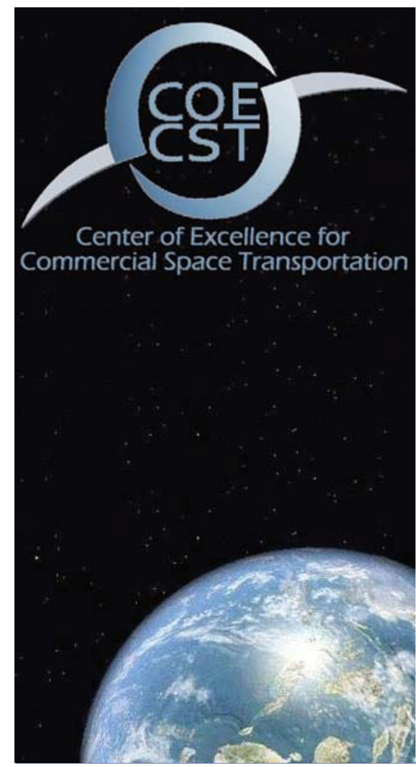
COE CST Third Annual Technical Meeting:

Space Situational Awareness

D.J. Scheeres

University of Colorado Boulder

October 29, 2013



Overview

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Team Members

Direct Current / Past Support from the FAA COE
•Dan Scheeres, CU Professor, PI
•George Born, CU Professor, Co-I
•Bob Culp, CU Professor Emeritus, Co-I
•Brandon Jones, CU Assistant Research Professor
•Jay McMahon, CU Assistant Research Professor
•Kohei Fujimoto, CU PhD Student (graduated May 2013)
•In-Kwan Park, CU PhD Student (future support)
Related Research from Fellowship Students
•Aaron Rosengren, CU Graduate Student, NSF Fellow
•Antonella Albuja, CU Graduate Student, NSF Fellow
•Daniel Lubey, CU Graduate Student, NSTRF Fellow
Government and Industry Partners
•AFRL Kirtland and Maui
•NASA Orbit Debris Program Office
•Analytical Graphics, Incorporated
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Government and Industry Partners
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•NASA Orbit Debris Program Office
•Analytical Graphics, Incorporated
•Orbital Sciences Corporation

Purpose of Task

- ***Space Situational Awareness***

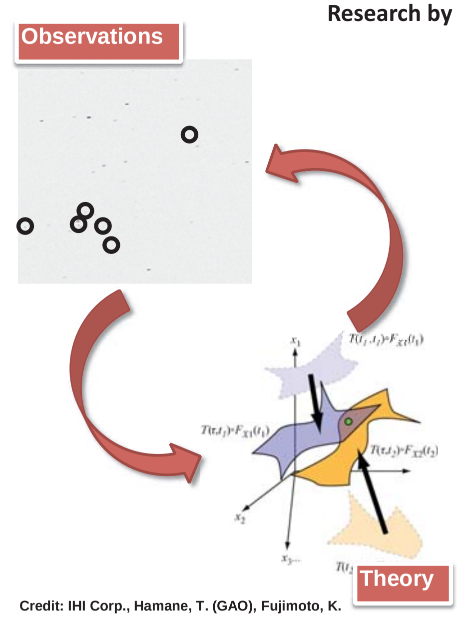
  SSA = Cognizance of Resident Space Objects (RSO) and activities in orbital regions of interest, both now and in the short and long-range future.
- **Objectives**
- **Current regions of focus** *down* *up*
- **Goals are to improve**

Research Methodology

- Directly funded FAA research on initial orbit determination, object correlation, uncertainty mapping and conjunction analysis
- Leverage other student support models to perform research of relevance to the overall goals of the FAA COE CST
  - Long-term orbit and physical dynamics of space debris, and their implications
  - Current student support from NSF and NASA through fellowships
- Previous research output and results
  - Presented 22 papers at 12 international conferences
  - Published 5 papers in peer-reviewed journals
  - Submitted additional 4 papers to journals

Association of Optical Observations

Research by Kohei Fujimoto

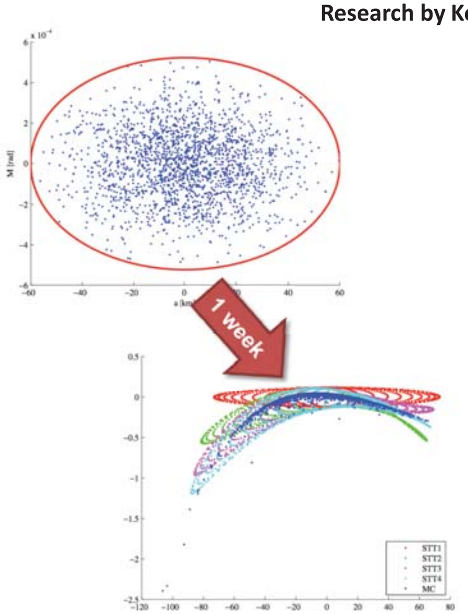


Credit: IHI Corp., Hamane, T. (GAO), Fujimoto, K.

- Direct Bayesian approach to observation association
  - Exploits sparseness of the estimation problem
  - Robust with little tuning
  - Presented at IAC 2012
- Experimentation with real-world observations
  - Collaboration with IHI Corp., University of Bern
  - Developed techniques to take into account measurement error
  - Presented at ISTS 2013
- "Closing the loop" on the too-short-arc problem
  - Papers describing our research advances submitted to Journal ASR

Analytic Propagation of Uncertainty

Research by Kohei Fujimoto



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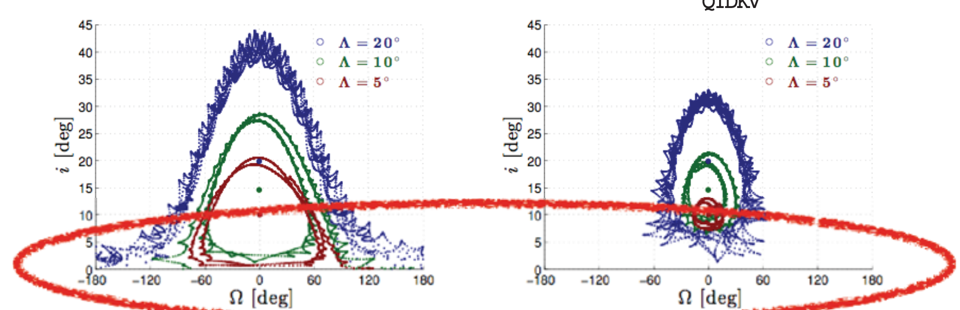

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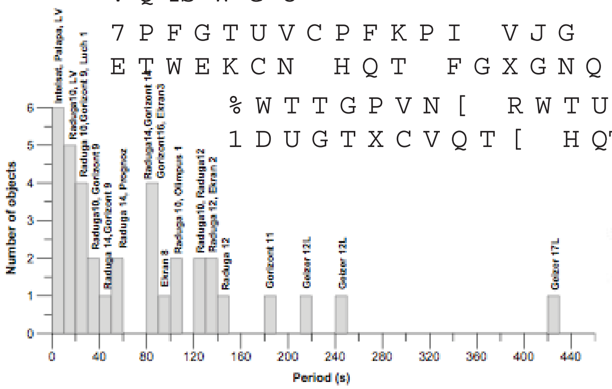

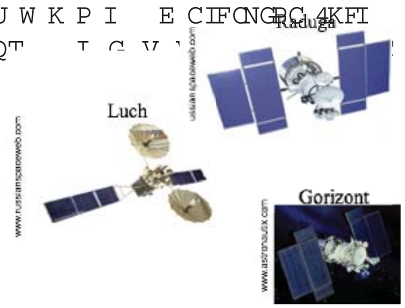

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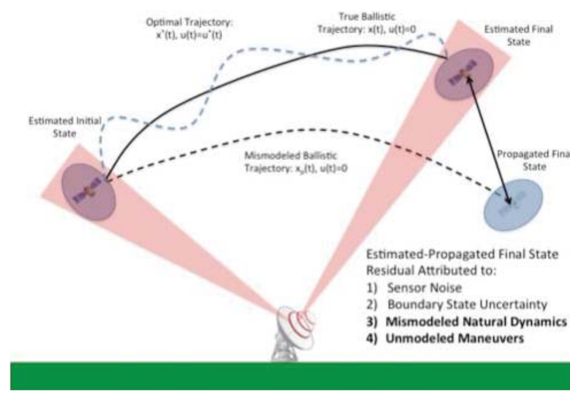
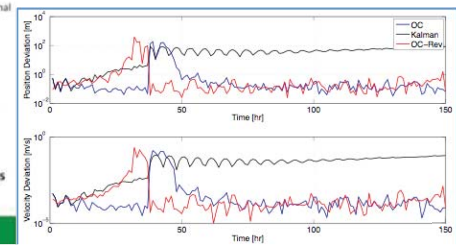




Next Steps

- Spent allocated funds through May 2013
  - Due to sequestration restrictions additional funds not available to date
  - Prospects for a restart on funding appear positive
- Next stage of FAA directly-funded research:
  - Plan to integrate previous research on uncertainty propagation, model estimation and conjunction analysis to develop a tool for rapid, long-term assessment of debris impact hazard and risk

Contact Information

- Questions:
  - Dan Scheeres
  - <scheeres@colorado.edu>
  - 1-720-544-1260

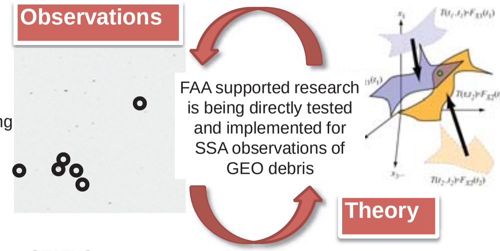
TASK 187. Space Situational Awareness Improvements

•**PROJECT AT-A-GLANCE**
•UNIVERSITY: University of Colorado at Boulder
•PRINCIPAL INVESTIGATOR: Dr. Dan Scheeres
•STUDENT RESEARCHER: Dr. Kohei Fujimoto (PhD)

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

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

Association of space debris observations



STATUS
- Graduated one PhD student: Kohei Fujimoto, May 2013
- Combined student team focused on relevant SSA research topics of direct interest to the COE
- Presented over 22 distinct papers at 12 conferences
- 5 papers published, 4 more in preparation

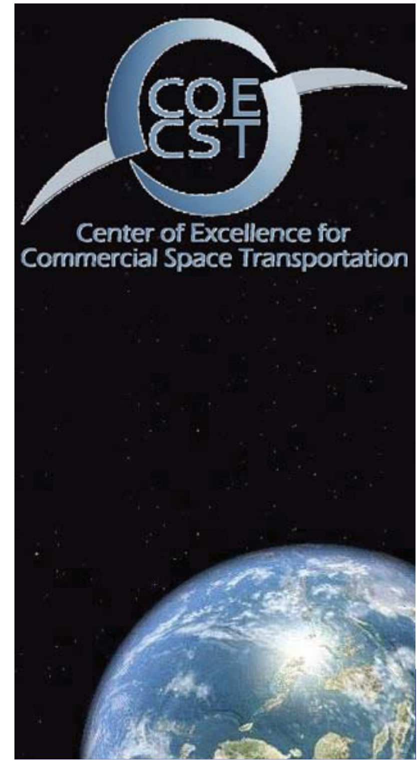
FUTURE WORK
- Next stage of direct FAA funded research will focus on developing a rapid asset/debris conjunction analysis tool
- Non-directly funded research will focus on:
  - Long-term space debris dynamics (orbit and attitude)
  - Modeling and estimation of debris non-gravitational forces

COE CST Third Annual Technical Meeting:

Task 193:Role of COE CST in EFP

PI: George H. Born

October 30th 2013



Overview

- Team Members
- Purpose of Task
- ESIL
- Other Support
- Publications
- Next Steps
- Contact Information

Team Members

- **George H. Born** – Director Emeritus, Colorado Center for Astrodynamics Research
- **Bradley Cheetham** – Graduate Research Assistant, CU Boulder, Aerospace Engineering Sciences
- **Juliana Feldhacker** – Graduate Research Assistant, CU Boulder, Aerospace Engineering Sciences

Recently Added Industry Partners

Purpose of the Task

Objectives:

- Identify key industry characteristics to facilitate EFP efforts
- Host targeted workshops to engage students and young professionals
- Support conferences to educate students and young professionals
- Incorporate young professional perspectives in ongoing industry planning efforts

COE CST Third Annual Technical Meeting (ATM3)
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Center of Excellence for Commercial Space Transportation

COE Objectives

Research

- Products of workshop and ongoing EFP supporting activities

Training

- Emerging Space Industry Leaders Workshop Series

Outreach

- Disseminating activity results, promoting a broader understanding of commercial space

COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013
Center of Excellence for Commercial Space Transportation

ESIL Workshops

- Emerging Space Industry Leaders Workshop series
- Objectives:
  - Inform – perspective, background, context
  - Perform – group analysis
  - Network – internal and external to industry
- Impact:
  - 62 participants and counting
  - 2 publications complete (1 in progress)

COE CST Third Annual Technical Meeting (ATM3)
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ESIL-01 – October 2011

- 26 participants
- Industry segments:
  - Point-to-point
  - Lunar Mining
  - Hosted Payloads
- Guest Contributors
  - Dennis Stone – NASA JSC
  - Max Vozoff – mv2space
  - Diane Dimeff - eSpace

ESIL-02 – March 2012

- 12 Participants
- Industry focus:
  - Government role in commercial space
- Guest contributors
  - Richard Dunn – DoD Acq.
  - Chris Shank – dCoS L. Smith
  - Alan Ladwig – NASA HQ
  - James Finch – OSD
  - Jim Van Laak – FAA AST
  - Clay Mowry - Arianespace

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ESIL-03 – November 2012

- 10 Participants
- Industry focus:
  - Commercial human spaceflight training
- Guest Contributors
  - Brienna Henwood

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ESIL-04 – June 2013

- 14 Participants
- Industry focus:
  - Microgravity utilization
- Guest contributors:
  - Sirisha Bandla – CSF
  - Cassie Kloberdanz – SNC
  - Dan Durda – SwRI
  - Khaki Rodway – XCOR

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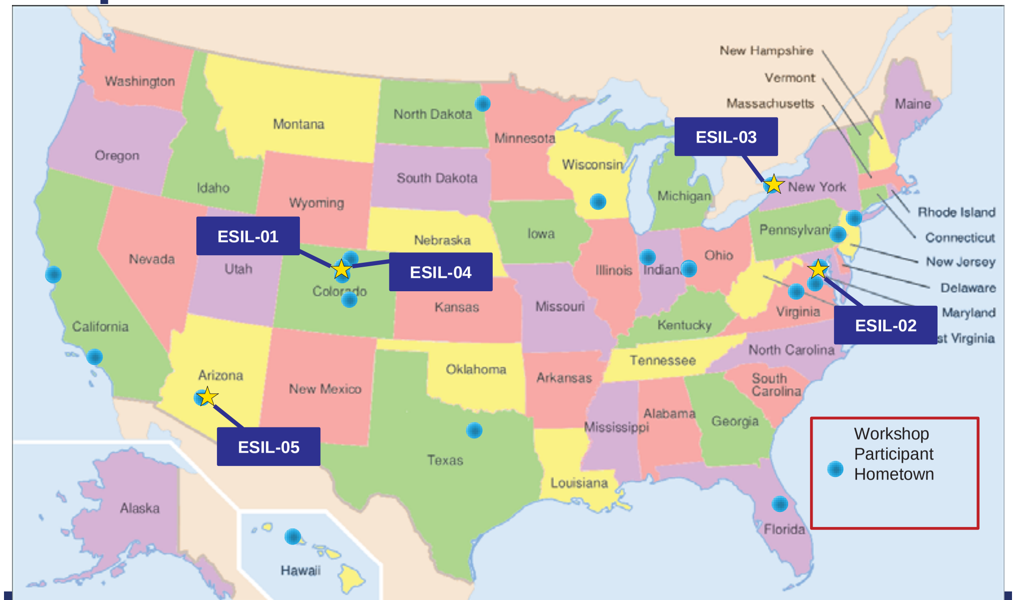
Impact



Support Other Events

- SpaceVision Conference (2011 & 2012)
  - Logistics/planning/speaker support
- Space Generation Fusion Forum (2012 & 2013)
  - Logistics/planning/speaker support
  - Video recording support
  - Badge lanyards

Publications/Presentations

- **Microgravity Utilization** (paper in progress, venue TBD)
- Henwood, Brienna, Nathan Wong, John Stark, Ken Davidian, Bradley Cheetham, Kaizad Raimalwala, Matt Cannella, Liz Kennick, Sirisha Bandla, Jules Feldhacker, Jim Crowell, **"The 'Game' of Training Humans for Commercial Suborbital Spaceflight,"** 64th International Astronautical Congress, Beijing China, IAC-13-E6.2.3
- Cheetham, Bradley, Juliana Feldhacker, Angela Peura, Ashley Chandler, Cassie Kloberdanz, Lewis Groswald, **"Government's Role in Commercial Space from the Perspective of Emerging Industry Leaders,"** 63rd International Astronautical Congress, Naples Italy, IAC-12-E6.4-D4.2.1.
- Cheetham, B.W**., "Theory Based Analysis of the Commercial Crew to Orbit Transportation Industry Structure and Evolution,"** IAC-12-E6.1.6, 63rd International Astronautical Congress, Naples, Italy, October 1-5, 2012.
- Cheetham, B.W**., "Strategic Evaluation of Commercial Crew to Orbit Transportation Industry Structure and Status,"** IAC-11-D4.2.1, 62nd International Astronautical Congress, Cape Town, South Africa, October 3-7, 2011.
- Cheetham, B.W., **"Industry Structural Analysis of Commercial Crew to Orbit Sector,"** IAC-10-E6.3.1, 61st International Astronautical Congress, Prague, Czech Republic, September 27 – October 1, 2010.

Next Steps

- ESIL-05 - Tempe Arizona - November 6th-7th
- Topic: Small spacecraft transportation to orbit (as hosted payload, secondary payload, or dedicated launch)
- Virtual forum
  - During workshop discussion
  - Post-workshop virtual sessions with industry members
- Future workshops
  - Silicon Valley, Boston, International, others?

COE CST Third Annual Technical Meeting:

Task SU-193: Opportunities for Secondary & Hosted Payloads on NASA Missions

Professor Scott Hubbard

October 30, 2013

Contact Information

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George.Born@Colorado.edu

Bradley Cheetham
Bradley.Cheetham@Colorado.edu

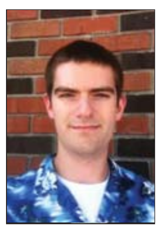
Bit.ly/ESIL_Home

Team Members

PI: Prof. Scott Hubbard

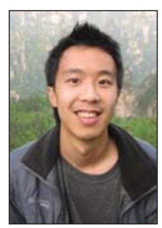
Stanford University
Department of Aeronautics and Astronautics

Jonah Zimmerman



Stanford University
Department of Aeronautics and Astronautics
PhD Candidate

Andrew Ow



Stanford University
Graduate School of Business
MBA

Industry Partners

ULA, Lockheed Martin, Scitor Corporation, Orbital, Space Systems Loral

Motivation

- Results of research roadmapping work for the COE:

  "What is the market?" remains an open question to the CST industries. Identifying and verifying the suborbital and orbital microgravity commerce and research opportunities is of prime importance.

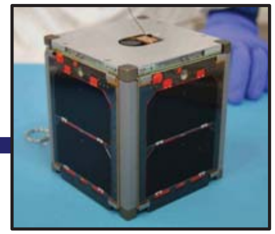
- Focusing on secondary and hosted orbital payloads represents a tractable portion of this task
  - Topic was strongly suggested by several industry partners during roadmap workshop

Secondary & Hosted Payloads

Terminology:

- **Secondary Payloads:** independent satellites that are carried into orbit on the same vehicle as the primary, utilizing any excess capability of the launch vehicle
- **Hosted Payloads:** small payloads that are directly affixed to the primary satellite, using its bus for power and communications

Title	Payload Size
Mini	100kg-500kg
Micro	10kg-100kg
Nano	1kg-10kg
Pico	100g-1kg



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The Opportunity

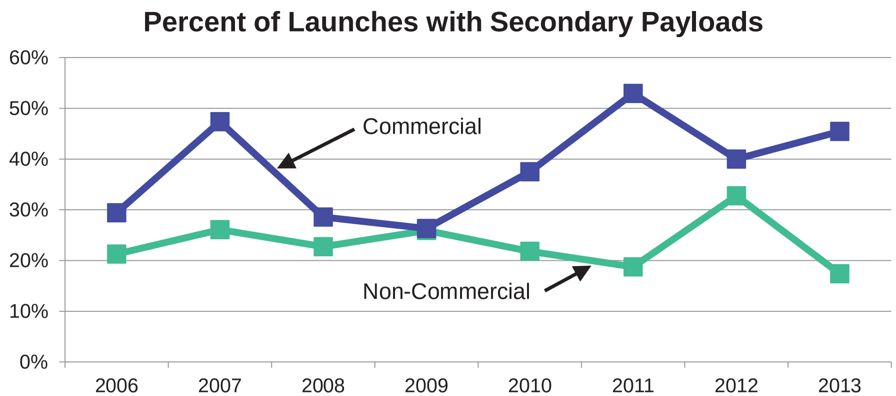
- Nearly every launch has some unused vehicle capacity
- Secondary and hosted payloads can use this resource
  - Low cost access to space for a small payload has many appealing applications and missions
  - Missions can be enabled by having distributed architectures across numerous small satellites or hosted payloads
    - e.g. communications networks, space situational awareness, earth observation, navigation

Commercially Hosted Infrared Payload (CHIRP)
USAF tech demo (SAIC) on SES-2 (Orbital)
- 13% of the cost of a dedicated mission
- 80% of the mission objectives accomplished

(Office of Space Commercialization)

Commercial vs Non-Commercial

Launches with a commercial satellite are more likely to have secondary payloads
- Worldwide average over 7.5 years: 38% vs 24%



What Can We Do?

- Commercial launches
  - Already taking advantage of secondary payloads
  - New companies are working to aggregate payloads
- Military launches
  - Information unavailable
- Civil government (NASA) launches
  - Public information
  - Launches organized by centralized authority
  - Many established contacts at NASA

Policy Impact

Impact on Future Policy

- If there is a convincing argument a new policy could be introduced
- For example, require that excess launch capacity be identified at the time of a strategic mission assignment or Announcement of Opportunity
- Utilize excess capacity for technology demonstration or science investigation

Current Policy (Launch Services Program "Path to the Future")

- *"Determine the best way to implement PPOD/Ridesharing/Dual Manifest opportunities"*
- *"Develop LSP's (small class) launch services strategy"*

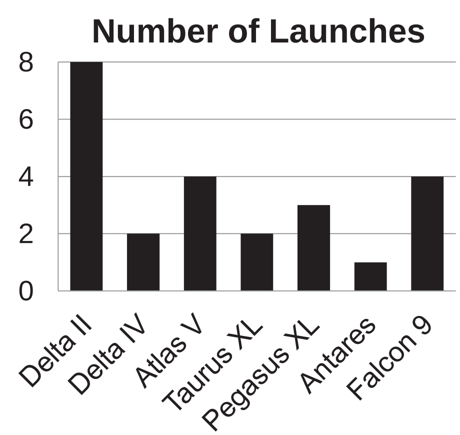
Approach

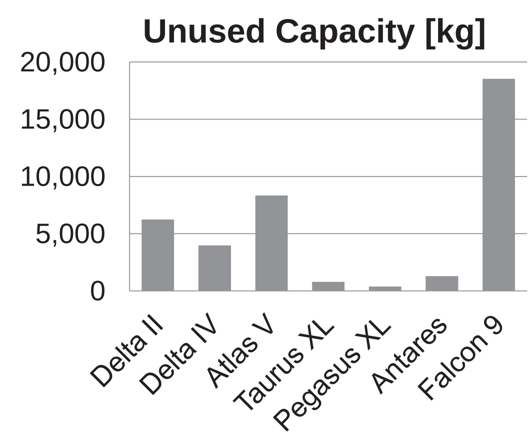
- Research and Document Key Elements of Argument:
  1. **Prove that there is excess capacity**
  2. Demonstrate that this capacity is a valuable resource
  3. Use case studies to show that the capacity could be useful for high-return missions
- Present results to NASA policy makers, for example:
  - Launch Services Office, NASA HQs
  - Science Mission Directorate
  - Space Technology Mission Directorate

Demonstrate Excess Capacity

- Compiled database of recent NASA launches
  - For each, determine payload mass and launch vehicle payload capacity
  - 34 launches from January 2006 to August 2013
  - 10 (29%) are to orbits with no published launch vehicle payload capacity
  - Of the 24 launches we have numbers for
    - 55,600 kg worth of payload launched
    - 39,600 kg worth of payload unused (42%)
    - 5,280 kg per year
    - 1,650 kg per launch

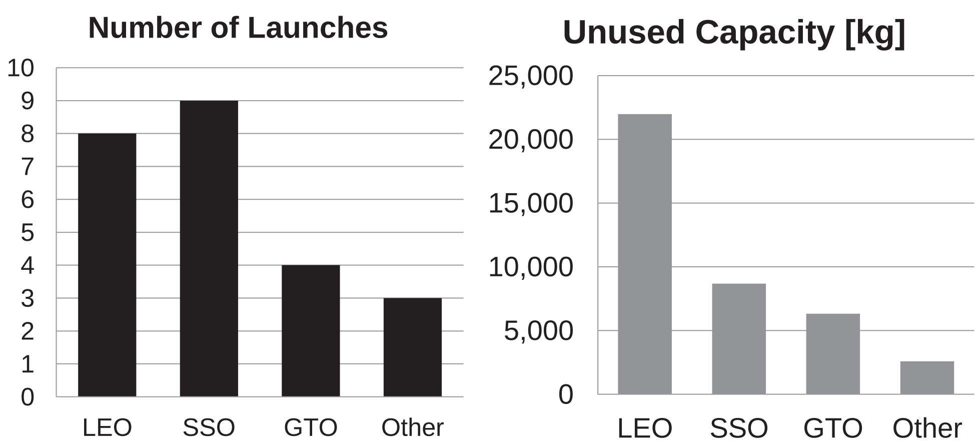
Breakdown by Launch Vehicle





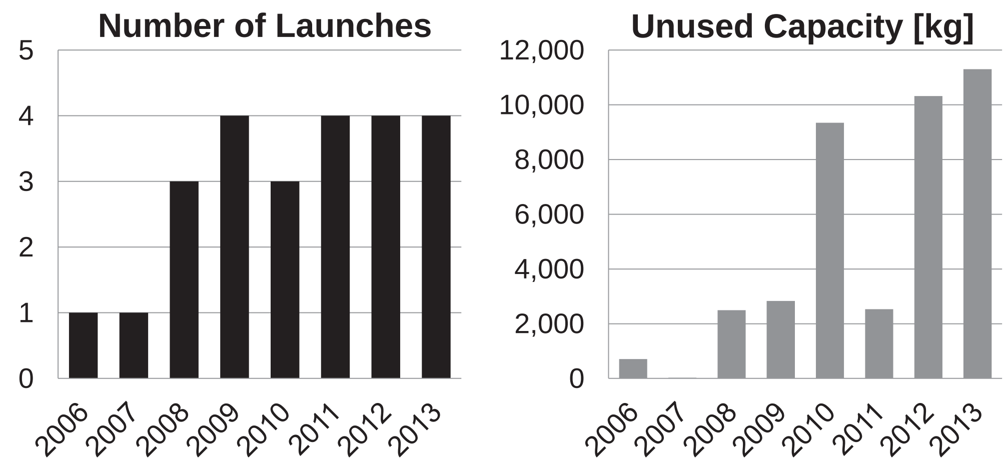
SpaceX and ULA have most unused capacity

Breakdown by Orbit



LEO has most unused capacity

Breakdown by Year



It's getting worse with time

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Caveats

Uses for Excess Capacity

- Wider launch windows
- Trajectory optimization possible
- Increase primary lifetime
- Larger margin on the launch vehicle

+

Reasons Not to Have SHPs

- Scheduling
- No adapter available
- Risk
- Volume constrained

Results should be interpreted as an upper bound on actual unused capacity

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Value of Excess Capacity

- 2002 study by the Futron Corporation on space transportation costs:

Price per kilogram (2000 dollars)

Vehicle Class	LEO	GTO
Small (Pegasus, Taurus)	$18,642	$41,591
Medium (Delta II, Antares)	$11,024	$26,783
Heavy (Atlas V, Delta IV, Falcon 9)	$9,801	$37,598

- Applied to NASA launch database (2013 dollars):
  - $900M total
  - $117M per year
  - $37.5M per launch

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Conclusions and Future Work

- Three point plan:
  1. ~~Prove that there is excess capacity~~
  2. Demonstrate that this capacity is a valuable resource
  3. Use case studies to show that the capacity could be useful for high-return missions
- Estimate payload capacity for orbits with no published values
- Identify missions to use for case study
- Present case to NASA policy makers

Acknowledgements

- Primary funding:
  - This work was funded by the Federal Aviation Administration Office for Commercial Space Transportation (FAA-AST) under cooperative agreement 10-C-CST-SU-002.
- Some of our industry partners:

ULA United Launch Alliance, Lockheed Martin, Scitor Corporation, Orbital, Space Systems Loral

- Others:
  - Patrick Shannon
  - Tom Komarek

Backup Slides

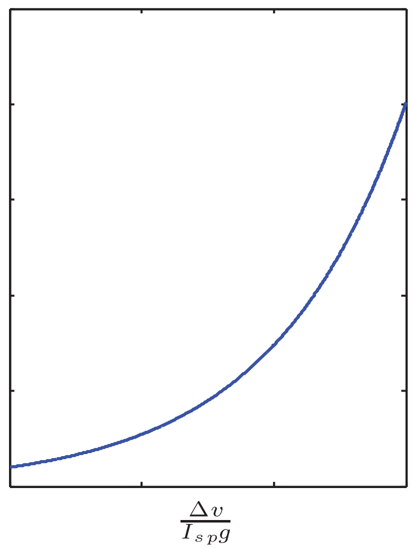
A Little Math

$$T = m\frac{dv}{dt}$$

$$\frac{dv}{dt} = \frac{I_{sp}g}{m}\frac{dm}{dt}$$

$$\Delta v = I_{sp}g \ln\left(\frac{m_i}{m_f}\right)$$

$$\exp\left(\frac{\Delta v}{I_{sp}g}\right) = \frac{m_i}{m_f}$$

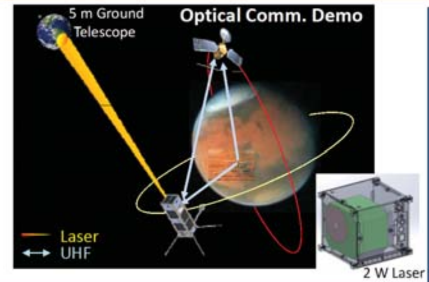


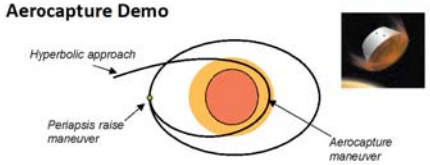
National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

Three Example Mission Concepts

Tom Komarek
JPL

Mars Formulation

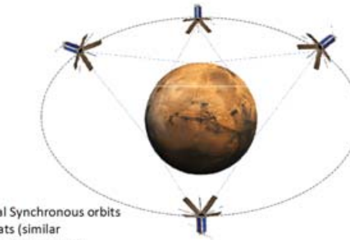




- Aerocapture replaces chemical propulsion as a method of insertion into Mars orbit
- Released on hyperbolic trajectory ~4 days prior to closest approach

- **Optical Comm. Demo:** 5 kbit/s from Mars at 2 AU
- **Aerocapture Demo:** Enables Mars orbit insertion without chemical propulsion
- **Mars CubeSat Network:** Enables spatially distributed continuous coverage for atmospheric or gravity science

Mars CubeSat Network



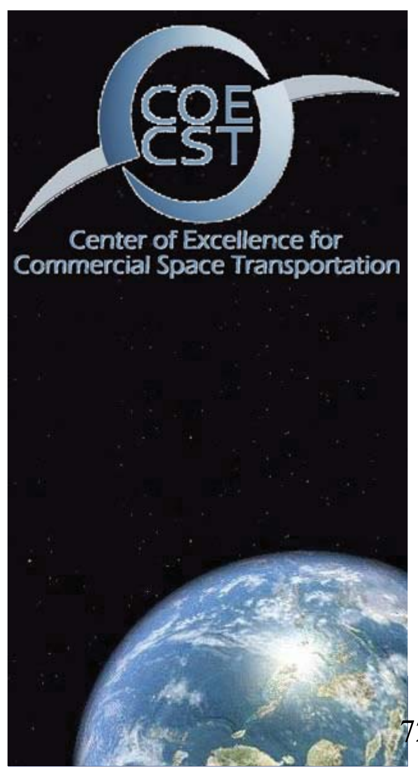
- 3 Equatorial Synchronous orbits
- 1-2 Polar sats (similar observation, lower orbit)

COE CST Third Annual Technical Meeting:

Develop Framework for Commercial Spaceport Operations that creates a Body of Knowledge that captures Best Practices

PI: Patricia C. Hynes, Ph.D

October 29, 2013



Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results or Schedule & Milestones
- Next Steps
- Contact Information

Team Members

- **Pat Hynes,** Principal Investigator, New Mexico State University

Industry Partners:

- **Paul Arthur,** Rear Admiral (Retired), Former Technical Director/Deputy Commander, White Sands Missile Range
- **Herb Bachner,** HBachner & Associates
- **Jim Hayhoe,** Spaceport America Consultants
- **Craig Day,** Director, Business Development, AIAA
- **Bill Gutman,** Chief Technical Officer, Spaceport America
- **Lou Gomez,** Program Manager, Spaceport America

Research Partners:

- **Norice Lee,** Associate Dean, Library, NMSU
- **Ingrid Schneider,** Metadata & Authority Control Librarian, Library, NMSU

Student:

- **Marianne Bowers,** Graduate Intern, Dept. of Government, NMSU

Purpose of Task 1

Develop a Framework - Completed

- Prepare the framework in collaboration with spaceport & federal range directors
  - Project began in February, 2011
  - Held Public meeting to discuss framework variables
  - Updated framework variables to account for public input
  - Surveyed 100% of FAA licensed Spaceport Executive Directors and 5 Federal range operators w Range Commanders Council

Purpose of Task 2

- Identify relevant documents, advisories and circulars for integration into the Framework
- Identify a Document Management System (DMS) that would enable:
  - Public online access 24/7/365
  - System would allow document search by Title, Subject, Or Keyword
  - Could be updated reliably and affordably
- Assure Copyright Protections on included documents.

Cont. Purpose of Task 2

Initial review of all Framework Sections Completed

- Began work 4th Quarter 2012
- Developed Document Management System (DMS) with New Mexico State University Library.
- Developed and sent permission letters to document author permissions for web data usage.
- All 10 sections of the Framework have documents with reference to space or aviation industry procedures, standards or regulations.

Framework Description

Commercial Spaceport Framework
(Top Level)

Reference	Topic
1.0	AIRFIELD & LAUNCH OPERATIONS
2.0	SITE SECURITY
3.0	EMERGENCY RESPONSE
4.0	VISITOR MANAGEMENT
5.0	GROUND AND FLIGHT SAFETY
6.0	ENVIRONMENTAL MANAGEMENT
7.0	MISSION READINESS
8.0	ITAR REQUIREMENTS
9.0	INTERNATIONAL COORDINATION AMONG SPACEPORTS
10.0	SELF-INSPECTION

- 10 Sections
- 133 Sub-Sections
- 60 Documents included
- 33 In progress

TASK 220. Spaceport Operational Framework

- **PROJECT AT-A-GLANCE**
- AST RDAB POC: René Rey, Ken Davidian
- UNIVERSITY: New Mexico State University, Las Cruces, NM
- PRINCIPAL INVESTIGATOR: Dr. Pat Hynes
- STUDENT RESEARCHER: Marianne Bowers, Esq.

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- The commercial space industry has not assembled a Body of Knowledge for commercial spaceport operations. Task 220 developed a framework encompassing tiered elements of commercial spaceport operations.
- Having a framework may allow spaceports to standardize some of their operations while increasing safety.

STATEMENT OF WORK
- Integrate the following into a Framework for Commercial Spaceport Operations
  - Applicable Standards, Documents, Circulars and Advisories
  - Relevant Procedures
- Establish a searchable Document Management System (DMS) containing:
  - Add documents to DMS Database
  - Maintain Access to the Body of Knowledge DMS &
  - Continued testing & dissemination
- Enable documents to be found by title, subject, or keyword
  - Assure copyright protections on DMS documents

Commercial Spaceport Operations
FRAMEWORK
(Top Level)

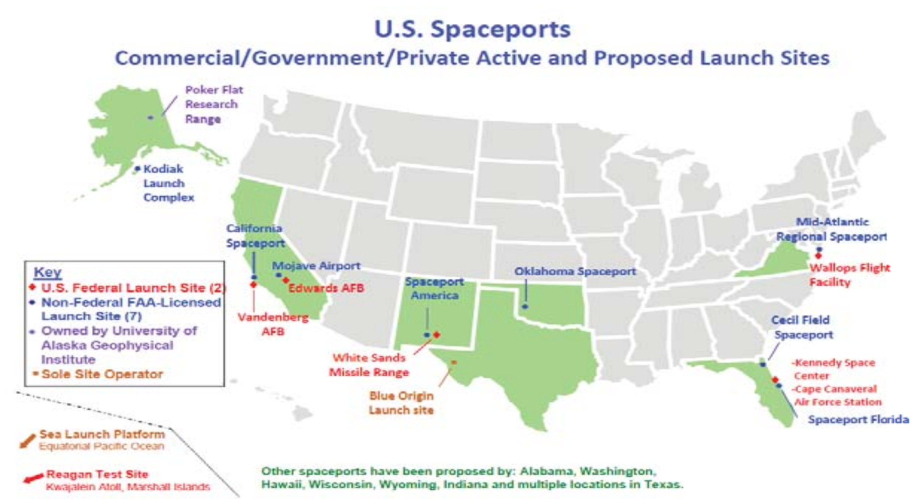
Reference	Topic
1.0	AIRFIELD & LAUNCH OPERATIONS
2.0	SITE SECURITY
3.0	EMERGENCY RESPONSE
4.0	VISITOR MANAGEMENT
5.0	GROUND AND FLIGHT SAFETY
6.0	ENVIRONMENTAL MANAGEMENT
7.0	MISSION READINESS
8.0	ITAR REQUIREMENTS
9.0	INTERNATIONAL COORDINATION AMONG SPACEPORTS
10.0	SELF-INSPECTION

STATUS
- Framework completed and reviewed by 100% of Spaceport Directors & 5 Federal Range Executives in 2012.
- Identified & aggregated over 300 standards & procedures that are relevant to commercial spaceports from 12 different government/non-government reference sources.
- Presented work to COMSTAC Operations Working Group and received support from KSC and Boeing.

FUTURE WORK
- Develop GAP Analysis to identify areas where no documents exist or are available
- List project limitations
- Prepare documentation discussing the development of the project and the steps taken to create the Framework for Commercial Spaceport Operations

Methodology to Establish Document Management System

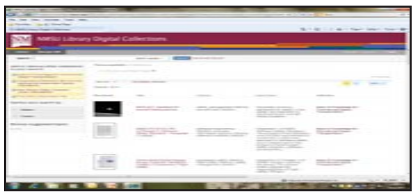
- NMSU Library Digital Library was selected to support the development of the Document Management System (DMS) for the Commercial Spaceport Operations Body of Knowledge
  - Established procedures for access to a database that would contain Spaceport Operational documents and web location references (URL)
  - New Mexico State University Library is licensed to use CONTENTdm, a system that facilitates the storage, management, and delivery of digitized documents and collections to users across the web.
  - The NMSU Library believes this COE project is important and excelled in provided the assistance of a meta-data librarian to set the DMS up.
  - The Body of Knowledge (BoK) Database now has secure access; will eventually be publically accessible and readily updated and maintained consistent with similar large publically available, searchable document collections.



Results

Current Status:

- Defined approach for capturing safety requirements
  - Defined what is in the "family" of commercial spaceport safety documents and what is not. Accepted that some documents used by Federal Ranges (NASA and Air Force) may be useful in a "family" of commercial spaceport safety documents.
  - Clarified/defined the criteria for Spaceport Operator and Spaceport User. A Spaceport User may include a launch operator, a payload developer, a payload operator or funding provider.



Results Cont'd

- Reviewed copyright requirements and developed letters requesting the use of on-line documents by the Spaceport Operations working group in the establishment of the Body of Knowledge (BoK).
  - Multiple document sources reviewed (NASA, AF, WSMR, FAA, NFPA)
- DMS tested by spaceport leaders and technical experts.
- Gathered and reviewed Air Force, NASA, WSMR, FAA, and industry (association) procedures, standards and regulations and inserted this information into the 10 sections of the DMS database in the form of URL's or copies of actual documents.

Results (Continued): Sample of Documents Added to Body of Knowledge (BoK)

- Air Force Space Command Manual 91-710 Range Safety User Requirements [USAF]
- NASA-STD-8719.12 : Safety standards for explosives, propellants, and pyrotechnics [NASA – JSC]
- NASA-STD-8719.13B NASA technical standard: Software Safety Standard [NASA]
- National Fire Protection Association 407 Standard for Aircraft Fueling Service [NFPA]
- NFPA 495: Explosives materials code [NFPA]
- NPD 8700.1E NASA policy for safety and mission success [NASA]
- NPR 8705.5A Technical probabilistic risk assessment (PRA) procedures for safety and mission success for NASA programs and projects [NASA – JSC]
- NPR 8715.3C NASA General Safety Program Requirements [NASA - JSC]
- NPR8715.5A Range flight safety program [NASA]
- United Facilities Criteria (UFC) 3-575-01: Lightning and static electricity protection systems [DoD]
- White Sands Missile Range: Range Customer Handbook [WSMR]
- Guide to reusable launch and reentry vehicle software and computing system safety [FAA]

Next Steps

- Finish adding all identified documents into the DMS
- Review links (URL's) to assure they work
- Develop a GAP analysis methodology for the Framework
- Clarify project limitations.
- Determine timeline for document updates to Framework
- Complete project documentation.

Contact Information

- Patricia C. Hynes, PhD
- 575-646-6414
- pahynes@nmsu.edu

CESTAC Assessment of COE CST Research Program

Partial Statement from the CESTAC Report:

Off nominal launches/landings and aborts are some examples where presumably Spaceports will have infrastructure and processes in place but what responsibilities (required/optional) will individual operators have and the FAA? What guidelines exist for operators?

- The Researchers Developing the Spaceport Framework have found that the Framework:
- Addresses Areas such as Emergency Response, Fire Protection, and other Hazards at an Operational Spaceport.
- Each Spaceport has developed their own procedures that they have shared with the FAA and commercial operators. Their procedures provide for a safe operational environment and these procedures are proprietary documents.

CESTAC Assessment of COE CST Research Program

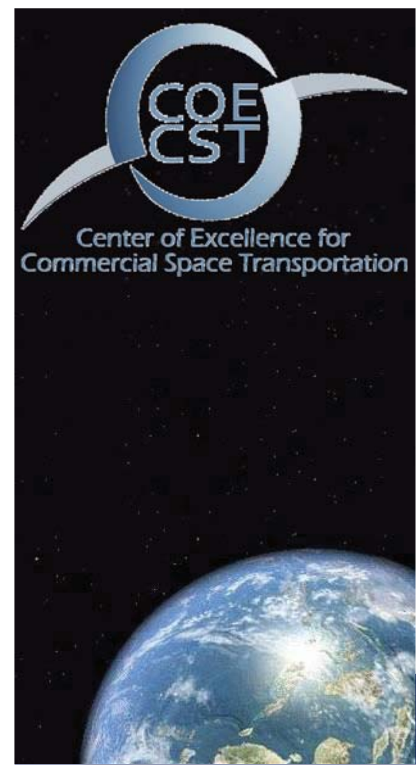
- FAA regulations- Research into the development of a Spaceport Framework indicates:
  - Coordination between the launch operator and the space launch site operator is required under FAA Part 417 including:
    - The launch operator must provide any information on its activities and potential hazards necessary for the launch site operator to determine how to protect any other launch operator, person, or property at the launch site.
    - A launch operator must conduct its operations as required by any agreements that the launch site operator has with Federal and local authorities under FAA Part 420.
    - A launch operator must maintain and document a safety organization.
    - A launch operator must coordinate test plans and associated test procedures with the spaceport operator.
    - Flight safety crews must complete launch site familiarization training.

COE CST Third Annual Technical Meeting:

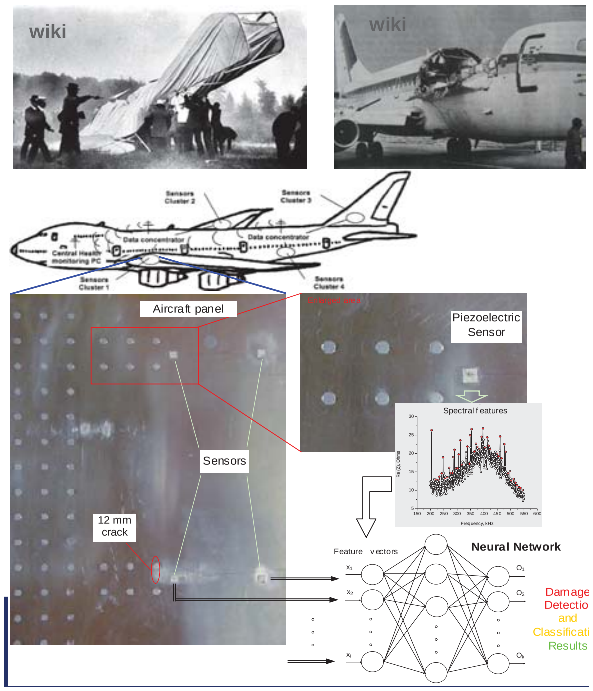
Task 228: Magneto-Elastic Sensing for Structural Health Monitoring

Andrei Zagrai and Warren Ostergren

29 October 2013



Aircraft Structural Condition Assessment

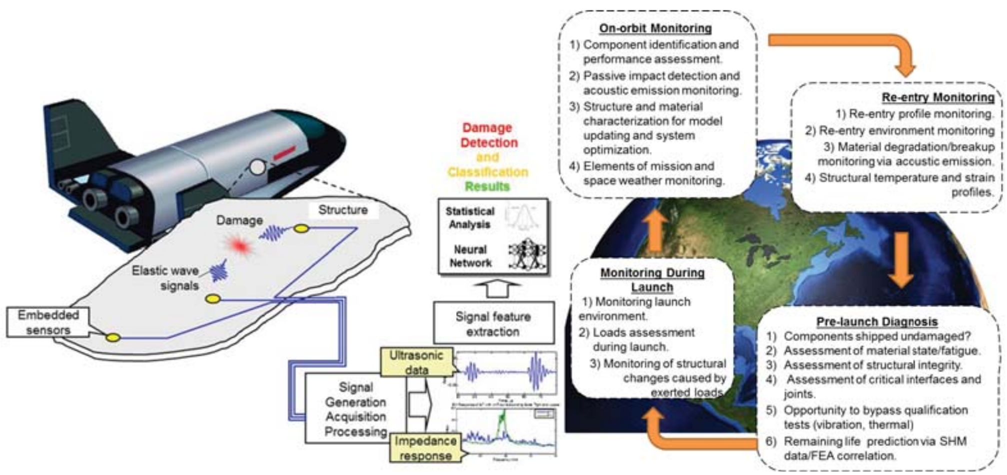


- PAST/CURRENT
  - Pre-flight critical components assessment
  - In-flight data (control, voice, communication, altitude, etc.) recording in "black box"
  - Mandatory periodic inspections (often manual) of structural elements (downtime!)
- +CURRENT/FUTURE
  - In-flight video
  - Improved inspections (corrosion, composites)
  - Automatic structural condition assessment using EMBEDDED sensor system
  - Real time structural assessment

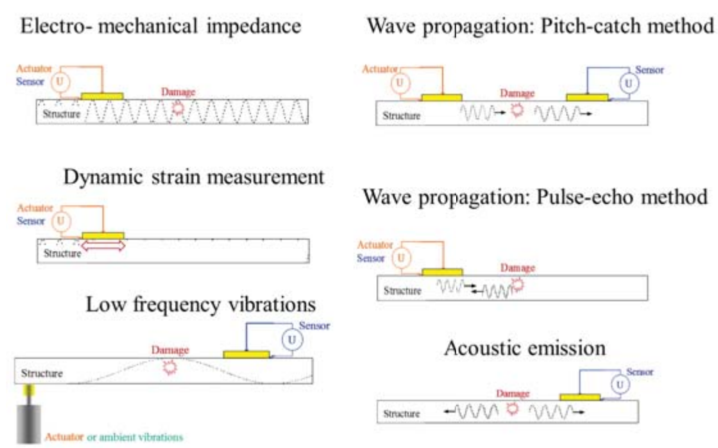
Spacecraft Structural Condition Assessment

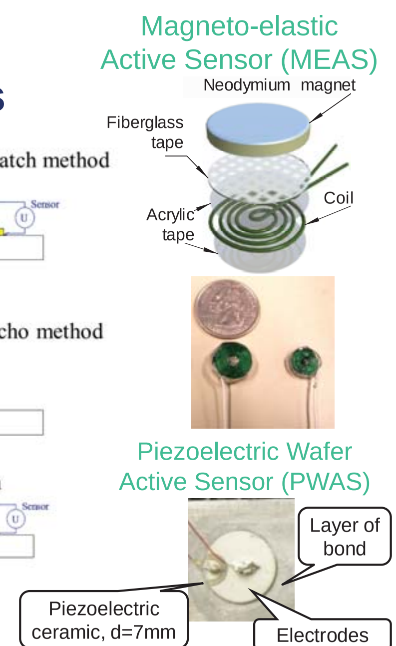
- Operational loads on spacecraft are higher, it fatigues faster
- No guidelines on what and how often to assess
- Likely require special sensors
- Data recorder WILL NOT be similar to aircraft "blackbox", Guidelines?
- Currently no work on this subject in emerging commercial space industry. Companies are busy developing launchable systems.
- If structural safety will be regulated, what are critical issues and potential solutions?

Flight Safety: Certification/anomaly detection



SHM Strategies for Commercial Space Vehicles



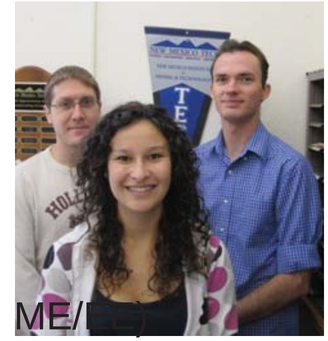


Focus on appropriate sensors + off-the-shelf hardware

Purpose of Task

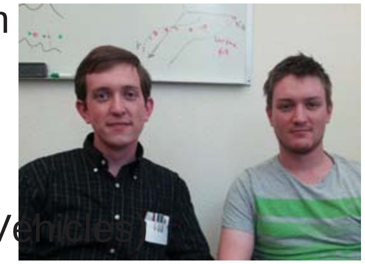
- Demonstrate utility of various SHM strategies during high altitude stratospheric balloon flight
- Investigate potential of magneto-elastic active sensors and embeddable thin wafer piezoelectric sensors to record acoustic emission activity due to structural fatigue and thermal damage
- Develop guidelines for sensor installation and measurement procedures in acoustic emission SHM of space vehicles.

Team Members



Task 228 NMT Team

- Jaclene Gutierrez (UG ME)(Graduated)
- Daniel Meisner (GR ME) (Graduated)
- David Conrad (GR ME) (Graduated)
- Joel Runnels & William Masker (UG ME/
- Andrei Zagrai & Warren Ostergren

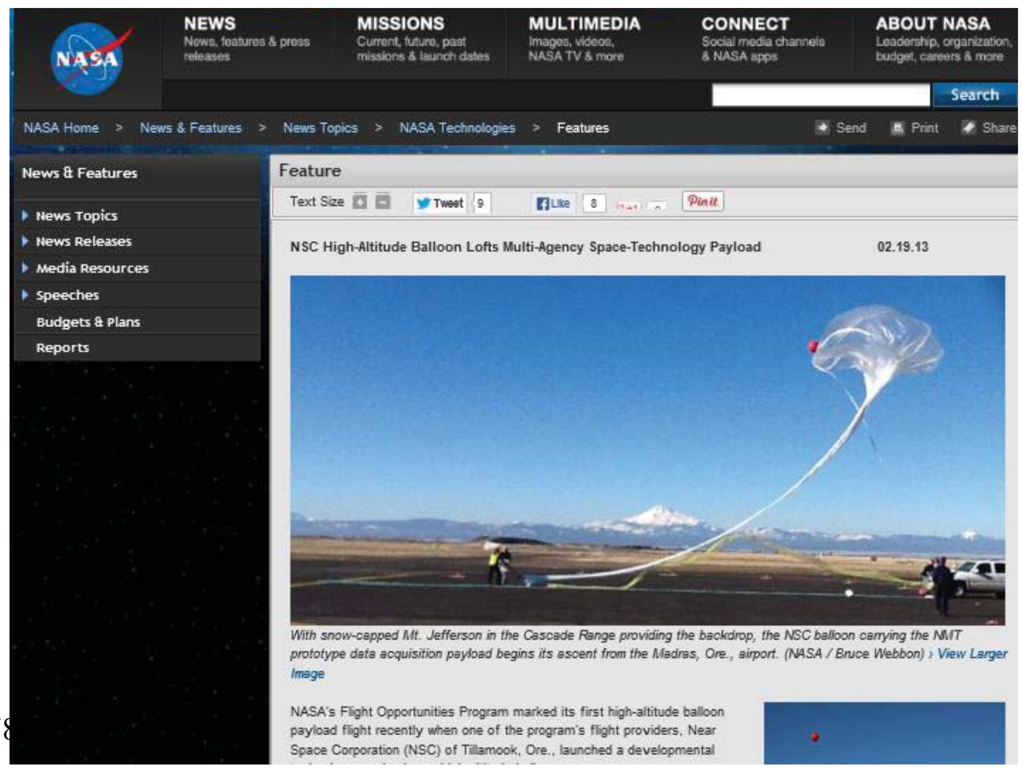


Collaborators

- Igor Sevostianov (MAE NMSU)
- Whitney Reynolds (AFRL Space Ve

038 BS NASA FOP Flight Team

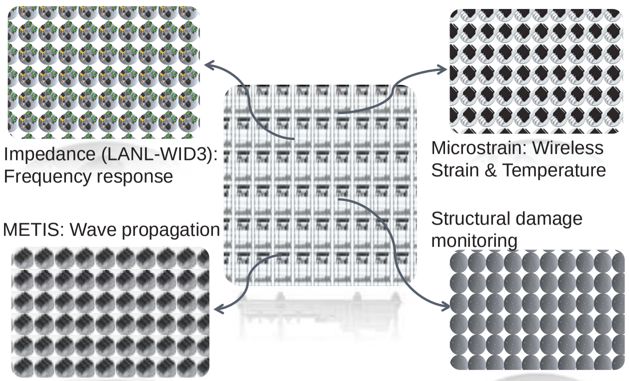
Andrei Zagrai (NMT), Nickolas Demidovich (FAA), Ben Cooper (NMT), Jon Schlavin (NMT), Chris White (NMT), Seth Kessler (Metis Design Corporation), Joe MacGillivray, Sam Chesebrough, Levi Magnusion, Lloyd Puckett, Karen Tena, Jaclene Gutierrez, Blaine Trujillo, Tiffany Gonzales. (NMT-undergrads)

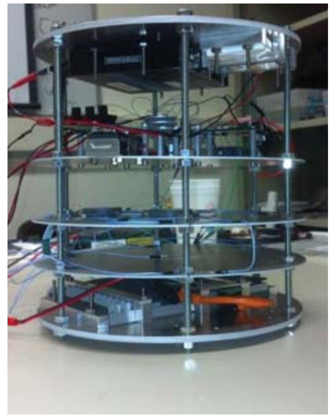


Structural Condition Assessment Payload

EXP 5: Electro-mechanical impedance structural dynamic measurements

EXP 6: Wireless strain and temperature sensing

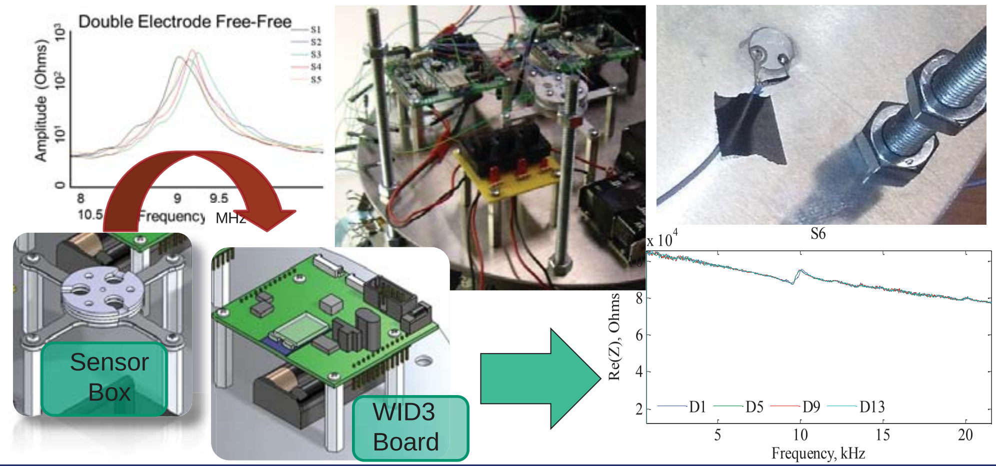




EXP 1: Structural sound speed measurements
EXP 2: Crack detection
EXP 3: Loose bolt detection
EXP 4: Acoustic emission (AE) measurements

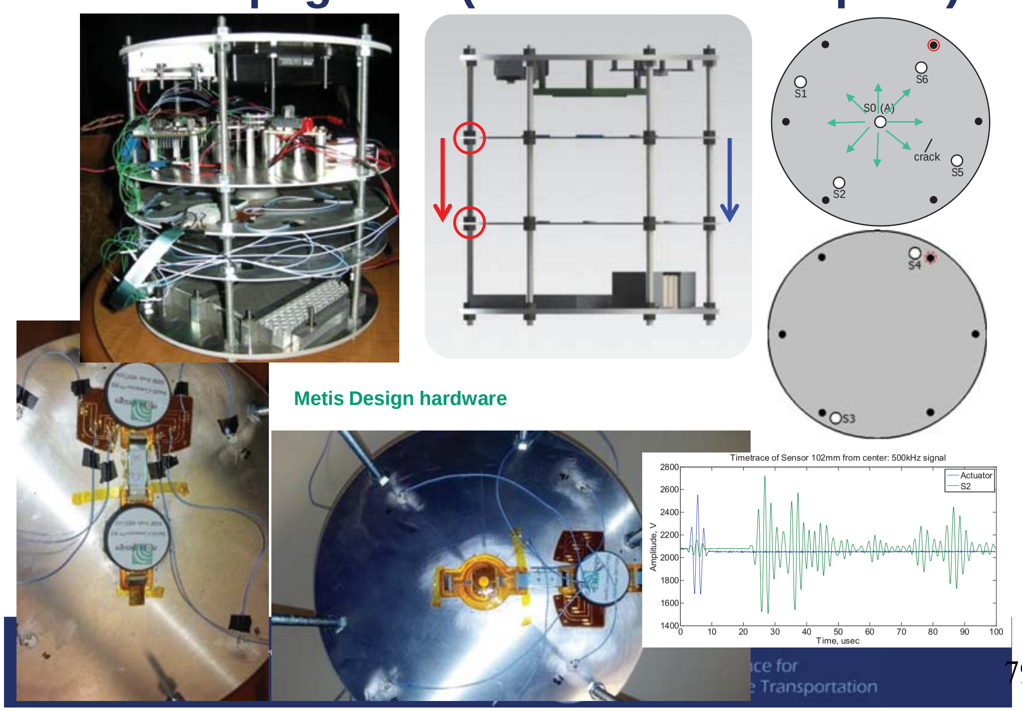
Impedance Measurements

- Electro-mechanical impedance measurements using LANL WID-3
  - Sensor characterization in near-space environment
  - Impedance-based SHM

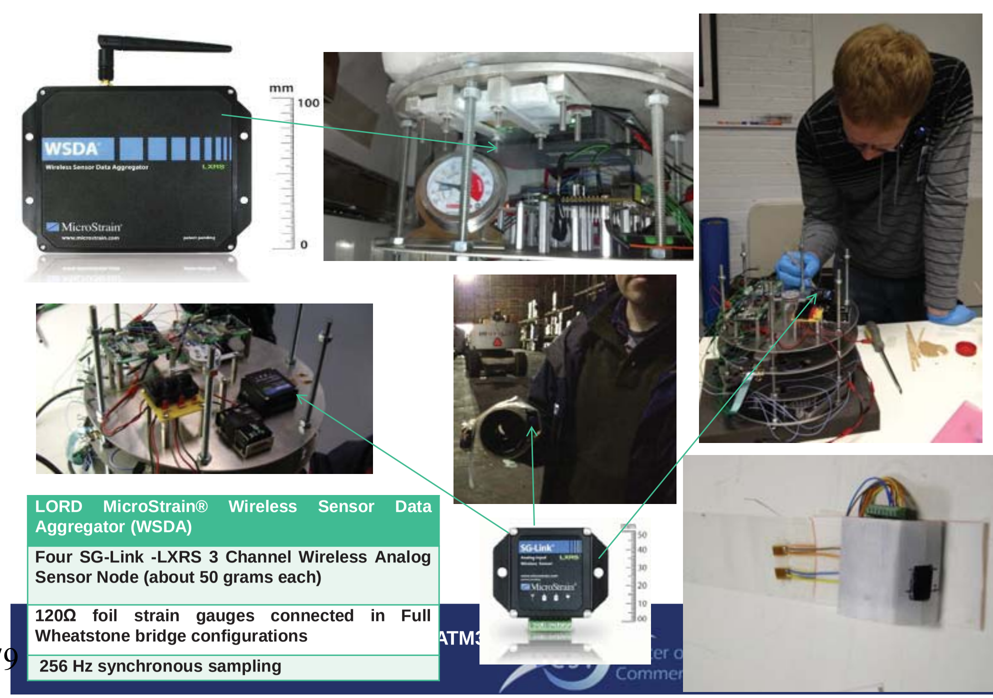


COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013
COE CST Center of Excellence for Commercial Space Transportation

Wave Propagation (SHM & Sound Speed)

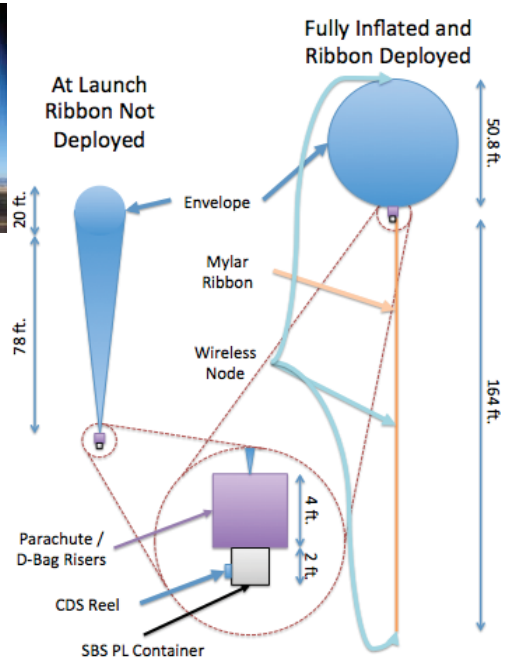


Wireless Hardware (Strain & Temperature)



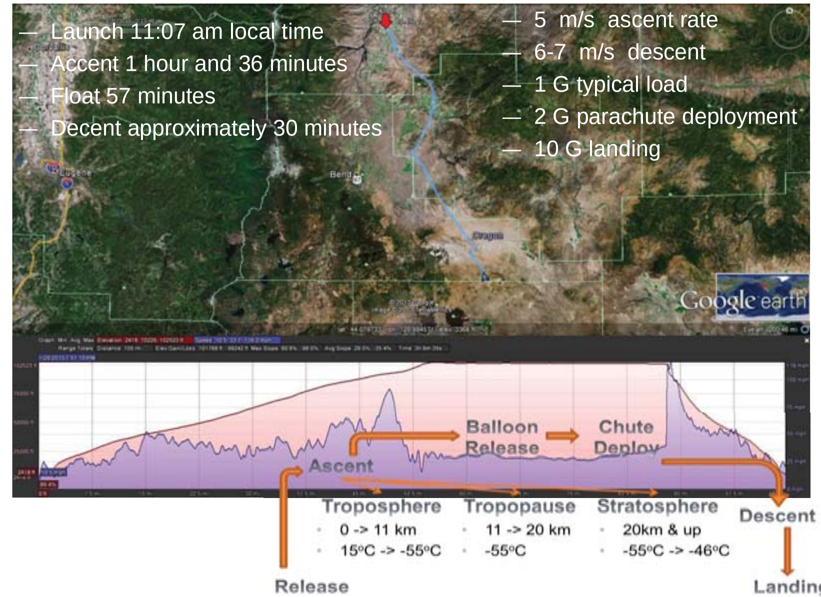
LORD MicroStrain® Wireless Sensor Data Aggregator (WSDA)
Four SG-Link -LXRS 3 Channel Wireless Analog Sensor Node (about 50 grams each)
120Ω foil strain gauges connected in Full Wheatstone bridge configurations
256 Hz synchronous sampling

Balloon / Payload / Ribbon



eting (ATM3)

Flight Profile



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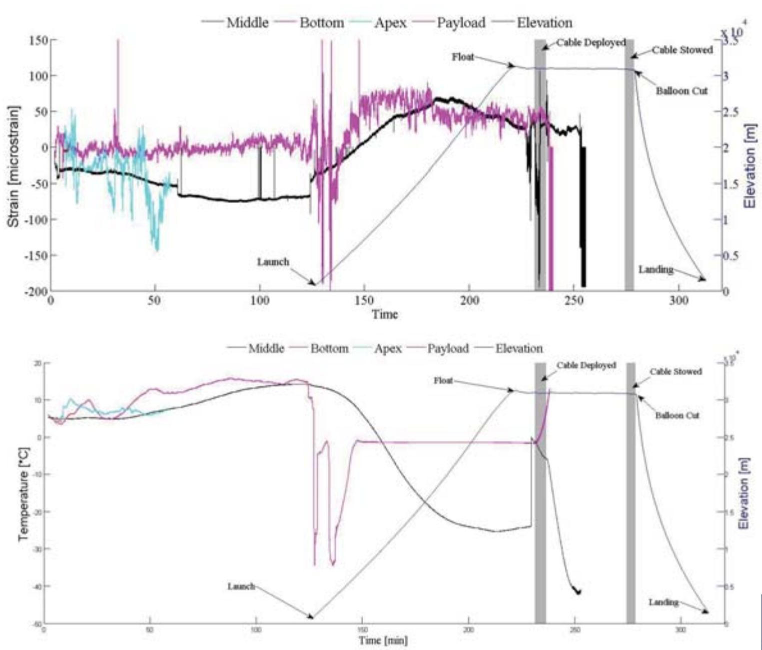
Wireless Sensing Results

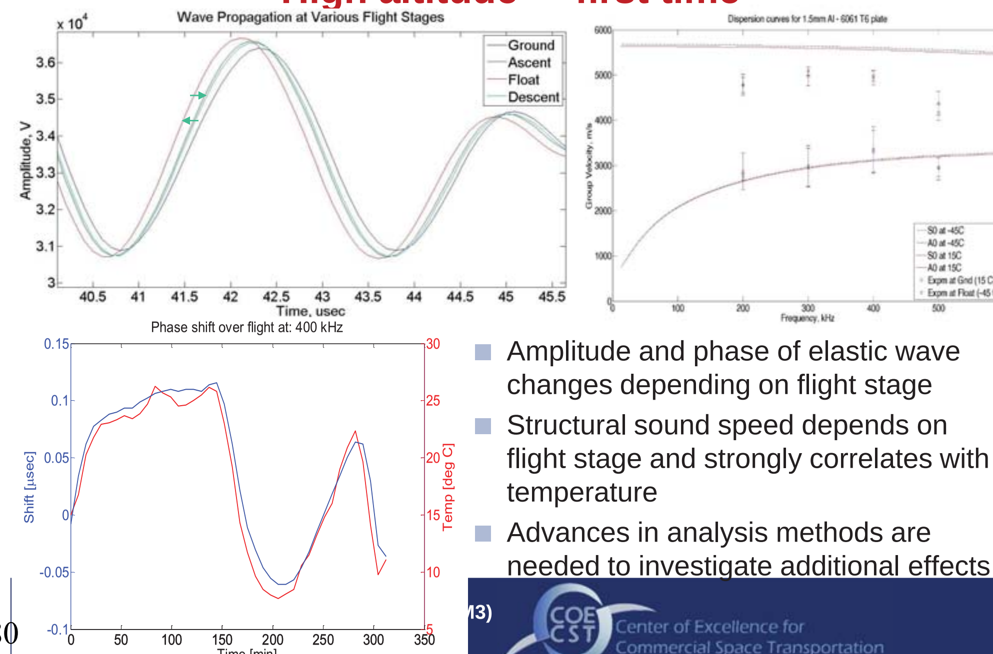


- High-rate dynamic events were detected !
- Temperatures were measured !
- Strain variation generally correlates with temperature variation
- Electromagnetic interference and shielding may be an issue
- Payload geometry and EM wave propagation may be an issue
- Hardware survivability may be an issue.

Commercial Space Transportation

Structural Sound Speed Measurements

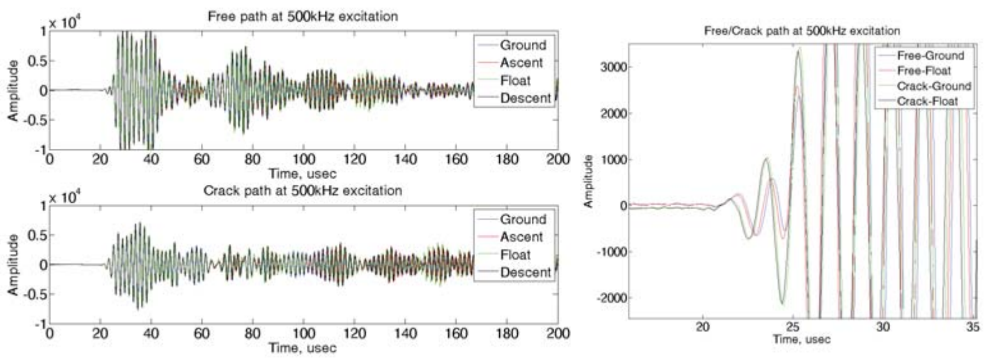
High altitude - first time



- Amplitude and phase of elastic wave changes depending on flight stage
- Structural sound speed depends on flight stage and strongly correlates with temperature
- Advances in analysis methods are needed to investigate additional effects.

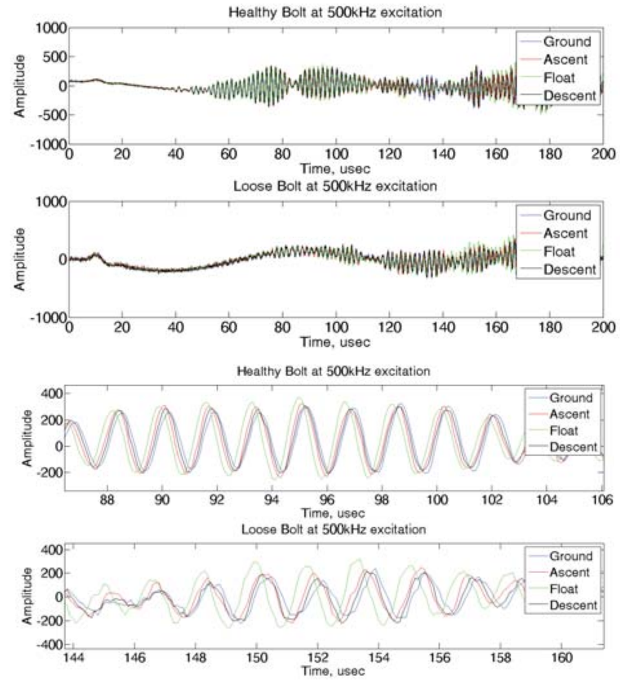
Center of Excellence for Commercial Space Transportation

Crack Detection High altitude - first time



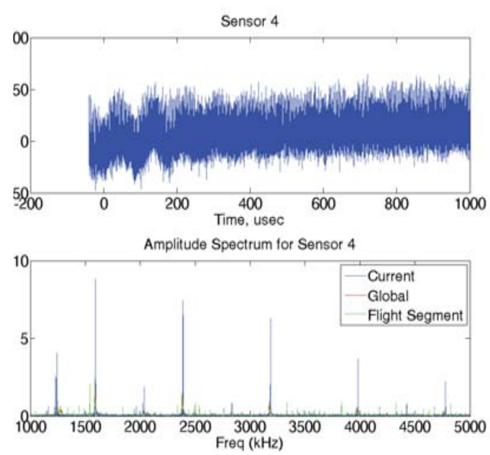
- Through transmission crack detection is demonstrated
- Amplitudes and phases of elastic wave depend on flight stage, but clearly distinguishable
- Changes are noticeable in the first and subsequent pulses.

Loose Bolt Detection High altitude - first time



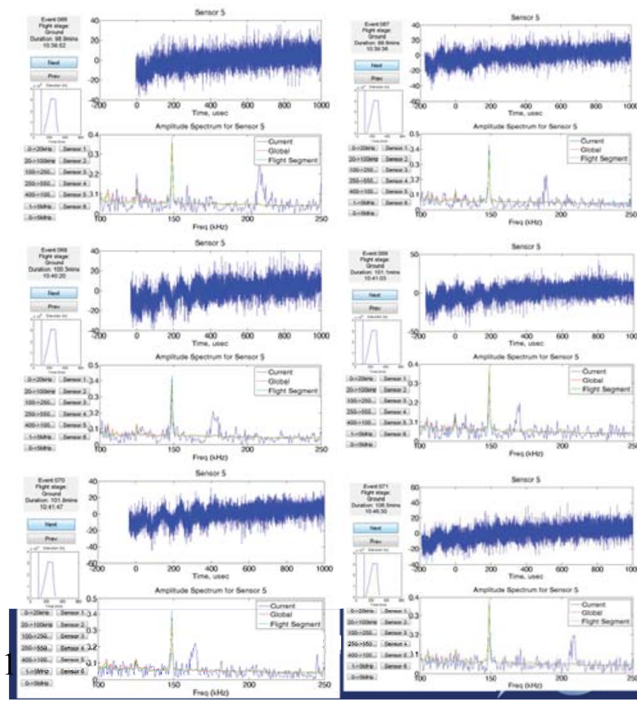
- More elastic energy passes through properly tight bolt as is evident in higher amplitude of elastic wave
- Loose bolt case exhibits low amplitude and higher nonlinearity of the through transmitted elastic wave
- Phase shift (temperature influence?) is also more pronounced in the case of loose bolt.

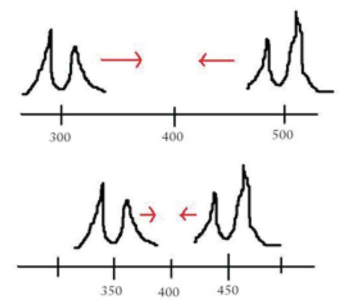
Acoustic Emission High altitude - first time



- Sensors are in passive mode listening for acoustic event.
- Acoustic emission spans broad frequency range from several kHz to hundreds of kHz
- Material degradation, crack development, friction, fracture and other mechanical activities result in acoustic emission
- Acoustic emission is seen as primary detection technology for re-entry breakup and unexpected events during flight.
- Acoustic emission data was collected every 10 seconds during 3 hours of stratospheric flight.

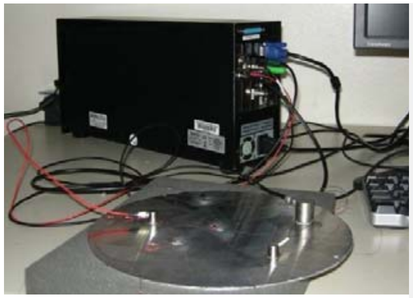
Acoustic Emission

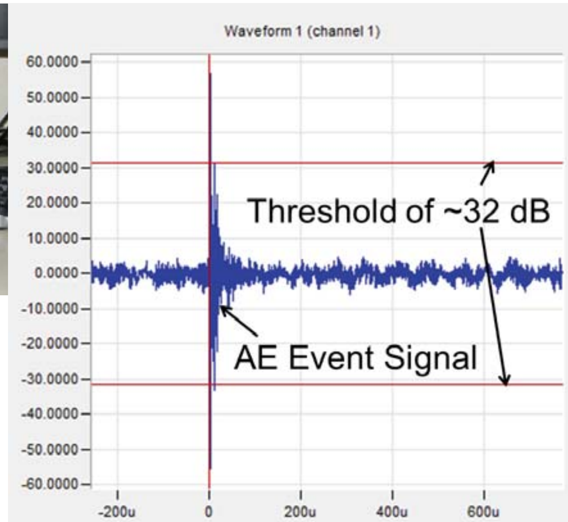




- Multiple frequency peaks were notices in spectrum of AE signal, some with repeatable dynamics every 7 minutes of flight
- Ribbon deployment was detected
- Most of acoustic emission data collected was associated with electrical interference.

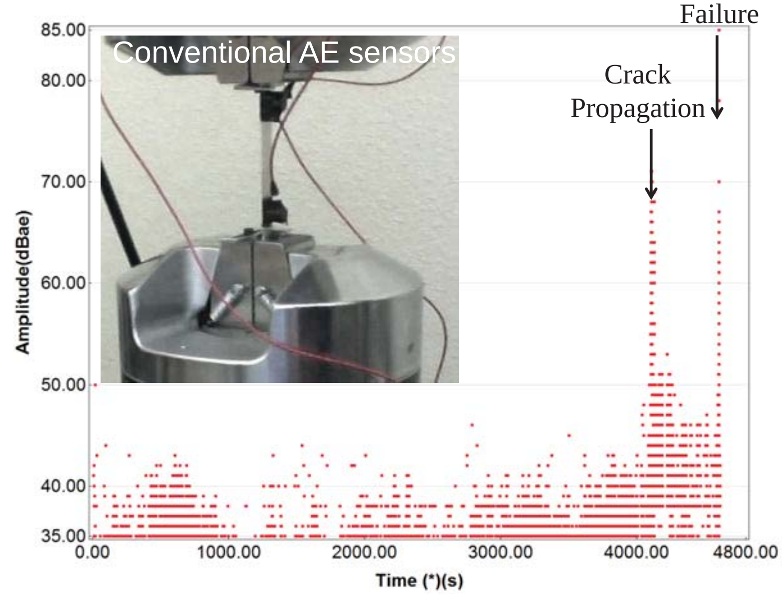
Acoustic Emission Investigations



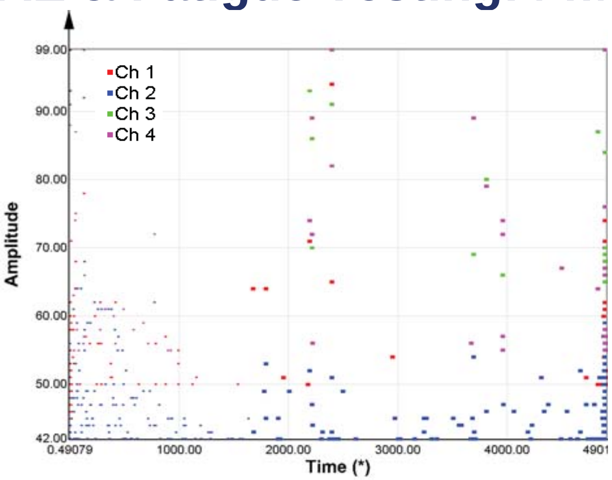


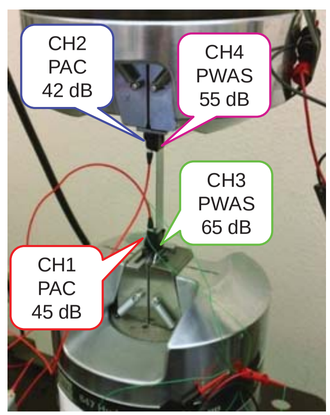
- PWAS and conventional AE sensors were were compared
- PWAS demonstrated utility in recording AE activity, but is more noisy
- New sensor design with shielding options is recommended.

Acoustic Emission During Fatigue Testing



AE & Fatigue Testing: PWAS + Conventional

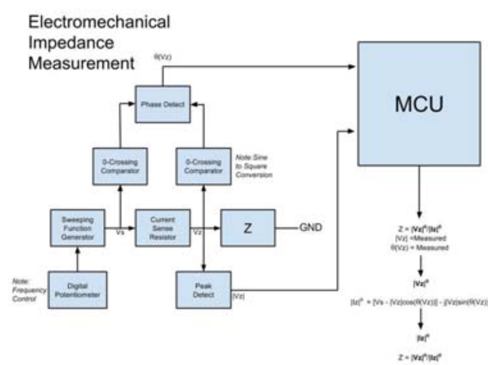


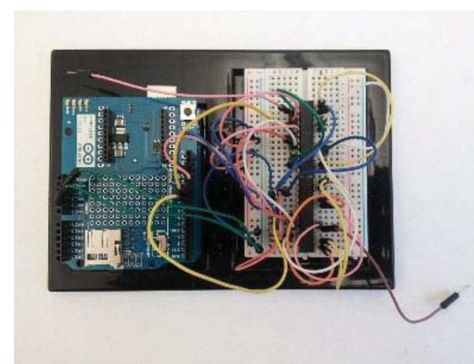


- PWAS are able to detect fatigue damage
- It is possible that PWAS detects fatigue damage at earlier stage
- Electro-magnetic shielding is an issue.

NMT Electro-mechanical Impedance Board

- Reliable impedance measurements in high-altitude and space environments.
- Frequency band up to 0.5 MHz to investigate sensor properties
- Compact, light, and user friendly.





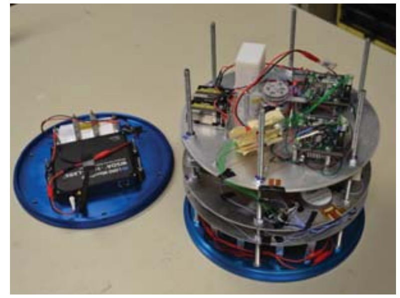
S38 Power On Sequence

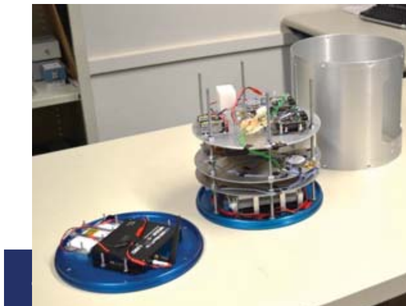
40 minutes before launch

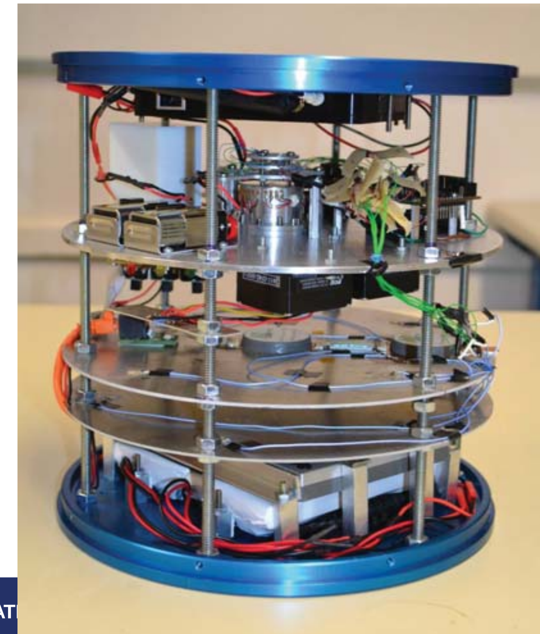
UP Aerospace Suborbital SL-8

- Flip 3 switches to activate WID3 impedance tests (will be triggered by signal from accelerometer during launch) , WSDA wireless base, Metis hardware. LED will light up indicating power on.
- Press power button on GoPro camera
- Flip a switch on each of two wireless nodes (opposite switch box).
- Flip a switch on each of two wireless nodes distributed on a vehicle

S38 Payload







Publications/Presentations

- Zagrai, A., Demidovich, N., Cooper, B., Schlavin, J., White, C., Kessler, S., MacGillivray, J., Chesebrough, S., Magnuson, L., Puckett, L., Tena, K., Gutierrez, J., Trujillo, B., Gonzales, T., (2013) "Structural Condition Assessment during High Altitude Stratospheric Balloon Flight," Presentation at *Next-Generation Suborbital Researchers Conference 2013,* June 3-5, 2013, Broomfield, Colorado.
- Zagrai, A., Demidovich, N., Cooper, B., Schlavin, J., White, C., Kessler, S., MacGillivray, J., Chesebrough, S., Magnuson, L., Puckett, L., Tena, K., Gutierrez, J., Trujillo, B., Gonzales, T., (2013) "Structural Health Monitoring using COTS Equipment during High Altitude Stratospheric Balloon Flight," Presentation at *Commercial and Government Responsive Access to Space Technology Exchange,* Bellevue, Washington, June 26, 2013.
- Zagrai, A., Cooper, B., Schlavin, J., White, C., Kessler, S., (2013) "Structural Health Monitoring in Near-Space Environment, a High Altitude Balloon Test," *Proceedings of International Workshop on Structural Health Monitoring,* Stanford University, September 10, 2013.
- Cooper, B., Zagrai, A., Kessler, S., (2013) "Effects of Altitude on Active Structural Health Monitoring," *Proceedings of SMASIS-13, ASME Conference on Smart Materials, Adaptive Structures and Intelligent Systems*, September 16 – 18, 2013, Snowbird, Utah, paper: SMASIS2013-3269.

Conclusions

- 038B high altitude balloon flight was successful and yielded considerable volume of data for the embedded ultrasonics structural health monitoring approach and wireless sensing.
- The experiment demonstrated basic proof-of-concept spacecraft ultrasonic SHM and wireless sensing through metallic spacecraft materials over considerable distances.
- Structural sound speed exhibited variation depending on flight stage. This variation correlates with temperature changes.
- In-flight loose bolt and crack detection has been demonstrated
- Acoustic emission recorded in-flight was mostly attributed to electronic interference, but also demonstrated ability to detect low frequency dynamics
- Further acoustic emission studies in laboratory (fatigue) and field conditions (shock wave) are underway.

Acknowledgements

- Nickolas Demidovich (Federal Aviation Administration)
- The flight opportunity was provided by the NASA Flight Opportunities Program http://flightopportunities.nasa.gov , flight 38 BS.
- Bruce Webbon (NASA) for helpful discussions and assistance.
- Federal Aviation Administration (FAA) through Center of Excellence for Commercial Space Transportation, AFRL Space Vehicles Directorate, and NMT Department of Mechanical Engineering are acknowledged for financial support.
- Los Alamos National Laboratory Engineering Institute for providing WID3 impedance measurements boards (Charles Farrar, Stuart Taylor, Gyuhae Park).
- Metis Design and LORD Microstrain for collaboration on measurement hardware and assistance with tests.
- Near Space Corporation (Tim Lachenmeier and the team) for payload integration, launch and recovery.

Contact Information

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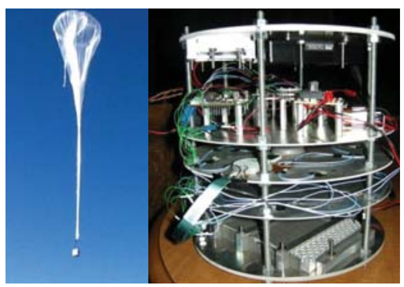
TASK 228: MAGNETO-ELASTIC SENSING FOR STRUCTURAL HEALTH MONITORING

PROJECT AT-A-GLANCE
- UNIVERSITY: New Mexico Tech
- PRINCIPAL INVESTIGATOR: Dr. Andrei Zagrai and Dr. Warren Ostergren.
- STUDENTS: Blaine Trujillo (MS), Joel Runnels (UG) and William Masker (UG)

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

The benefits of SHM for space vehicles include: pre-launch diagnostic, monitoring during launch and/or re-entry, in-orbit structural verification and structural assessment for rapid re-launch.

STATEMENT OF WORK
- Demonstrate utility of various SHM strategies during high altitude stratospheric balloon flight
- Investigate potential of magneto-elastic active sensors and embeddable thin wafer piezoelectric sensors to record acoustic emission activity due to structural fatigue and thermal damage
- Develop guidelines for sensor installation and measurement procedures in acoustic emission SHM of space vehicles.



STATUS
- 038B NASA FOP Flight completed
- Acoustic emission measurements of fatigue damage is conducted
- Utility of PWAS for AE testing is investigated

FUTURE WORK
- Sound speed data analysis
- 038S Suborbital SL-8 flight
- PWAS design for AE testing
- Thermal damage assessment

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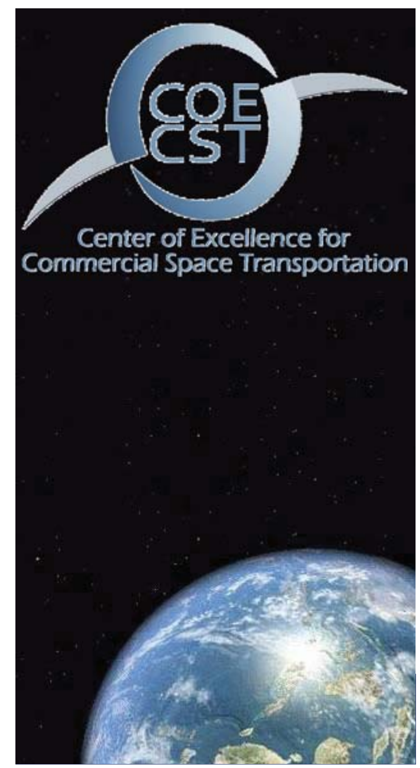
COE CST Third Annual Technical Meeting: Fracture Mechanics of Sapphire for High Temperature Pressure Transducers William Oates

Date of Presentation



Overview

- Team Members
- Motivation
- Background
  - Structure property relations
- Experimental Work
  - SEM Characterization
  - TEM Characterization
- Modeling
  - Coupling dislocation evolution with fracture mechanics
- Summary and future work
- Contact Information

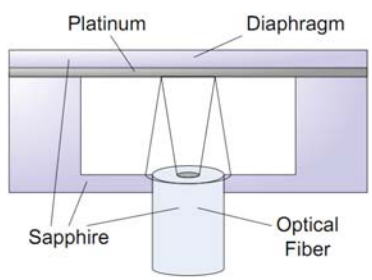
Team Members

- Mark Sheplak (UF)
- Justin Collins (FSU), David Mills (UF), Daniel Blood (UF), Tony Smitz (UNC Charlotte)

Motivation

- Commercial sensors capable of up to approximately 600℃
  - Uses SOI technology
- Alternative material sapphire: potentially capable of up to 1500 (
- Laser machining to cut specimens
  - Hard
  - Chemically Inert

Kulite Pressure Transducer



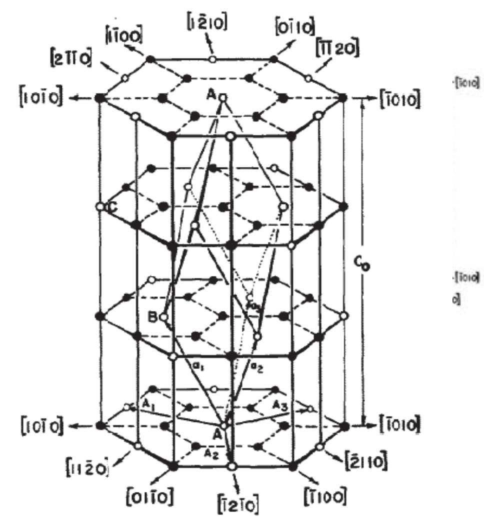
Structure-Property Relations

- Sapphire crystallographic structure
  - Complicated by hexagonal cage & internal rhombohedral structure
- *Anisotropic elastic behavior
  - Rhombohedral—not hexagonal

$$\sigma_{ij} = c_{ijkl}\varepsilon_{kl}$$

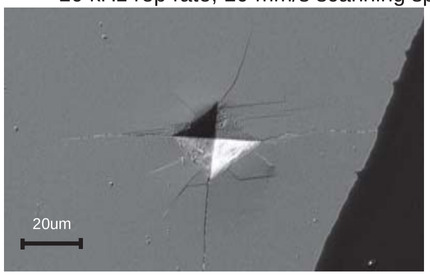
- Melting temperature 2030 (

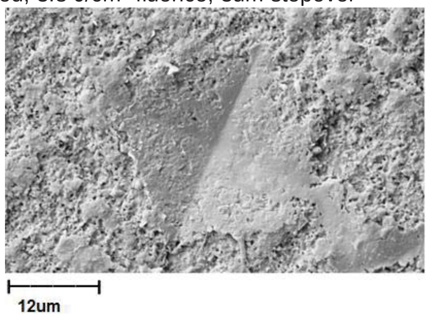
Hockey, Journal of the American Ceramic Society, May 1971, Vol. 54, No. 5



Toughness Induced Laser Machining

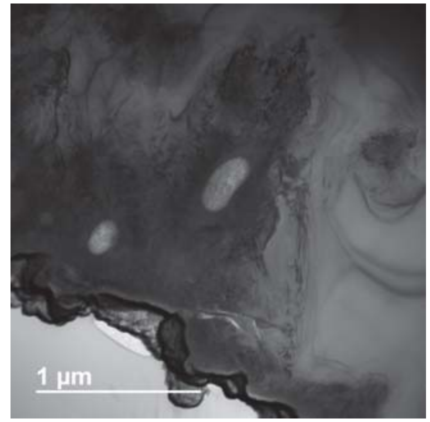
- Vicker's indentation characterization
- No visible cracks in laser machined specimens
- Laser machining parameters
  - 10 kHz rep rate, 10 mm/s scanning speed, 3.8 J/cm^2 fluence, 3um stepover

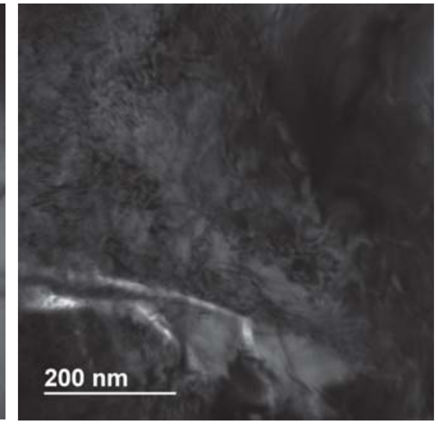




TEM Characterization

- High resolution TEM located at the NHMFL
  - 0.8 Angstrom resolution





Coupling Dislocation Theory and Solid Mechanics

Linear Momentum Balance

$$\frac{\delta T_{iJ}{}^{o}}{\delta X_J} = 0$$

PDE Governing Dislocation Mechanics

$$\xi_{I,I} - \eta = \beta \dot{\rho}$$

Energy to formulate dislocations

$$\psi = \frac{1}{2} C \rho^2 - \frac{1}{2} c_{IJKL}(E_{KL} - E_{KL}{}^{P}) K_{IJ}\, \rho$$

Where

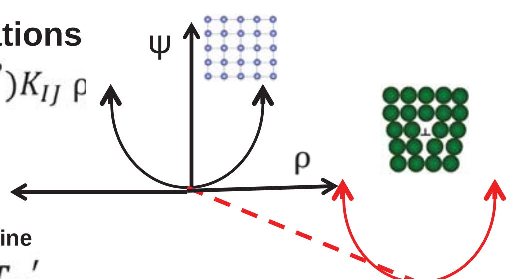
$$E_{KL}{}^{P} = \frac{1}{2} \rho (s_K m_L + s_L m_K)$$

Single Crystal

$$K_{IJ} = E_{IJ}{}^{P}$$

Polycrystalline

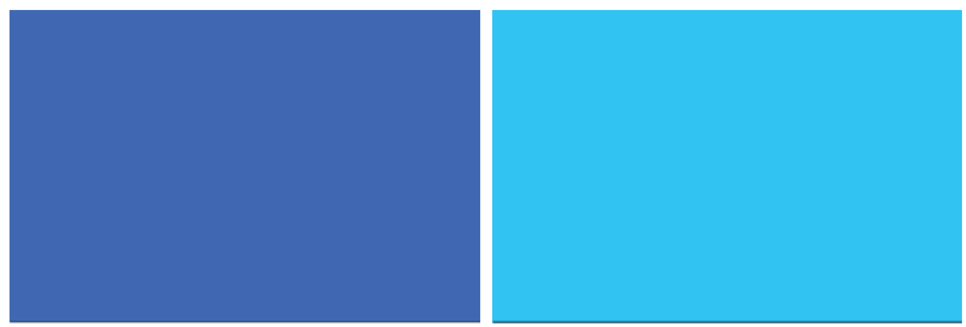
$$K_{IJ} = T_{IJ}{}'$$



FEM Model of Single and Polycrystalline

Polycrystalline

Single crystalline



Fracture Analysis

Stroh's Formalism

Equilibrium

$\sigma_{ji,j} = 0$

Constitutive Relation

$\sigma_{ij} = C_{ijks}u_{k,s}$

Boundary Condition

$t_i = \sigma_{ji}n_j$

Generalized Displacement Potential

$$u_i = 2\sum_{j=1}^{3} Re\{Aijf(z_j)q_j\}$$

J-Integral

Eshelby stress tensor

$b_{ij} = W\delta_{ij} - \sigma_{jk}u_{k,i}$

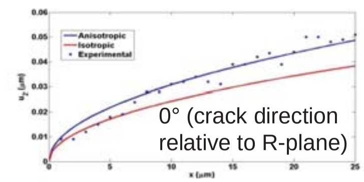
J_1 (direction of the crack)

$J_1^* = \int_\Gamma (b_{j1}n_j)dS - \int_\Omega (f^{INH})dA$

$J_c = J^*$ When this condition occurs a crack propagates.

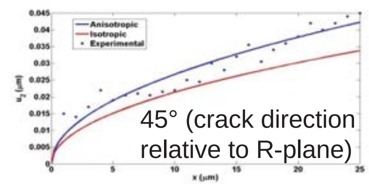
Comparison of Fracture Toughness

Experimental



$K_{1c} \cong 2.2\ MPa * m^{\frac{1}{2}}$

$J_c \cong 11.64\ \frac{N}{m}$

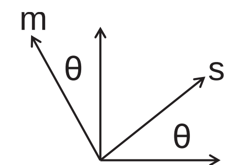


$K_{1c} \cong 2.50\ MPa * m^{\frac{1}{2}}$

$J_c \cong 15.25\ \frac{N}{m}$

Simulation

Crack Tip Driving Force Comparison, J*	
Θ=0	Θ=45
$20.9\frac{N}{m}$	$18.84\frac{N}{m}$



Summary

- Laser machining subsurface damage quantified
  - TEM characterization identified dislocations
- Dislocations modeling coupled with solid mechanics
  - Changes in slip system cause change in the crack tip driving force.
- Future work
  - Comparison of slip systems in Sapphire for 3D model.
  - Thermal annealing & laser parameter studies

Acknowledgements

- National High Magnetic Field Laboratory
  - Dr. Yan Xin
  - NHMFL-Applied Superconductivity Center
- FCAAP
- FAA
- FAMU-FSU College of Engineering
- University of Florida
  - Mark Sheplak, David Mills, Daniel Blood, Tony Smitz (UNC Charlotte)

Contact Information

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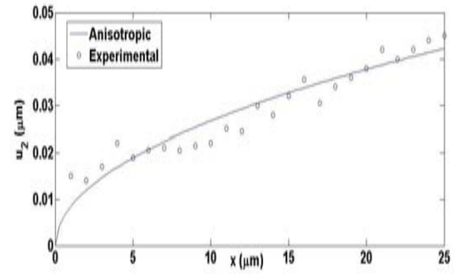
  - Fax: (850) 410-6337

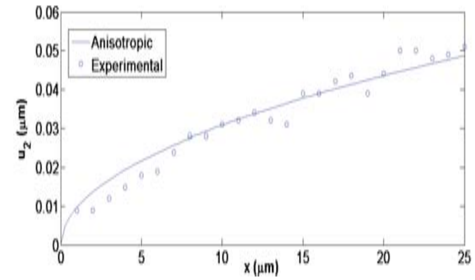
Fracture Toughness

- $K_{1c} \cong 2.2\ MPa * m^{\frac{1}{2}}$
- $J_c \cong 11.64\ \frac{N}{m}$



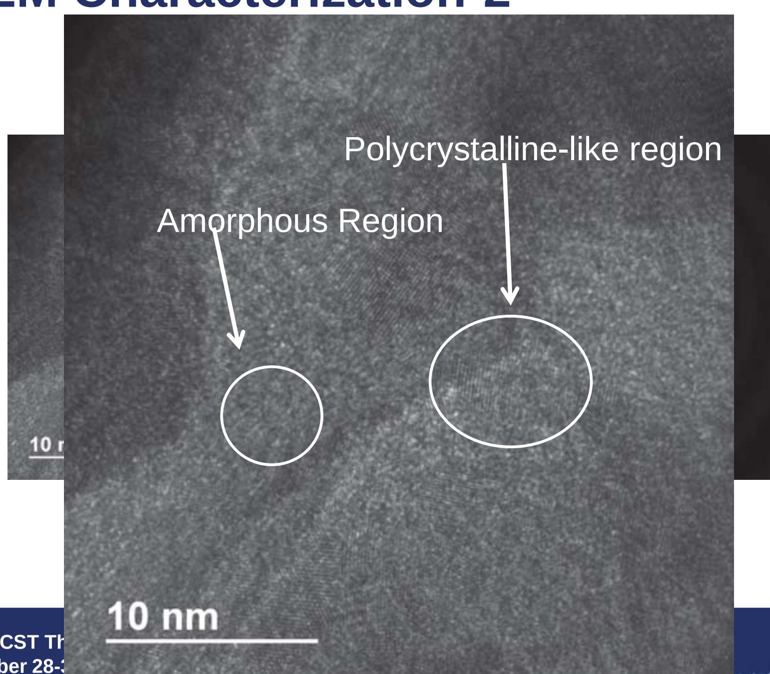
Indentation at ~0

- $K_{1c} \cong 2.50\ MPa * m^{\frac{1}{2}}$
- $J_c \cong 15.25\ \frac{N}{m}$



Indentation at 45°

TEM Characterization-2

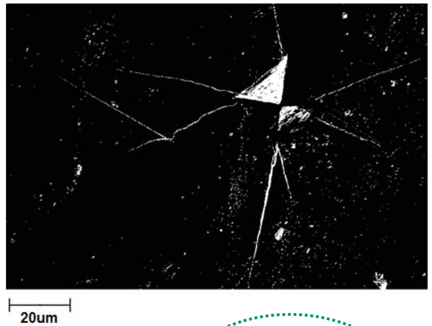


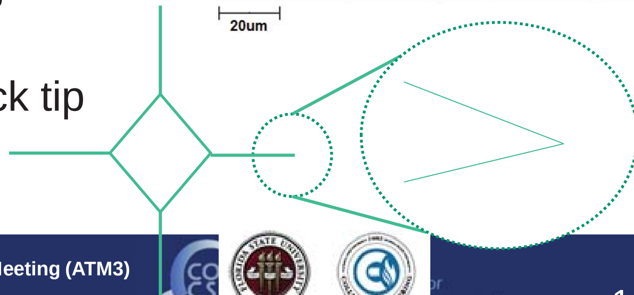
Anisotropic Fracture Stroh's Formalism

- Equilibrium
  - $\nabla \cdot \sigma = 0$
- Constitutive Relation
  - $\sigma_{ij} = C_{ijks} u_{k,s}$
- Boundary Condition
  - $t_i = \sigma_{ji} n_j$
- Generalized Displacement Potential
  - $u_i = 2 \sum_{j=1}^{3} Re\{Aijf(z_j)q_j\}$

SEM Characterization

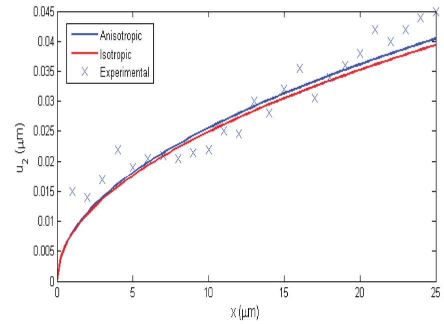
- Fracture characterization
  - Virgin vs. laser machining
- Crack opening quantified
  - Intrinsic crack tip toughness measured

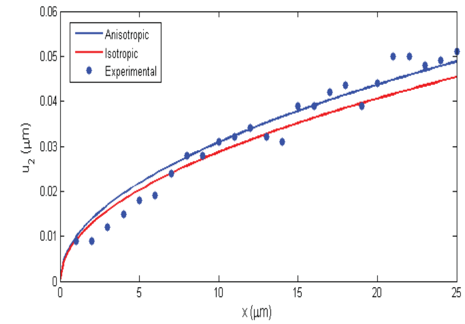




Fracture Toughness

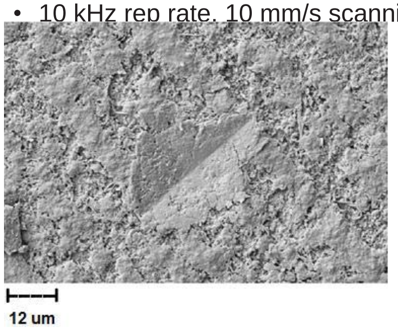
- $K_{1c} \cong 2.3$ MPa*m$^{1/2}$
- $G_c \cong 11.65$ N/m

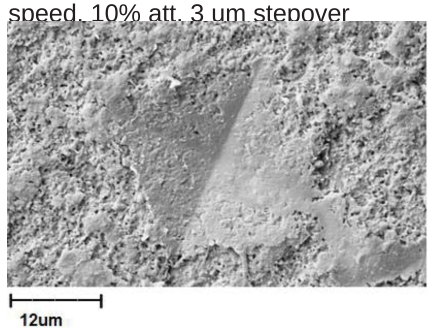




Toughness Induced Laser Machining

- Preliminary Vicker's indentation characterization
- No visible cracks
- Laser machining parameters
  - 10 kHz rep rate, 10 mm/s scanning speed, 10% att, 3 um stepover





Summary

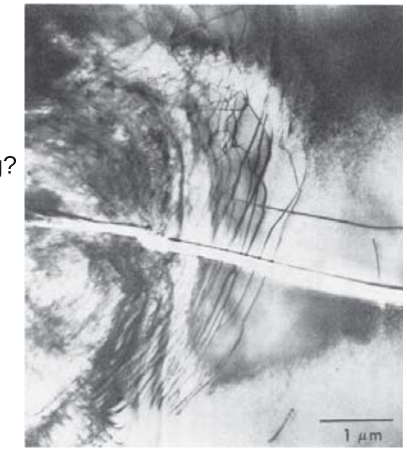
- Correlated crystal structure with anisotropic elastic properties
- Quantified crack tip toughness in virgin sapphire specimens
  - Good correlation with data in literature
- Laser machining effects on fracture
  - Unusual toughness enhancement
- Hypothesis: Laser induced dislocations
  - TEM characterization and dislocation/fracture modeling currently underway

Acknowledgements

- NHMFL-ASC
- FAA
- FAMU-FSU College of Engineering
- University of Florida
  - Mark Sheplak, David Mills, Daniel Blood, Tony Smitz (UNC Charlotte)

Dislocation Mechanics

- Basal dislocations associated with a 100-g indentation on a (0001) basal plane section
- Specimen polished with abrasive paper.
- How does this influenced by laser machining?



Background

- Brittle
- Extremely hard material
  - Ranks a 9 on the Mohs scale
- Melting temperature of 2030℃
- Chemically inert

Introduction

- Crystallographic Structure
  - Hexagonal
  - Rhombohedral

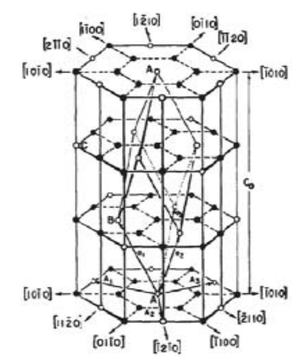


Table 4. Determined elastic constants of corundum and their standard deviations in GPa. Previous data are also shown

C_{11}	C_{33}	C_{44}	C_{12}	C_{13}	C_{14}	Ref.
496.9 ± 1.4	500.3 ± 1.6	146.8 ± 0.2	162.3 ± 1.6	115.5 ± 1.6	−21.9 ± 0.2	present work
496	502	141	135	117	−23	[8]
496.8 ± 1.8	498.1 ± 1.4	147.4 ± 0.2	163.6 ± 1.8	110.9 ± 2.2	−23.5 ± 0.3	[9]
490.2	490.2	145.4	165.4	113.0	−23.2	[10]
497.4	499.4	147.4	164.0	112.3	−23.6	[11]
497.60 ± 0.18	501.85 ± 0.21	147.24 ± 0.13	162.6 ± 0.4	117.18 ± 0.19	−22.90 ± 0.11	[12]

Current Work

- Using Stroh's Formulism for 2D anisotropic elastic body.

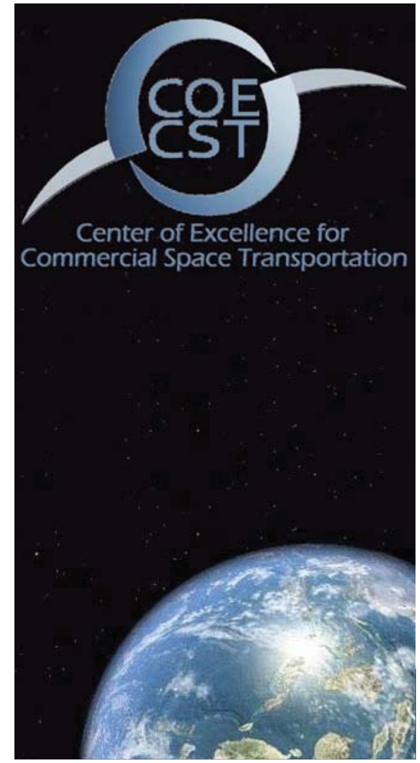
Stress-strain law	$\sigma_{ij} = C_{ijks} u_{k,s}$
Equation of Equilibrium	$C_{ijks} u_{k,sj} = 0$
Let	$u_i = a i f(z)$
Assume Solution	$z = x_1 + p x_2$
	$(C_{1k1} + p(C_{i1k2} + Ci_{2k1}) + p^2 C_{i2k2}) a_k = 0$

COE CST Third Annual Technical Meeting:

High-Temperature Pressure Sensors for Hypersonic Vehicles

David Mills
Mark Sheplak

October 28 – 30, 2013



Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results
- Next Steps
- Contact Information

Team Members

- **University of Florida**
  - **Mark Sheplak** – Professor, Dept. of Mechanical and Aerospace Engineering
  - **David Mills** – Graduate Research Assistant
  - **Daniel Blood** – Graduate Research Assistant
- **Florida State University**
  - **William Oates** – Asst. Professor, Dept. of Mechanical Engineering
  - **Justin Collins** – Graduate Research Assistant

Purpose of Task

- Conventional instrumentation is unsuitable for continuous measurement in high-temperature environments such as:
  - High-speed reentry vehicles
  - Hypersonic transports
  - Gas Turbines
  - Scramjets
- Pressure sensors capable of high-temperature operation (>1000°C) will improve understanding of shock-wave/boundary layer interactions which directly influence critical vehicle characteristics such as lift, drag, and propulsion efficiency

Objectives

- Identify a suitable sensing method, material, and fabrication process for a high-bandwidth pressure sensor capable of continuous operation in temperatures in excess of 1000°C
- Fabricate a prototype sensor and create a robust high-temperature package
- Characterize the packaged sensor at room temperature and in high-temperature environments
- Implement the packaged sensor in a hypersonic or hot jet flow facility and/or a gas turbine

COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013
Center of Excellence for Commercial Space Transportation

Research Methodology

- Sapphire fiber-optic sensors provide the following advantages over traditional silicon-based electrical sensors:
  - Electrically passive
  - Highly chemically inert
  - Immune to EMI
  - Non-conductive
- Requires development of the following processes:
  - Ultra-short pulse laser micromachining
  - Thermocompression bonding via spark plasma sintering (SPS) technology

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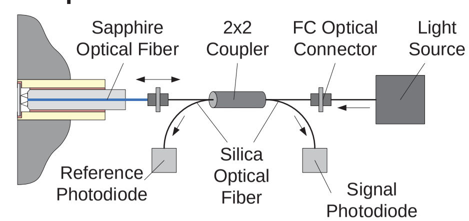
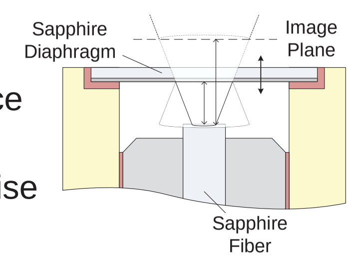
Research Methodology

- Transduction Method: Fiber-optic lever
  - Intensity modulation via diaphragm deflection
  - Single send/receive fiber



- Optical Configuration
  - LED source with multimode fibers eliminates interferometric effects
  - Silica optical fiber components reduce back-end packaging costs
  - Reference photodiode eliminates noise from source



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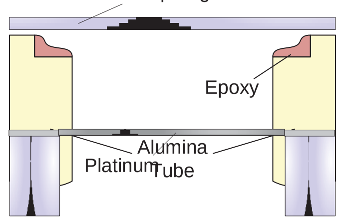
Process Flow

- Initial prototype sensor
  - Machine 4.5 mm diameter diaphragm from 50 μm thick sapphire
  - Deposit 200 nm platinum reflective layer with 20 nm titanium adhesion layer
  - Machine 4.5 mm recess in 3 mm ID alumina tube
  - Epoxy diaphragm inside recess

- Bonded prototype sensor
  - Machine 7 mm diameter hole in 1 mm thick sapphire substrate to form back cavity
  - Deposit 500 nm platinum bonding layer on back cavity substrate
  - Align and bond 50 μm sapphire diaphragm to back cavity substrate
  - Deposit 200 nm platinum reflective layer with 20 nm titanium adhesion layer in center

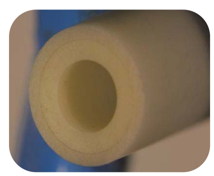


Fabrication Challenges

- Picosecond laser micromachining of sapphire
  - Thermal damage to surrounding material affects material properties and reliability
  - Understand relationship to machining parameters
- Spark plasma sintering (SPS) bonding of sapphire
  - Reduced temperatures and holding time compared to traditional vacuum hot press
  - Understand relationship between bond parameters and bond strength, thermal damage
- High-temperature packaging
  - Provide robust packaging solution while minimizing thermal stress effects

Prototype Fabrication & Packaging

- Developed laser machining processes for alumina and sapphire



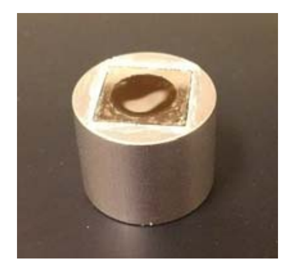
- Poor definition of diaphragm shape and boundary condition due to application of epoxy

- Demonstrated method to determine optimal fiber distance from diaphragm

- Stainless steel package capable of 600°C operation

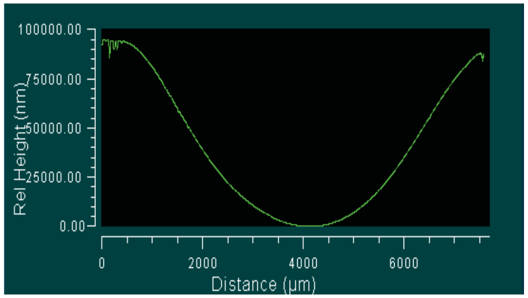
Bonded Sensor Design & Fab

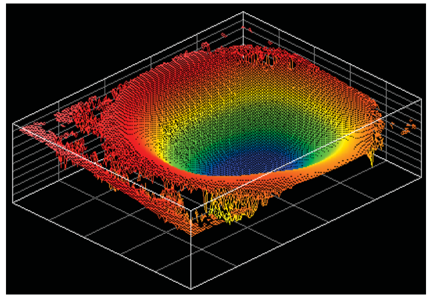
- Larger diameter – improved pressure sensitivity
  - Diaphragm size: 7 mm diameter, 50 μm thick
  - Resonant frequency: 19.6 kHz
  - Mechanical sensitivity: 0.55 nm/Pa
- SPS Bond – better control of boundary
  - Heat/Cool Rate: 50°C/min
  - Temperature: 1200°C
  - Hold Time: 5 min
  - Diaphragm buckled during process



Post-bond Buckling Analysis

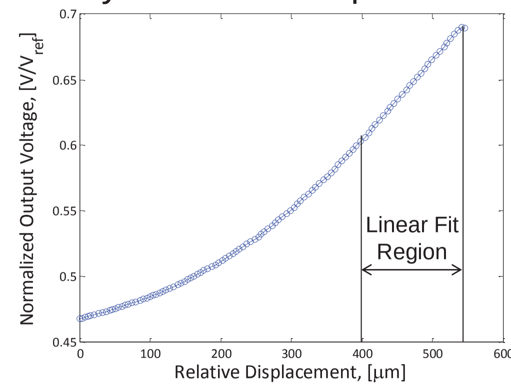
- Buckled diaphragm analyzed using scanning white light interferometer (SWLI)
- Measured center deflection of 90 µm corresponds to ~275 MPa residual compressive stress





Sensitivity Calibration

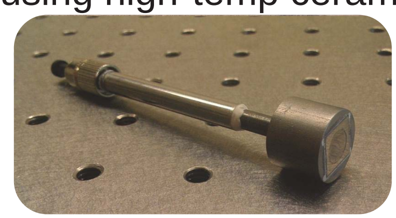
- Optimal distance between fiber and diaphragm determined based on deflection sensitivity
- Polyfit to linear region of normalized output gives a sensitivity of 0.62 mV/V/µm



High-Temperature Packaging

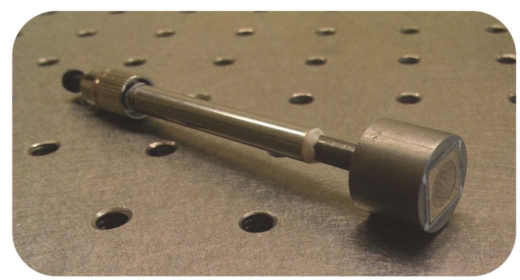
- Sapphire optical fiber packaged in FC connector on one end with bare zirconia ferrule on other end

- Zirconia ferrule epoxied into stainless steel housing in position determined by sensitivity calibration
- Stainless steel tubing used to protect sapphire optical fiber attached using high-temp ceramic epoxy



Results

- Measured sensor resonance of 22.1 kHz
- Theoretical sensitivity of 0.12 µV/V/Pa based on estimated sensitivity of buckled diaphragm
- Max continuous operating temperature of 900°C



Next Steps

- Complete SPS bond process development and characterization of bond interface
- Room-temperature plane wave tube characterization
  - Sensitivity
  - Frequency response
  - Linearity
- High-temperature characterization
  - Demonstrate survivability
  - Determine thermal drift
- Testing of the sensor in a high-temperature flow facility or gas turbine

Contact Information

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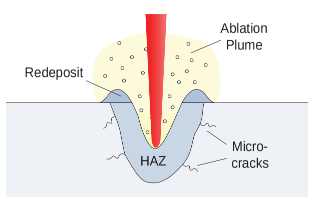
Backup Slides

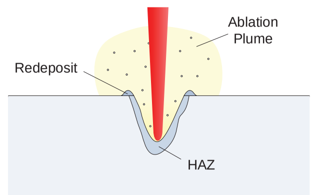
Laser Micromachining

- "Long" Pulsewidths (>10 ps)
  – Industry standard
  – High reliability
  – Large heat affected zone (HAZ)
  – Micro-cracking and redeposit

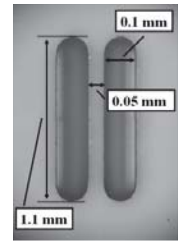


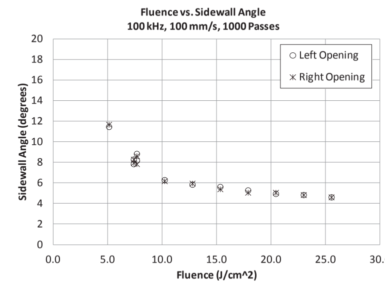
Laser Micromachining

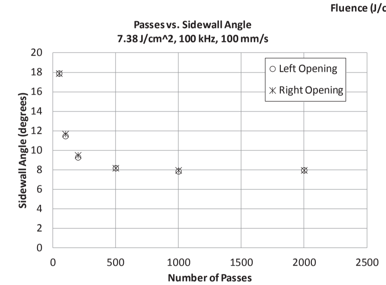
- Ultrashort Pulsewidths (<10 ps)
  - Direct solid-vapor transition
  - Reduced HAZ and micro-cracking
  - Lower fluence required
  - Deterministic material removal rate
  - Research tools
- Oxford Lasers J-355PS Laser Micromachining Workstation
  - Coherent Talisker 355 nm DPSS laser
  - Pulse length <10 – 15 ps
  - Pulse frequency up to 200 kHz
  - Power adjustable from ~0.05 – 4.5 W
  - XYZ stages & galvonometer

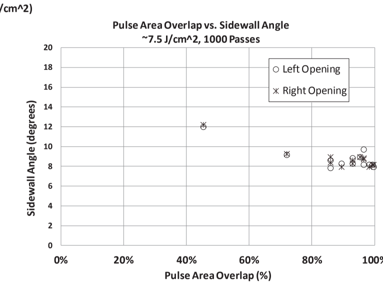


Laser Micromachining Trends







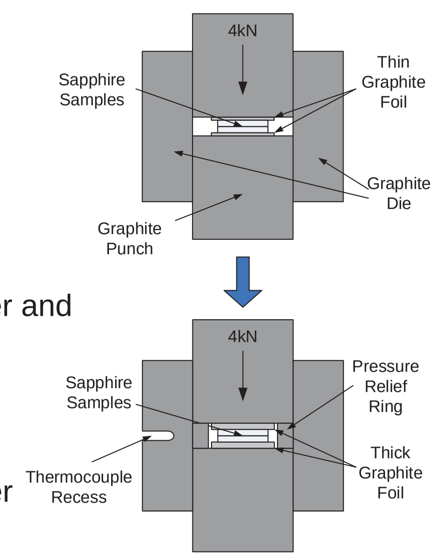


Thermocompression Bonding

- High temperature bonding process
  - 70-90% of melting point (up to 1450°C for sapphire & Pt)
  - 1-10 MPa substrate pressure
  - Up to 24 hour hold time – issues with survivability of patterned features
- Spark Plasma Sintering (SPS) process
  - Large current density (~1000 A/cm^2) causes rapid resistive heating of substrates
  - Faster heating and cooling rates than hot press
  - Reduced temperature and holding time for similar performance

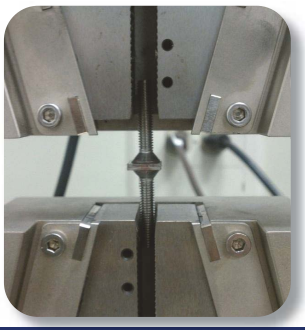
SPS Bonding Process

- Original Process
  - Bond parameters
    - Max temp: 800°C
    - Heating rate: 25°C/min
    - Hold time: 5 minutes
  - Low bond strength
  - Substrate cracking issues
- Modified Process
  - Reduced pressure load via spacer and compressible graphite foil
  - Bond parameters
    - Max temp: 1200°C
    - Heating rate: 50°C/min
    - Hold time: 5 minutes
  - Improved bond strength via higher temps
  - No visible cracks observed



Bond Characterization

- Tensile test
  - Studs bonded to substrates using Hysol 9309.3NA adhesive
  - Original SPS sample tensile strength: ~350 kPa
  - Samples created using modified SPS process: >12 MPa
    - Adhesive joint failed before the bond interface
    - Need improved method for characterization

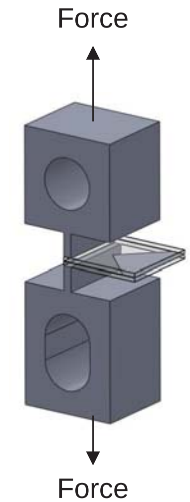


Bond Characterization

- Chevron test
  - Based on SEMI Standard MS5-1211
  - Platinum bonding layer patterned in chevron geometry on sapphire substrate
  - Blocks are attached at the free ends of the bonded specimen
  - Chevron tip creates a pre-crack to initiate failure
  - Max load related to fracture toughness, K_c , and critical wafer bond toughness, G_c

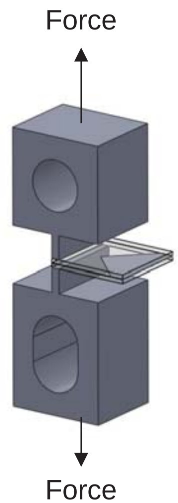
$$K_c \propto F_{max}$$

$$G_c \propto K_c^2$$



Bond Characterization

- Chevron test
  - Based on SEMI Standard MS5-1211
  - Fracture toughness, $K_c = \frac{F_{max}}{B\sqrt{w}} Y_{min}$ where $B = w = 10\ mm$, and Y_{min} is a geometry function determined using FEM simulations
  - Critical wafer bond toughness, $G_c = \frac{K_c^2}{\bar{E}}$ where $\bar{E} = \frac{E}{1-\nu^2}$ for an isotropic material



Sensor Design

- Mechanical Sensitivity

$$\frac{w_0}{P} = \frac{3}{16}\frac{a^4}{h^3}\frac{1-\nu^2}{E}$$

- Resonant Frequency

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{1}{C_{me}M_{me}}}$$

$$C_{me} = \frac{9a^2(1-\nu^2)}{16\pi E h^3}$$

$$M_{me} = \frac{\rho\pi a^2 h}{5}$$

Residual Stress Estimate

- Pressure drop determined as a function of center deflection[1] (solved using Ritz method)
  - Assumed deflection profile: $w(r) = w_0\left(1 - \frac{r^2}{a^2}\right)^2$

$$\Delta P = \frac{4hw_0}{a^2}\left(\frac{4}{3}\frac{h^2}{a^2}\frac{E}{1-\nu^2} + \sigma_0 + \frac{64}{105}\frac{w_0^2}{a^2}\frac{E}{1-\nu^2}\right)$$

- Solve for σ_0 assuming no pressure drop ($\Delta P = 0$)

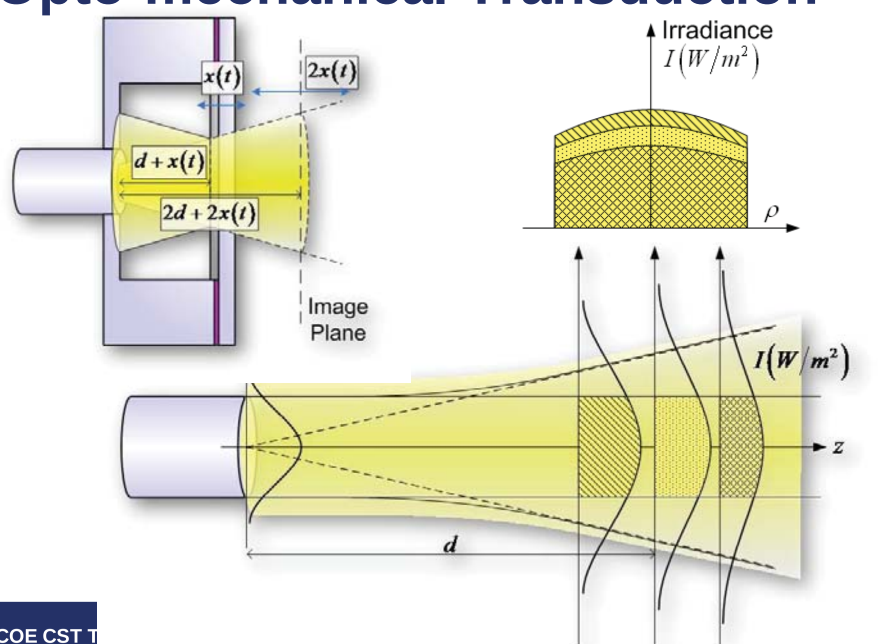
$$\sigma_0 = -\left(\frac{4}{3}\frac{h^2}{a^2} + \frac{64}{105}\frac{w_0^2}{a^2}\right)\frac{E}{1-\nu^2}$$

[1] W.K. Schomburg, *Introduction to Microsystem Design*, Springer, New York, NY, pp. 29-50, 2011.

Choosing a Transduction Scheme

- Factors Influencing Choice of Transducer Concept
  - Specifications: "what do you want to measure?"
    - Physics related: dynamic range, bandwidth, spatial resolution, single sensor versus arrays, fundamental vs. control, etc.
  - Environment: "where do you want to measure it?"
    - Wind tunnel, flight test, gas versus liquid, etc.
      - **Temperature, pressure, humidity, dirt, rain, EMI, shocks, cavitation, fouling, etc.**
  - Packaging Requirements: "where do you mount device?"
    - Application dependent: flush-mounting, single sensor versus arrays (packing density), etc.
  - Other Factors:
    - Budget, time-scale for test, risk tolerance, etc.

Opto-mechanical Transduction



Towards High-Temperature

- Somewhat Uncharted Territory in MEMS
  - Silicon starts to plastically deform at 650 °C
  - Any circuit devices will be temperature limited (diodes, ICs, etc.)
- High-Temperature Limits Transducer Choices
  - Piezoresistive:
    - Leakage current and resistor noise increase with temperature
    - Limited to around 200 °C or must be cooled
  - Capacitive:
    - Low capacitance requires buffer amplifier close to sensor
      - **High-temperature, low noise, high-input impedance amplifiers do not exist**
- Optical is best if you can get it off optical bench
  - Detection electronics are remotely located
  - High temperature sapphire fibers and substrates exist

Oxsensis "Wavephire" Sensor

- Micro-machined sapphire pressure sensor with sapphire fiber-optic
  - Extrinsic Fabry Perot interferometer using at least two wavelengths
  - Diaphragm is micromachined using proprietary process
    - Limitations prevents further miniaturization to sub-millimeter size

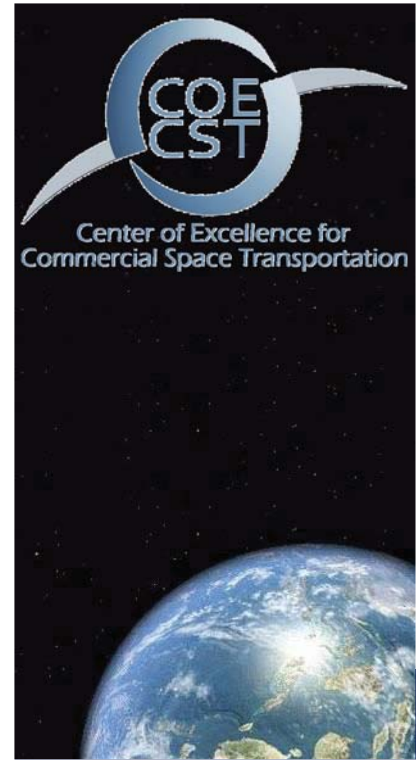
- Specifications
  - Temperature range
    - -40 to 600°C (continuous)
    - -40 to 1000°C (research and development)
  - 100 dB dynamic range
  - Uncertainty <±10%

COE CST Third Annual Technical Meeting:

Autonomous Rendezvous and Docking

Penina Axelrad
University of Colorado Boulder

October 30, 2013



Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results or Schedule & Milestones
- Next Steps
- Contact Information

COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013

Team Members

- PI: Dr. Penina Axelrad, University of Colorado Boulder
- Dr. Jay McMahon
- Students: Aerospace Engineering Sciences
  Steve Gehly (PhD student)
  Heather LoCrasto (MS student)
- Industry Partner: Ball Aerospace

COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013

Purpose of Task 244

- **Purpose:** To develop overall rendezvous, approach, docking methodology
- **Objectives**:
  - Standards are required to enable the FAA to license multiple vendor vehicle systems to make orbital rendezvous and docking a routine and safe activity.
  - These standards must be established to define appropriate requirements for safe operations without specifying a particular design.
  - Increase autonomy, improve flexibility, robustness, reduce cost
- **Goals**: The goals of this project are to develop a draft set of standards and to fill key technology gaps for automated rendezvous and docking of vehicles in LEO/GEO encompassing approach trajectories, sensing, estimation, guidance and control, and human interaction.
  - Systems engineering analysis for draft standards
  - Feasibility of Flash LIDAR based relative position and attitude

Target Missions

Increasing Challenge →

Knowledge	Marked	Drawings	None	
Controlled	Active	Passive Stable	Tumbling	
Cooperative	Maneuvers	Measurements 2-way Comm	2-way Comm	None

Configuration	Knowledge	Controlled	Cooperative
Refuel/Material Delivery	Marked	Active	2-way Comm
	Drawings		None
Repair/Retire	Marked	Passive Stable	None
	Drawings		
Debris Disposal	None	Tumbling	None

Mission Phases

Phase	~Range	Objective	Sensor	Safety
Launch	>10,000 km	• Insert chaser into orbit in same orbit plane, below target	GPS	Resume mission on nav failure
Phasing	>5 km	• Reduce range to target • Chaser acquires initial aimpoint for approach	GPS	
Homing/Closing	5000-250 m	• Relnav • Reach then enter approach ellipsoid	Radar, Lidar, RGPS	• Preclude collision • Maintain target sensing
Final Approach	0-250 m	• Chaser achieves docking capture conditions • Interfaces within docking range	Optical, RF, LIDAR	• Preclude collision • Low velocity • Keep-out zone • Avoid plume impingement

Key Technology – Flash LIDAR

Motivation

- Flash LIDAR may be a key sensor that makes ARD more practical
- Provides range measurements to a variety of points on target object, allowing the relative position and attitude to be estimated
- As an active sensor, LIDAR is robust to poor lighting conditions and offers an advantage over traditional optical measurements

Study Objectives

1) To generate a realistic model of flash LIDAR measurements and determine the levels of accuracy and uncertainty anticipated in ARD scenarios

2) To understand how sensor noise and errors in calibration affect predicted performance

3) To evaluate the information/measurement profile and maneuver accuracy required to achieve specific position and attitude accuracy

Flash LIDAR for Relative Navigation - Overview

- Actively illuminates target spacecraft
- Combination of pulsed laser with flash focal plane array returns both a range and intensity measurement (3D image)
- High frame rates (up to ~30 Hz)
- Instruments made by Ball and ASC have flown on space shuttle missions
- Does not require target cooperation
- Reduces slewing/pointing requirements and search algorithms with respect to single beam systems
- ASC chosen to provide a flash system for OSIRIS-Rex mission
- Challenges: systems are new and still being developed; each pixel must be characterized/calibrated

Ball's VNS system for Orion

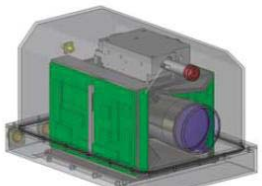


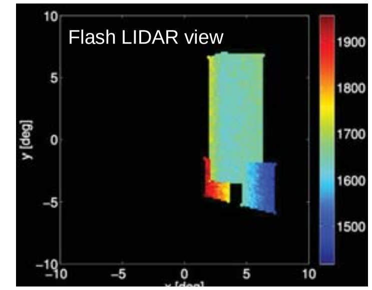
Image credit: R. Craig & P. Earhart, Ball Aerospace & Technologies Corp.

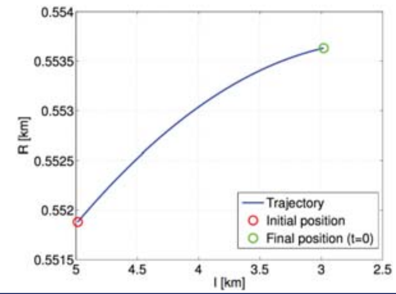
ASC's DragonEye system on the Shuttle

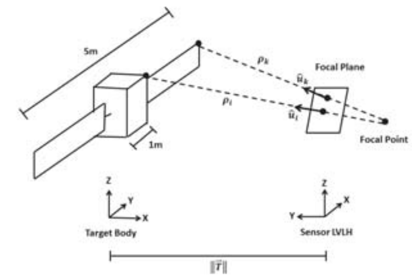
Image credit: R. Stettner, Advanced Scientific Concepts, Inc.

Flash LIDAR for Relative Navigation - Modeling

- Instrument Characteristics: 256 x 256 array, 20 deg FoV, random range errors with 1-sigma of 1% added, pointing errors due to finite pixel size
- For phasing stage, measurements are averaged, knowledge of target shape not required, creates errors in estimates on the order of size of target
- Modeled an ISS type approach to an Iridium style satellite: phasing catches up from below/behind, burn to transfer to slow approach







Flash LIDAR – Phasing Results

Phasing Orbit Determination

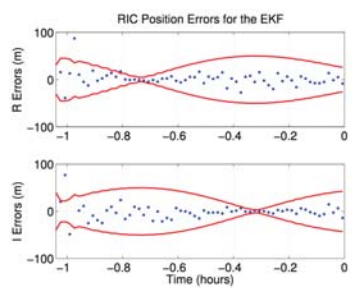
Target acquisition at 5 km (at -1.2 hours)
Initial errors [radial, in-track directions]:
[1 -1] km, [1 -1] m/s
Measurement taken every 60 seconds
Start updating state with EKF after 10 measurements
Process noise added

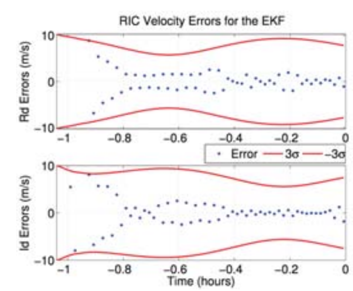
Results:

Post-fit residuals:
range = 0.32 meters , angle in plane = 1.0e-05 deg

<u>Measurement interval 60 sec</u>
Position RMS = [70.9, 58.7] m
Velocity RMS = [5.78, 3.956] m/s

<u>Measurements interval 10 sec</u>
Position RMS = [9.82, 15.0] m
Velocity RMS = [1.02 2.85] m/s

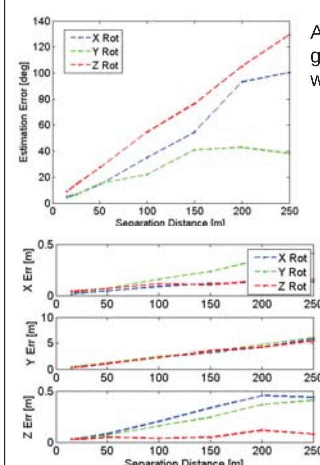




Flash LIDAR– Final Approach Results

250 to 15 meter separation

RMS errors computed for rotations from 1-90 deg about each axis as a function of separation distance

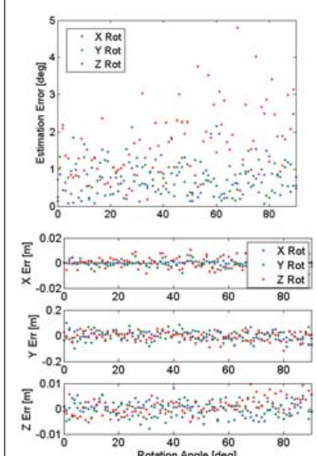


Attitude errors grow quickly with distance

Position errors worst in along-track (y) ~ 5m at 250m

15 meter separation

Attitude and position estimation errors for rotations from 1-90 deg



Attitude errors under 5 deg for all cases

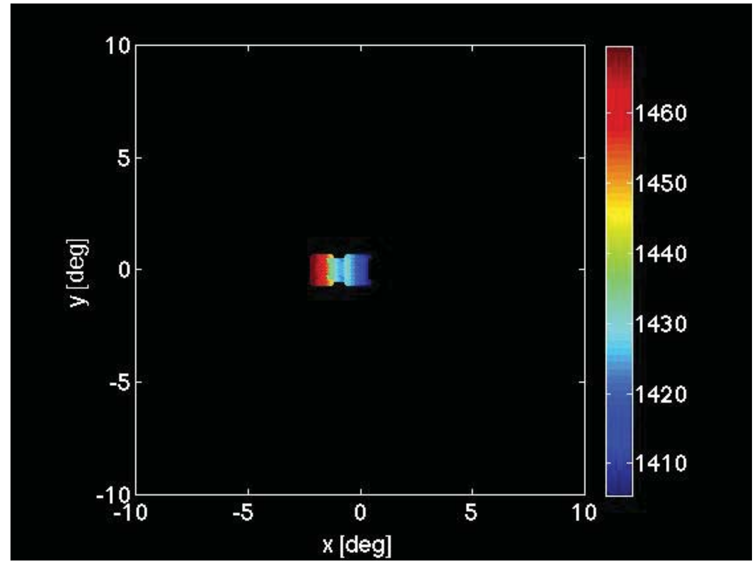
Position errors worst in along-track (y) direction, due to noise in range measurements

Next Steps

- Research and analyze US and ISO regulations, standards and guidelines for ARD
- Identify critical requirements and determine if existing approaches support these requirements without overconstraining design
- Describe common/good ARD architecture options and perform trade-offs

- Implement feature identification algorithm
- Use Flash LIDAR simulation to quantify uncertainty for position and attitude under various approach trajectories & vehicles
- Develop/implement algorithms for unknown target configuration in Flash LIDAR simulation
- Incorporate models for calibration errors

Questions?



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2. Wertz, J. and Bell, R., “Autonomous Rendezvous and Docking Technologies – Status and Prospects”, Space Systems Technology and Operations Conference, 2003.
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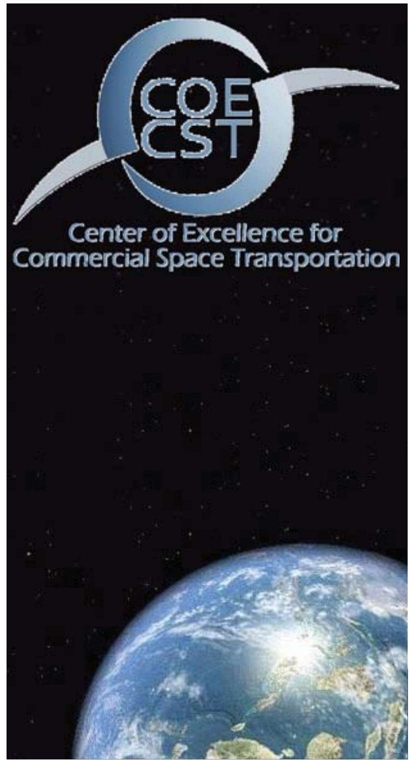
4. Mortari, D., Rojas, J.M., and Junkins, J.L., “Attitude and Position Estimation from Vector Observations,” *Proceedings of the American Astronautical Society (AAS) Space Flight Mechanics Meeting*, Maui, HI, 2004.
5. Flewelling, B., *3D Multi-Field Multi-Scale Features From Range Data in Spacecraft Proximity Operations*. PhD thesis, Texas A&M University, College Station, TX, 2012.
6. Shahid, K. and Okouneva, G., “Intelligent LIDAR Scanning Region Selection for Satellite Pose Estimation,” *Computer Vision and Image Understanding*, Vol. 107, Feb 2007, pp.203-209.

COE CST Third Annual Technical Meeting:

Autonomous Rendezvous and Docking: Rapid Trajectory Generation

Griffin Francis
Emmanuel Collins, PI
Florida State University

October 30, 2013



Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results
- Future Work
- Contact Information

Team Members

- Emmanuel Collins, PI
- Griffin Francis, PhD Student, Mechanical Engineering
- Aneesh Sharma, PhD Student, Computer Science
- Oscar Chuy, Assistant Scholar Scientist, Mechanical Engineering

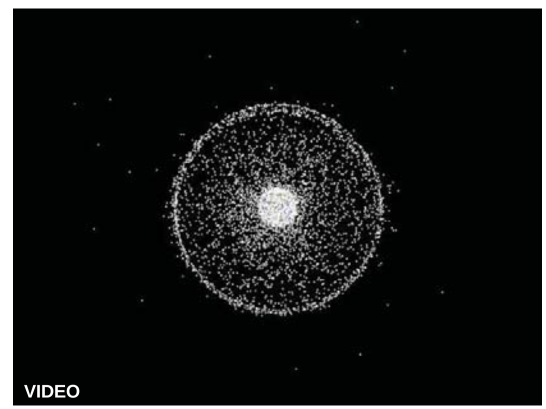
FCAAP FLORIDA CENTER FOR ADVANCED AERO-PROPULSION TECHNOLOGIES FOR THE NEXT GENERATION

CISCOR Center for Intelligent Systems, Control, and Robotics

Purpose of Task

Purpose: As indicated by recent NASA study, there is an immediate need to develop orbital debris mitigation technology.

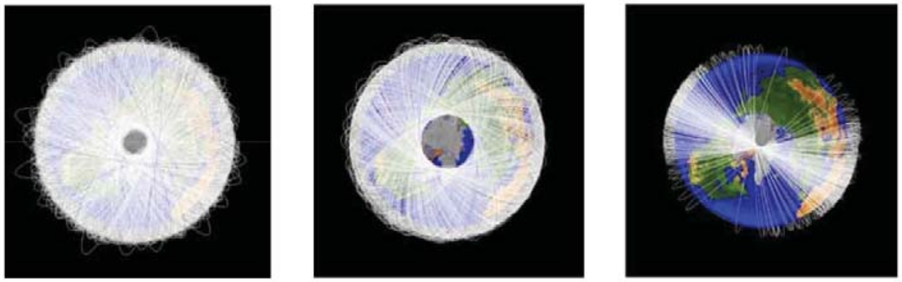
- A promising solution for direct debris removal is the development of a "Space Tow Truck."
- Requires automated guidance to approach targeted debris.



Debris in motion: about 95% of these currently tracked objects in orbit are debris and not functional satellites. (NASA Orbital Debris Program Office)

Purpose of Task

Objective: Develop the technology for rapid (within a few seconds), onboard generation of dynamically feasible trajectories that enable a spacecraft to approach a target for docking.



Impact of unmitigated debris: the profiles of three major debris clouds resulting from the January 2007 destruction of the Chinese Fengyun-1C (left) spacecraft and the February 2009 collision between the Russian Cosmos 2251 (middle) and U.S. Iridium 33 (right) spacecraft. (NASA Orbital Debris Program Office)

Purpose of Task

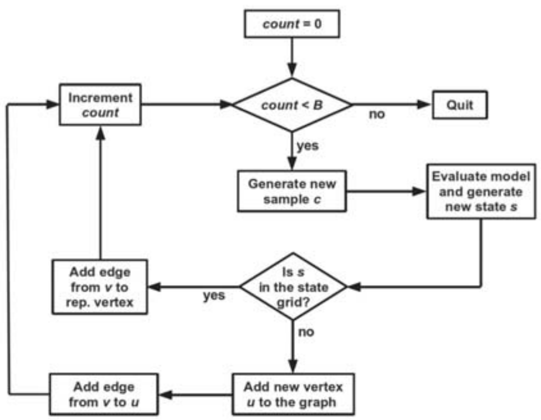
Goals:

1. Develop spacecraft dynamic model for the planner to account for actuator characteristics, vehicle momentum, and power consumption.
2. Use the dynamic model to develop trajectories for effective rendezvous with targets.
3. Optimize trajectories based on relevant metrics such as distance, time, or energy.
4. Rapidly replan trajectories as new information becomes available.

Targeting debris: artistic conceptualization illustrating the challenge of navigating to pursue an object in an orbital environment that is densely occupied. (R. Harris/SPL)

Research Methodology

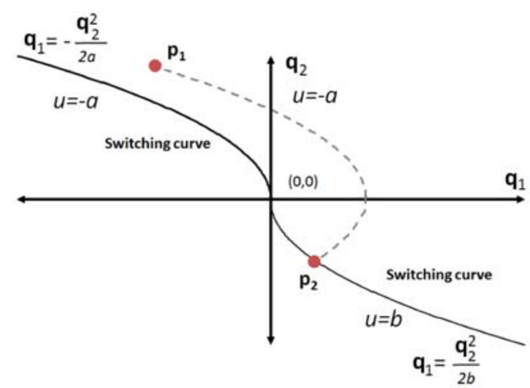
- The primary tool used is **Sampling-Based Model Predictive Optimization (SBMPO)**.
- SBMPO is a graph search method characterized by:
  - Graph that is based on sampling of model inputs;
  - Optimization via A*;
  - Incorporation of dynamic model in planning;
  - Ability to rapidly replan;
  - Generation of trajectories, not simply paths.



Fundamental Steps of SBMPO: (1) Select highest priority vertex in queue. (2) Sample input space. (3) Add new vertex to graph. (4) Evaluate new vertex cost. (5) Repeat 2-4 for defined number of successors. (6) Repeat 1-5 until stopping criteria is achieved.

Research Methodology

- The key to fast computations with SBMPO is the judicious selection of an optimistic heuristic.
  - Optimistic A* heuristic: a rigorous lower bound on the cost from the current node to the goal.
- For example, in a planning scenario requiring a specified velocity at the goal, a heuristic for minimum time optimization can be based upon the solution to the a “simple” time optimal control problem.



Derived from Pontryagin’s Maximum Principle, this minimizing control curve corresponds to the solution of the time optimal control problem.

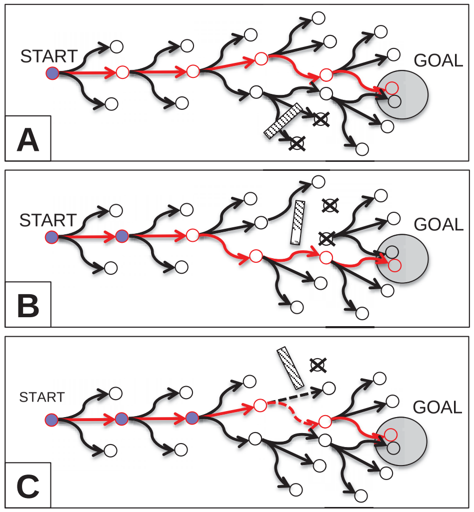
Research Methodology

Incremental Replanning:

(A) Algorithm forms initial graph and plans optimal trajectory.

(B) The graph is restored but the initial plan is violated due to obstacle movement. Invalid edges are removed and the trajectory is replanned.

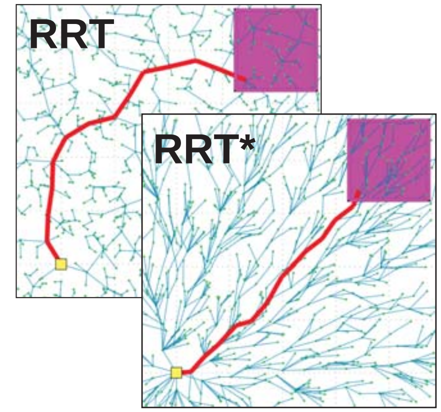
(C) The updated graph is restored but a more optimal trajectory is now achievable. Connectivity is restored and the trajectory is replanned.



Results

Introduction to Optimal Rapidly-Exploring Random Trees (RRT*)

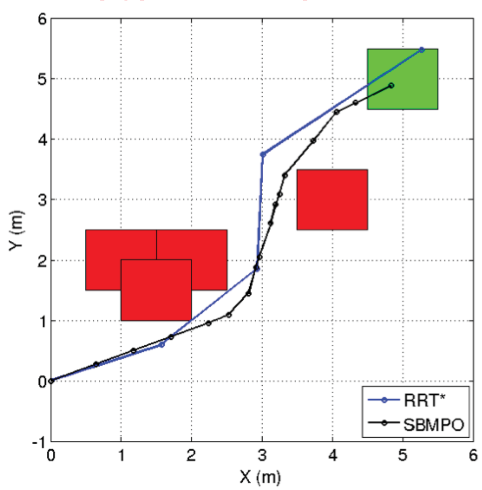
- Among the most popular motion planning methods, RRT* is an improvement of the RRT algorithm.
- Comparable to SBMPO, RRT* utilizes sampling, graph search, and cost-based optimization.
- However, RRT* does not employ prediction to speed up computations.



When compared with RRT (rear), it is clear that RRT* (front) produces a more optimal planning result. In fact, it has been proven that RRT* guarantees an asymptotically optimal solution. (*Sampling-Based Algorithms for Optimal Motion Planning*, Karaman and Frazzoli)

Results

Comparison of SBMPO with RRT* (Typical Result)



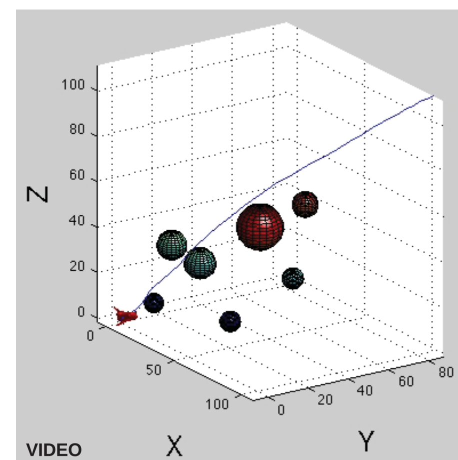
	SBMPO	RRT*
Distance (m)	7.39	8.28
Comp. Time (ms)	1.9	50.0

- Similar trajectories are determined, but SBMPO performs the calculation more than one order of magnitude faster.
- In complicated planning scenarios, this discrepancy in computation time prohibits the use of RRT* and similar approaches.
- As shown in this simple comparison, the use of a heuristic (in SBMPO) facilitates rapid computation.

Results

3D Trajectory Generation in Cluttered Space

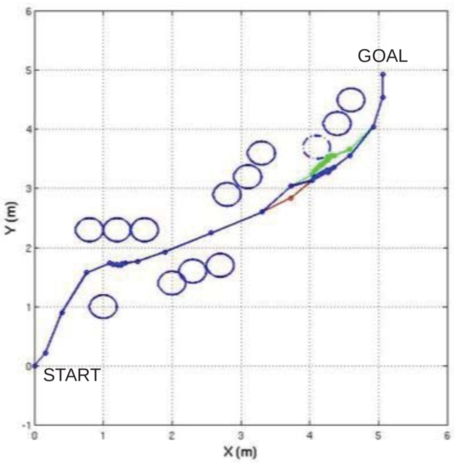
- Spacecraft is disoriented and trailing the target. Several nearby obstacles are detected.
- SBMPO sampled thrusters and rotation wheels aligned to the body axes (6 inputs).
- Maneuver time is optimized (similar result obtained minimizing distance).
- Zero relative velocity at the goal is enforced.
- Route to target is computed in less than one second.



- Other approaches compute similar trajectories in 25+ seconds.

Results

Efficient Replanning via Lifelong Planning A* (LPA*)



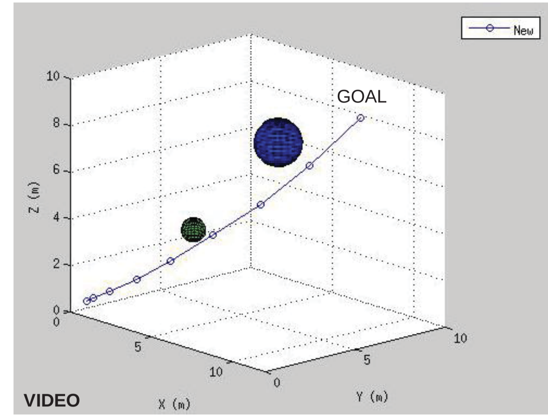
	Initial	Modified	
	SBMPO	w/ LPA*	SBMPO
Distance (m)	7.33	7.34	7.33
Comp. Time (ms)	887	13.6	653

A* algorithm as a substitute for traditional A*, the planner is able to utilize past trajectory data.
  - In terms of computation time, LPA* is much more effective when obstacle motion is likely.
- By enabling rapid replanning, LPA* essentially paves the way for an incremental version of SBMPO.
  - Crucial step for hardware implementation.

Results

3D Replanning in a Non-deterministic Environment

- Obstacle field changes as vehicle progresses to the goal.
- Route to target is replanned when changes in obstacle characteristics are detected.
- By using previous graph information and managing graph connectivity, minimal nodes are added.



	Computation Time (ms)
w/ Replanning	44.1
w/o Replanning	531.3

Results

Publications

G. Francis, E. Collins, O. Chuy, and A. Sharma, "Sampling-Based Trajectory Generation for Autonomous Spacecraft Rendezvous and Docking," in *Proceedings of the AIAA Guidance, Navigation, and Control Conference*, Boston, MA, August 19-22, 2013.

G. Francis, E. Collins, O. Chuy, and A. Sharma, "Rapid Trajectory Generation for Autonomous Spacecraft in Stochastic Environments" (in preparation), for submission to *Journal of Guidance, Control, and Dynamics*.

Future Work

- Integrate state-estimation error correction within SBMPO to accommodate minor course corrections without replanning.
- Continue development of an "anytime" version of SBMPO that enables trajectory planning over a fixed amount of time.
- Progress toward on-orbit implementation.
- Laboratory demonstration of planning for aerospace rendezvous.

- Utilize recently acquired quadrotor as precursor to on-orbit deployment.
- Employ VICON motion capture system for trajectory tracking.

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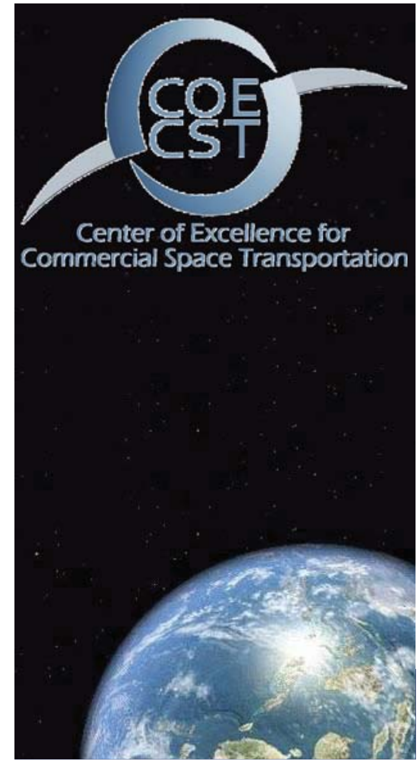
COE CST Third Annual Technical Meeting:

Task Area 244:

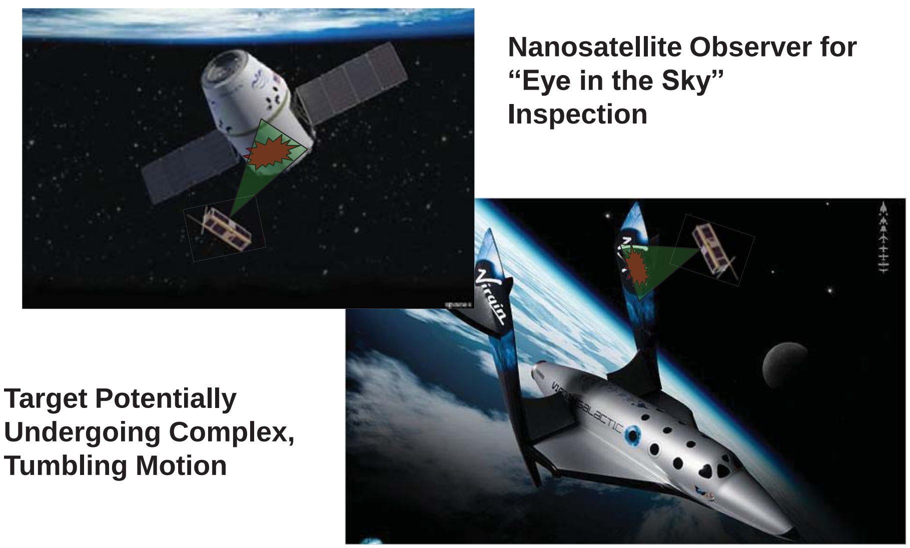
AUTONOMOUS RENDEZVOUS AND DOCKING
(Using nano-satellites for inspection and proximity operations)

PI: Steve Rock
Stanford University

October 30, 2013



Motivation



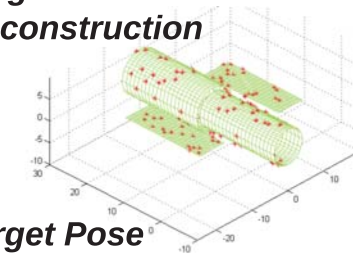
Nanosatellite Observer for "Eye in the Sky" Inspection

Target Potentially Undergoing Complex, Tumbling Motion

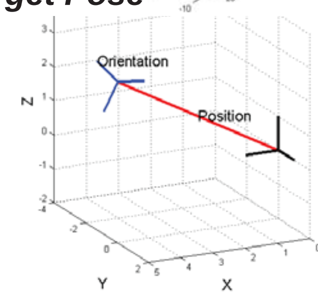
Statement of Purpose

- Goal: To develop new technology for spacecraft proximity operations that is safety enabling
- Target Reconstruction and Pose Estimation
- Unstructured rendezvous situations
  - Tumbling target motion
  - No a priori information
  - Uncommunicative target
- Enable this capability on a nano-satellite observer
  - **Small satellites impose sensing, size, and power constraints**

Target Reconstruction



Target Pose



Outline

- Prior Work as of Last Technical Meeting
  - Monocular Vision and Sparse-Pattern Range Data
    - Estimation Methodology
    - Simulation Results
- Work Since Technical Meeting
  - Shift in Direction
    - *Flash LIDA*R and Visual Imagery scheduling for minimal power consumption
  - Hardware Testbed
    - 6-DOF relative motion simulation
  - Estimation Codebase

Team Members

- PIs: Steve Rock

- Students:
  - Jose Padial, PhD Candidate
  - Andrew Smith, PhD Candidate

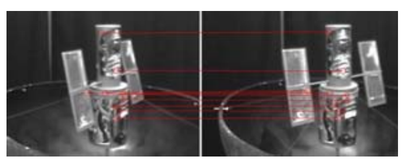
- Department of Aeronautics & Astronautics, Stanford University

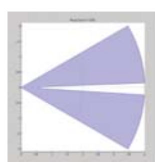
Prior Investigation as of Last TM

- **Fusion of vision and sparse pattern range data**
  - Power and size drove sensor choice
    - Camera can be tiny and very low power (passive sensor)
    - There exist small line-scanning range finders with *relatively* low power consumption

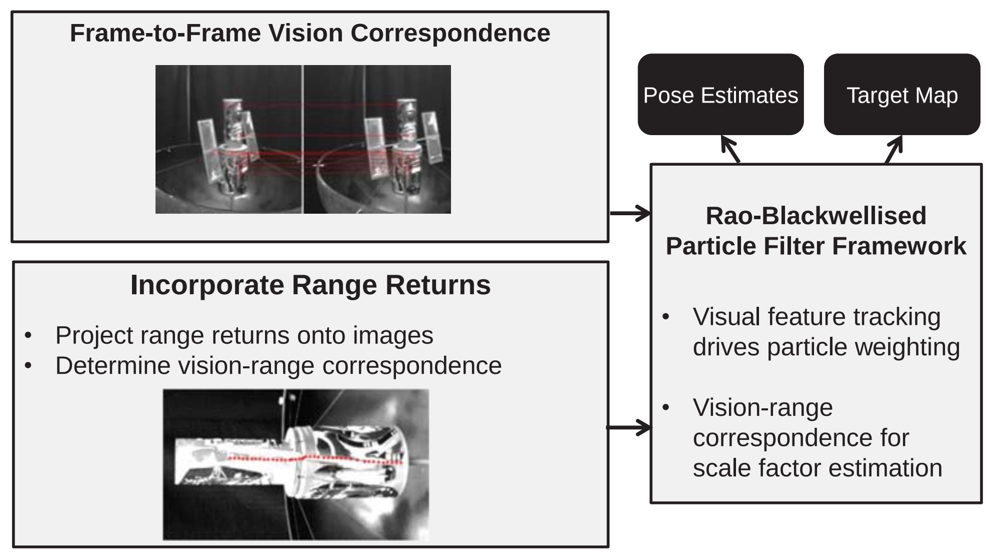
- **Monocular vision**
  - Robust feature tracking (SIFT) provides frame-to-frame correspondence

- **Sparse-pattern Range Data**
  - e.g. Line-scanning Laser
  - Provides 3D mapping of target geometry

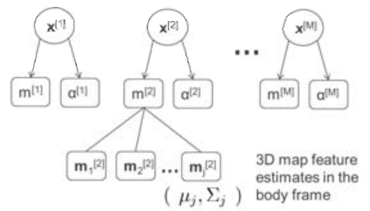




Algorithm Overview



Algorithm Details



Details of the algorithm in:
Padial et al, "Tumbling Target Reconstruction and Pose Estimation through Fusion of Monocular Vision and Sparse-Pattern Range Data", *IEEE MFI Conference 2012.*

(μ_j, Σ_j)

2D Vision Feature Measurements

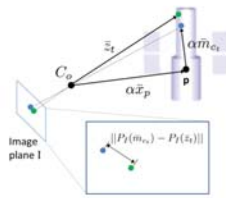
$$y_i^t = [u_i, v_i]_t^T$$

Expected Vision Measurements

$$\hat{y}_j^{t[i]} = K(R_t^{[i]}\mu_j^{[i]} + \bar{x}_{p,t}^{[i]})$$

Particle Weighting

$$w^{[i]} = \prod_{j=1}^{N} \frac{1}{|2\pi\Sigma_j^{[i]}|^{0.5}} e^{-\frac{1}{2}||y_j^t - \hat{y}_j^{t[i]}||^2_{\Sigma_j^{[i]}}}$$



Vision-range Correspondence

$$\hat{c}_t = \arg\min_{c_t} ||P_I(\bar{m}_{c_t}) - P_I(\bar{z}_t)|| \quad \text{subject to } ||P_I(\bar{m}_{c_t}) - P_I(\bar{z}_t)|| \le \beta$$

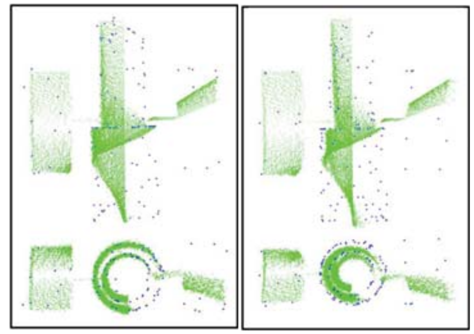
Scale Estimation System is *Linear*

$$\bar{z}_t = (R(\bar{\theta}_t)^{B/C}\bar{x}_{p,t} + \bar{m}_{c_t})\alpha_t + \bar{\delta}_z$$
$$\bar{\delta}_z \sim \mathcal{N}(0, \Gamma_z)$$

Gaussian Measurement Distribution is *Linear* in Scale

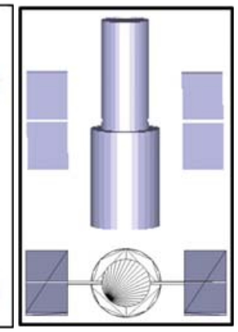
$$p(z_t|\alpha_t, x^t, z^{t-1}, c^t) \sim \mathcal{N}(z_t;\ (R(\bar{\theta}_t)^{B/C}\bar{x}_{p,t} + \bar{m}_{c_t})\alpha_t,\ \Gamma_z + \alpha_t^2\Sigma_{\hat{c}_t})$$

Simulation Results

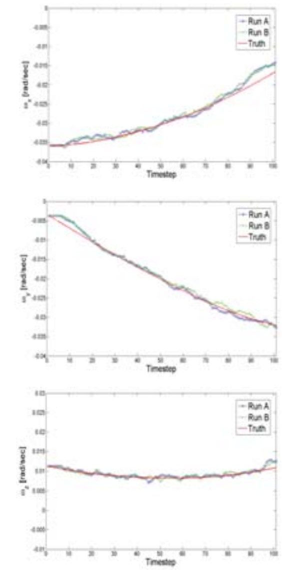


Run A: 0.42% scale error, 3.42% angular velocity error

Run B: 4.36% scale error, 3.68% angular velocity error



Target Model



Estimate Error	Mean	Std. Deviation	Max
Scale	2.14%	0.86%	4.36%
Angular Velocity	3.62%	0.71%	5.77%

Outline

- Prior Work as of Last Technical Meeting
  - Monocular Vision and Sparse-Pattern Range Data
    - Estimation Methodology
    - Simulation Results
- Work Since Technical Meeting
  - Current Direction
    - *3D Flash LIDAR* and Visual Imagery scheduling for minimal power consumption
  - Hardware Testbed
    - 6-DOF relative motion simulation
  - Estimation Codebase

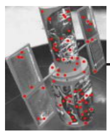
Current Investigation Direction

- **3D Flash LIDAR**
  - Flash LIDAR systems are coming down in size and power consumption
  - Dense 3D data is far more rich than that obtained by line-scanning laser range finders
    - Capable of use in frame-to-frame correspondence
    - Allows for computationally less intense estimation as compared to monocular vision + line-scan range data
- **Nanosatellite observer craft our goal**
  - Power consumption of the Flash LIDAR still too high
  - *Potential solution*: Intelligent scheduling of "flashes" in order to minimize power consumption while maintaining estimation performance

Current Investigation Direction

Sensor Scheduling for Minimal Power Consumption

- Fusion of 3D Flash LIDAR and visual imagery data for pose estimation and target reconstruction
- Develop scheduling algorithms to selectively choose when to “flash” LIDAR in order to minimize power consumption while maintaining sufficient pose estimation and target reconstruction performance



Visual Imagery

3D Range Data

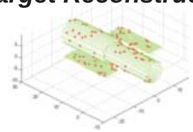
Data Fusion and Estimation Method

- Feature (SIFT) correspondence
- Pose estimation with 3D point alignment

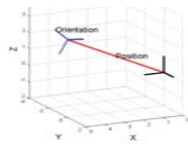
Scheduling for Minimal Power Consumption

- When should the LIDAR flash?

Target Reconstruction



Target Pose

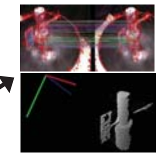


Current Investigation Direction

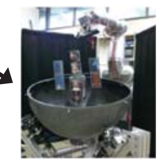
Sensor Scheduling for Minimal Power Consumption

- Fusion of 3D Flash LIDAR and visual imagery data for pose estimation and target reconstruction
- Develop scheduling algorithms to selectively choose when to “flash” LIDAR in order to minimize power consumption while maintaining sufficient pose estimation and target reconstruction performance

In order to investigate sensor scheduling need to develop baseline capabilities

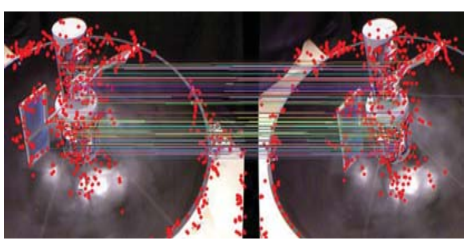


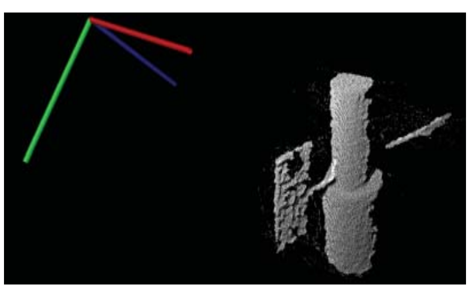
Estimation Algorithm
Pose estimation and target reconstruction with visual imagery and 3D range data



Hardware Testbed
6-DOF relative motion between target and observer

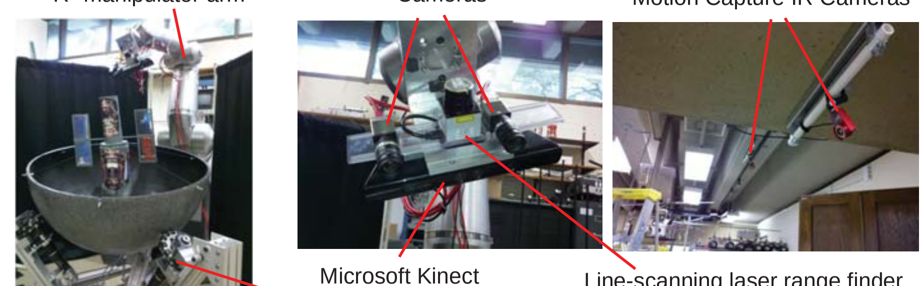
Estimation Methodology





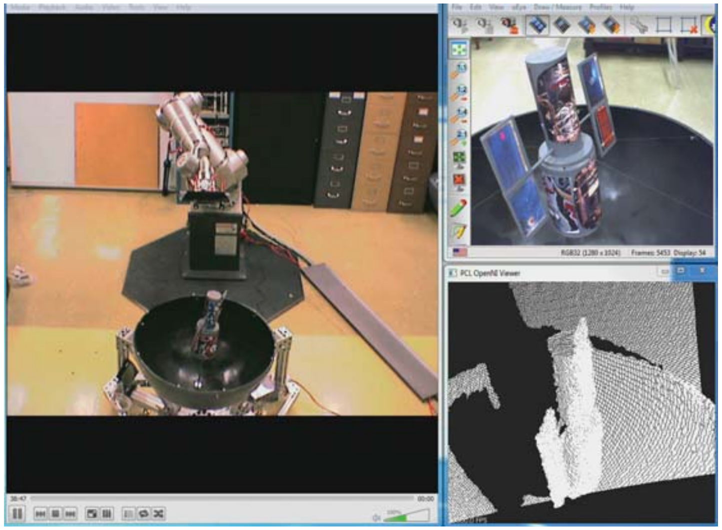
- **Vision feature correspondence (SIFT)**
  - Provides the alignment of points between 2 successive frames
- **Range data provides depth for corresponding points (full 3D points)**
  - Well-known Horn’s method used to estimate rotation and translation of target between frames (relative to observer frame)
- **Estimation is *well-behaved* compared to monocular vision case**

ARL Hardware Testbed



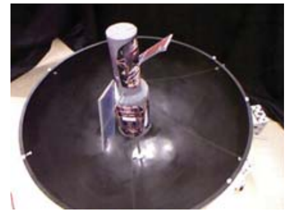
- Mounted sensors to manipulator end-effector for 6DOF relative motion
  - Microsoft Kinect as a surrogate for Flash LIDAR
- Mounted Motion Capture IR Cameras (6)
- Simulink-based manipulator and tumbling base control with synchronized camera/ranging data collection and IR truth data collection

ARL Hardware Testbed

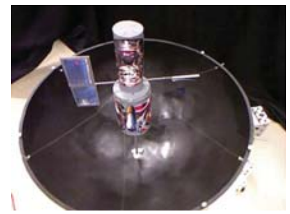


Pose Estimation / Reconstruction

Target Range of Motion

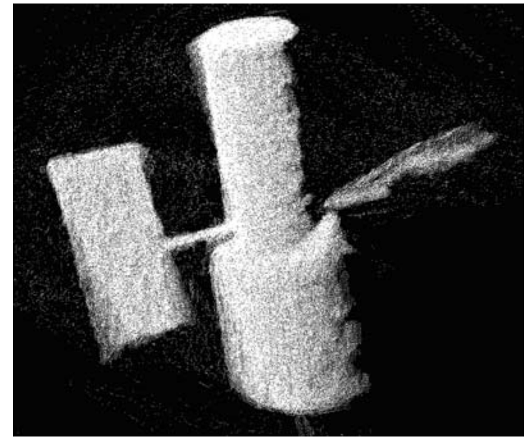


First Frame



Last Frame

Reconstruction



Contact Information

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- Jose Padial
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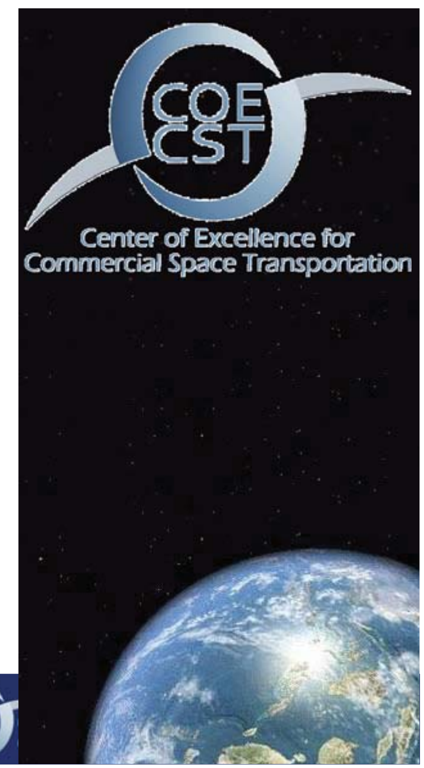
COE CST Third Annual Technical Meeting

Task 244: Autonomous Rendezvous & Docking for Space Debris Mitigation

Norman Fitz-Coy

October 30, 2013



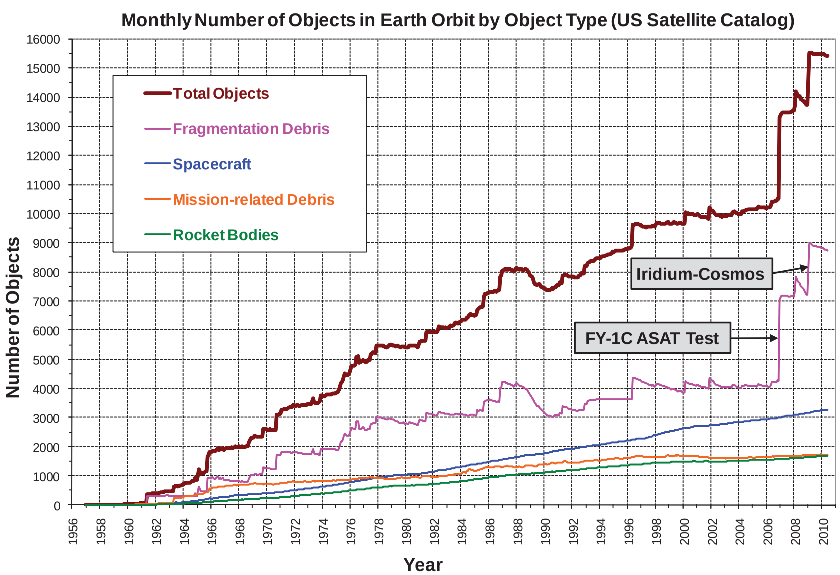
Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results/Summary
- Next Steps
- Contact Information

Team Members

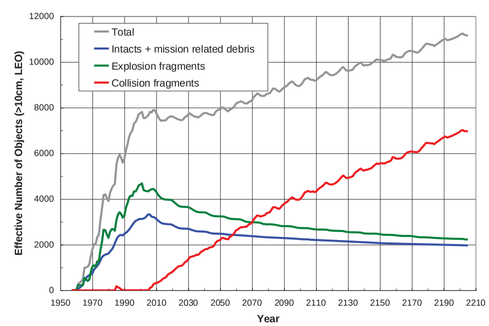
- PI: Norman Fitz-Coy (MAE Dept. Univ. of Florida)
- Students
  - Takashi Hiramatsu (graduated 2012)
  - Kathryn Cason (accepted job)
  - Tristan Newman (new)
- Related Activity
  - DebriSat for NASA's ODPO (update to the 1992 SOCIT experiment)

Purpose of Task



Purpose of Task

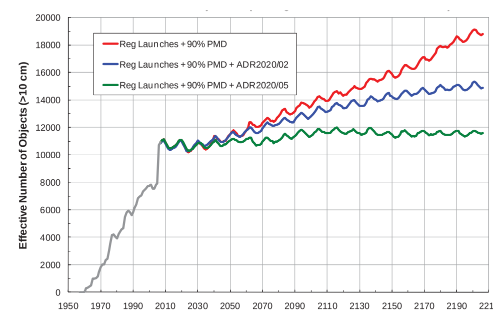
NASA study on debris considering no new launches after 1/1/2006



- **Collision fragments replace other decaying debris through the next 50 years, keeping the total population approximately constant**
- **Beyond 2055, the rate of decaying debris decreases, leading to a net increase in the overall satellite population due to collisions**

(Liou and Johnson, *Science,* 2006)

Justification for Active Debris Removal (ADR)



- **PMD scenario predicts the LEO populations would increase by ~75% in 200 years**
- **LEO environment can be stabilized with PMD and a removal rate of ~5 objects/year**

(Liou, Johnson, and Hill 2010)

Purpose of Task

- Active debris removal is required
- Interests in small satellites (e.g., CubeSats) especially by new space entrant leads to:
  - More spacecraft $\Rightarrow$ more failure (debris)
  - Debris likely to be non-cooperative

Objective

- Develop strategies to minimize interactions during removal of non-cooperative debris
- Develop strategies for safe proximity operations / collision avoidance during removal

Research Methodology

- Debris Size
  - < 0.5 cm (not practical)
  - 0.5 – 10 cm (not tracked/not retrieved)
  - 10 cm – 1 m (tracked but not retrieved)
  - > 1 m (tracked and can be retrieved)
- Removal concepts
  - Space Tugs
  - Tethers
  - Lasers

Research Methodology

- Space Tug Concept
  - Use a space tug (ST) to maneuver larger disabled satellite (debris) into disposal orbit
  - ConOPs:
    - Autonomous proximity operations
    - Autonomous capture of target
    - Minimizing interactions between ST and non-cooperative debris

On-orbit repair of Intelsat 603 (May 1992)

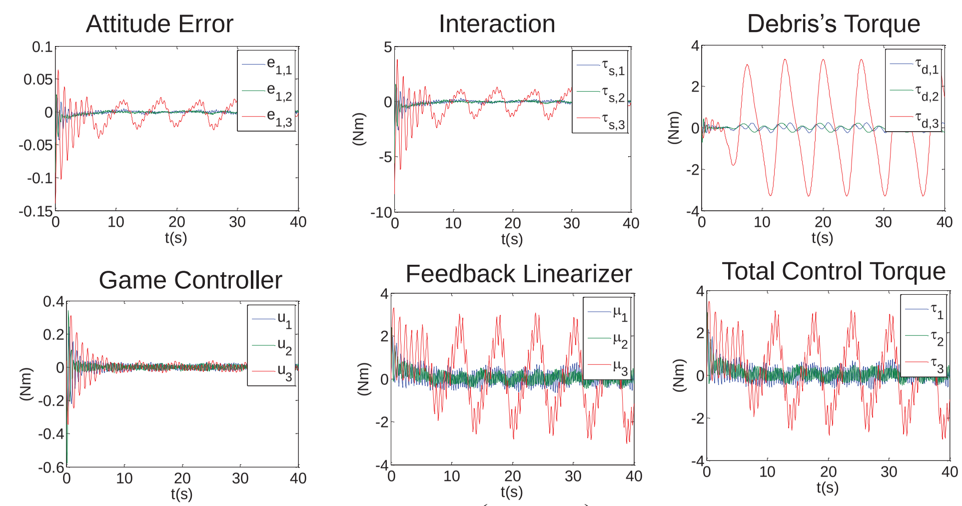
Research Methodology

- Game theoretic approach
  - Formulate a two player game between the space tug (ST) and the debris
  - Use a hierarchical approach with the debris as the leader and ST as the follower (i.e., ST minimizes interaction with a non-cooperative debris)
  - Develop appropriate strategy (Stackelberg)
- Solve differential game problem

Research Methodology

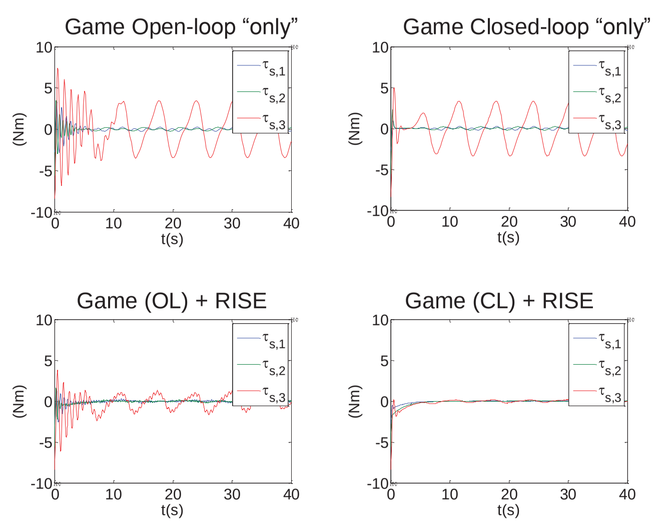
- Indirect solution method
  - Currently the only way to find a solution in general
  - Only known existing solution (LQ case only)
- Direct solution method
  - Solution algorithms for bilevel programming are not as mature as those for nonlinear programming
- Approach: Start with a LQ game and extend by adding more complexities; i.e.,
  - Linear dynamic model (small perturbations)
  - Nonlinear dynamics with linear error model (RISE)

Results / Summary



Total momentum input $\left(\sum_{i=1}^{3}\int \tau_i dt\right) = 73.32\ \mathrm{N \cdot m \cdot s}$

Results / Summary



Summary of Interaction/Input

Momenta	Interaction	Input
RISE "only"	83	73
Open-loop game + RISE	72	72
Closed-loop game + RISE	46	71
Open-loop game "only"	104	8
Closed-loop game "only"	82	19

Results / Summary

- Demonstrated the viability of game theoretic approach for removal of non-cooperative debris
  - Linearized dynamic model (restrictive)
  - Nonlinear dynamic model (via linearized error model)
- Investigated open-loop and closed-loop Stackelberg strategies
  - Both open- and closed-loop strategies when combined with RISE "linearizer" appear to produce lower interactions
  - Closed-loop + RISE appears to be best overall

Next Steps

- Continue assessment of game-theoretic methods to reduce interactions with non-cooperative debris
  - Explore multiplicative attitude error
  - Further investigate numerical approaches to solving static games / bilevel programming
- Initiate vision-based APFG for proximity operations and collision avoidance
- Collaborate with NASA ODPO (e.g., in situ characterization of LEO debris)

Contact Information

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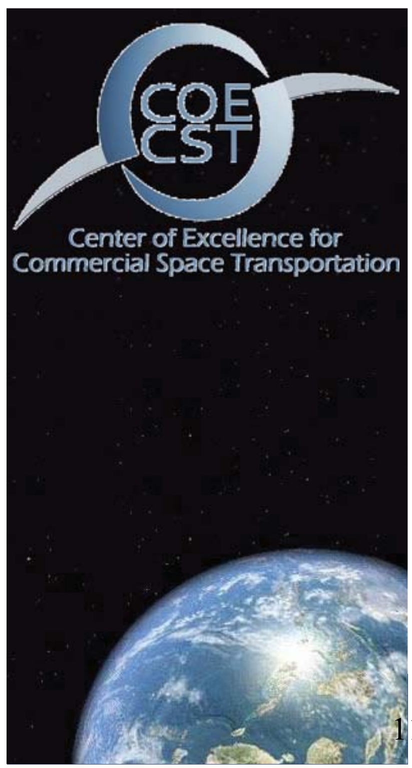
COE CST Third Annual Technical Meeting:
Task 247 - Air & Space Traffic Considerations for CST

Dr. Nathaniel E. Villaire, Professor Emeritus

October 29, 2013



Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results
- Next Steps
- Contact Information

Team Members

- Dr. Nathaniel E. Villaire, Professor Emeritus
- Dr. John Deaton, Professor
- Dr. Samuel T. Durrance, Professor
- Dr. Daniel Kirk, Associate Professor
- Dr. Tristan J. Fiedler, Associate VP for Research
- Mr. Sebastian Rainer, Research Assistant
- Mr. Dennis W. Wilt, Research Assistant
- Space Florida – Industry Partner

Purpose of Task

- Purpose
  - Quantify the cost of diversions around airspace closed due to commercial launch operations
- Objectives
  - Develop a user program that will provide the delta cost associated with airline and air cargo diversions around closed airspace
- Goals
  - Develop a database of flight routes, airspace areas, and sample flight data
  - Create a proof of concept program that suggests alternate routes around closed airspace based on cost savings
  - Keep the user interface and installation simple enough for even most basic computer users
  - Be compatible with most common computer systems
  - Determine the cost of a diversion
  - Be able to scale project to handle larger amounts of flight data

Research Methodology

- Review of Oceanic Routes
- Review of Warning, Alert, and Restricted Areas for Launch Sites
- Review of Software Compilers that work on various operating systems (Apple and Microsoft)
- Develop program to perform simple cost analysis
- (Future Development) Expand program to perform cost analysis on more complicated route changes
  - Provide more realistic route diversions
  - Determine delta costs based on original routing vs. diversion

Results

- Current Demonstration Program Capabilities
  - Calculates Flight Diversion on a Specific Oceanic Route
  - Provides Flight Location Entering Diversion Airspace
  - Provides Time of Diversion
  - Provides Distance to Normal Airspace
  - Provides Cost of sending the aircraft to the nearest corner of the closed airspace
  - Data saved to a text file
- Operator needs to have moderate computer skills
  - Installation and Setup are not simple
  - Program Operation requires understanding of the airspace detail
  - Operates on JAVA code compiler (Some JAVA updates may render the program inoperable)

Next Steps

- Divert all aircraft around the entire restricted launch area
- Calculate real diversion costs
  - Provide the delta costs for the diversion vs. original flight path
- Calculate Diversion for Any Flight in the Data Base
- Place all Data in an Excel Data Base File
- Would like to collaborate with outside expertise in Air Traffic Management for diversion models (more realistic ATM modeling for diversions)
- Simplify and update installation, setup, and operation of the program
- Possibly update to a code compiler that is backwards compatible

Contact Information

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(Research Assistant)
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Florida Institute of Technology C/O 2014
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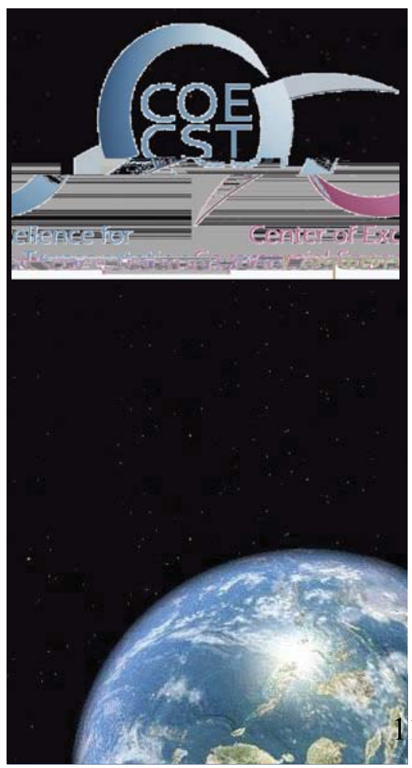
COE CST Third Annual Technical Meeting: Ultrahigh Temperature Composites for Thermal Protection Systems (TPS)

James McKee, Donovan Lui, Hongjiang Yang, Cassandra Carpenter, Jay Kapat, Jan Gou

Department of Mechanical and Aerospace Engineering
University of Central Florida

October 29, 2013



Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results or Schedule & Milestones
- Next Steps
- Contact Information

Team Members

Principle Investigators

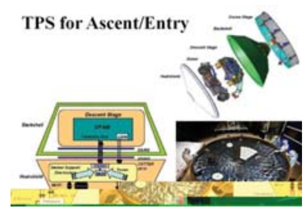
- **Jan Gou -** Composites design and manufacturing, composites mechanics
- **Jay Kapat -** Heat transfer, film cooling, aerodynamics testing
- **Ali Gordon -** Thermo-mechanical testing and modeling

Graduate Students

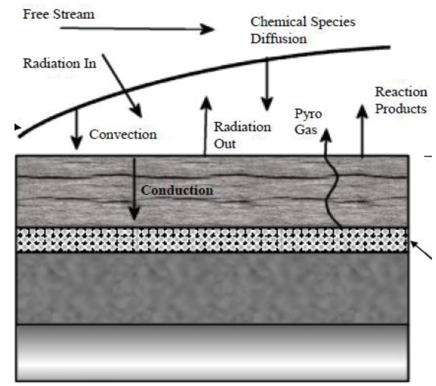
- **James McKee, Hongjiang Yang**: Composites TPS design & manufacturing
- **Donovan Lui**: Ablation testing
- **Cassandra Carpenter**: Aerothermal modeling

Purpose of Task

Develop **ultrahigh temperature**, **light weight**, **low erosion**, and **cost effective** ablative thermal protection systems with embedded health monitoring for inherent safety and real-time assessment of TPS performance in hypersonic space vehicles



Reentry Vehicles



Purpose of Task

RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- Ultra-high temperature, light weight, low erosion, and cost effective thermal protection systems (TPS) are enabling technologies for viable commercial space transportation vehicles and their high-temperature systems.

STATEMENT OF WORK

- Develop nanocomposites TPS with embedded health monitoring for inherent safety and real-time assessment of hypersonic TPS applications.
- Provide an analysis tool for the aerothermal modeling of reentry vehicles and rocket propulsion.
- Provide an analysis tool for thermal degradation modeling of new ablative materials.
- Provide ablation sensing to monitor the structural health of the ablative thermal protection system.

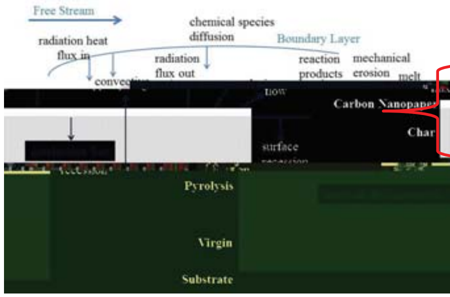
Current Approach

- PICA: Phenolic Impregnated Carbon Ablator
- SICA: Silicone Impregnated Carbon Ablator
- Carbon/Carbon Composites

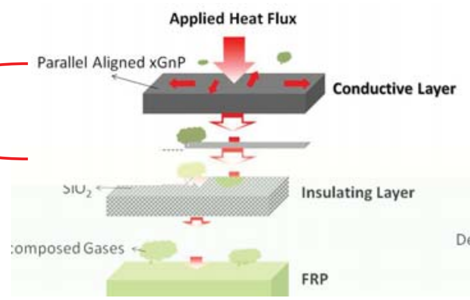
Problems

- The resulting chars are structurally weak and susceptible to mechanical erosion, severely reducing the lifetime of the TPS. Reducing spallation or erosion of the char can enable use of less ablative materials thereby reducing the total weight of TPS.
- The evaluation of ablation performance needs to consider the structural integrity of TPS structures
- Recession monitoring is most important measurement to the aerothermal analysis of the TPS structure. This measurement provides critical information about how the TPS mass and shape changes during the fight.

Ablative TPS Design - Nanocomposites Approach



TPS Materials Design



Bi-layer thermal protective coating

Nanocomposite prepreg systems

Nanocomposite thermal protective coating

Research Methodology

Vertically Aligned Carbon Nanotubes (VACNT)

- Aligned CNT Arrays grown by means of Chemical Vapor Deposition (CVD)
- Highly anisotropic properties
- Improved thermal soak rate
- Combinable with other technologies being explored

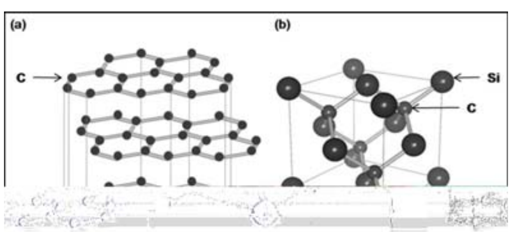
Research Methodology

Polymer Derived Ceramics (PDC)

- Corrosion and wear resistant
- Simple processing with moldable geometries
- Strong and high quality ceramic matrix yield
- Lower thermal material requirement

Fiber Reinforced Ceramic Matrix Composites (CMC)

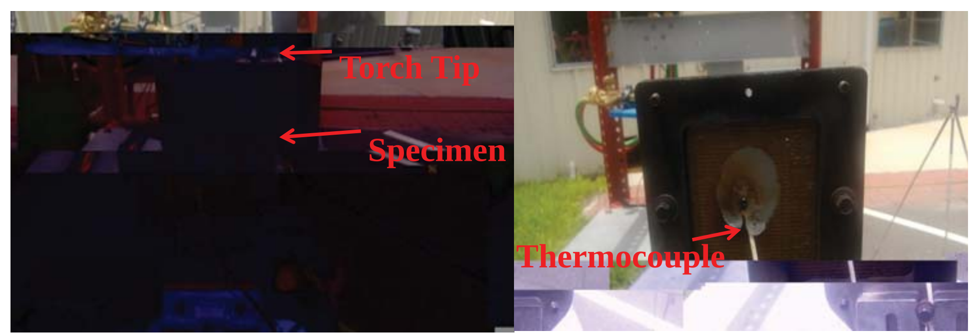
- High fracture toughness, crack resistance
- Resistance to thermal shock
- Higher oxidation temperatures (>1000°C)



Results

PICA - Nanocomposite Thermal Protective Coating

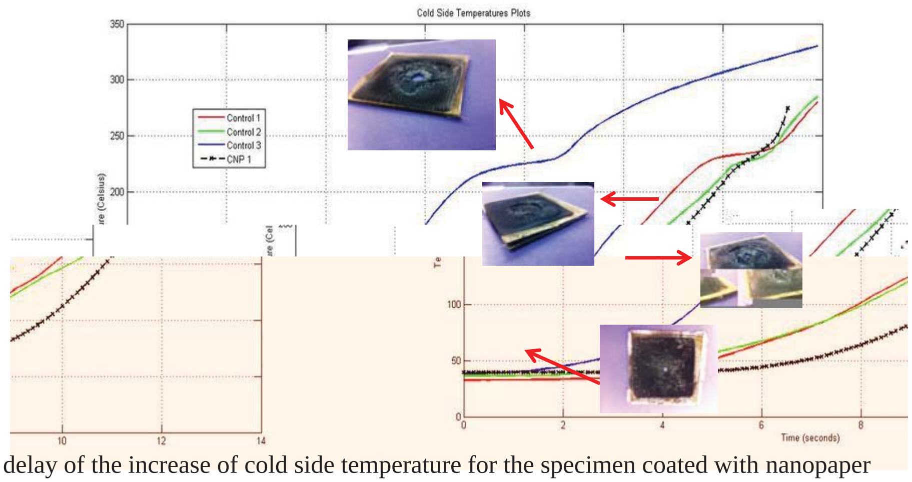
- Introduction of organized, structured carbon layer
- Improvement in insulation as well as ablative regression
- Delays first layer delamination



Oxyacetylene Ablation Testing

Results

Cold Side Temperature from Ablation Test



A delay of the increase of cold side temperature for the specimen coated with nanopaper indicates the nanopaper provided good thermal protection for the composites at high heat flux.

Next Steps

- Continue oxyacetylene torch testing of composite panels
- Integration of nanoparticles into PDC composites
- Incorporation of VACNT into composite panels
- Aerothermal analysis of TPS structures with curved geometry
- Thermomechanical characterization and testing for structural integrity evaluation

Contact Information

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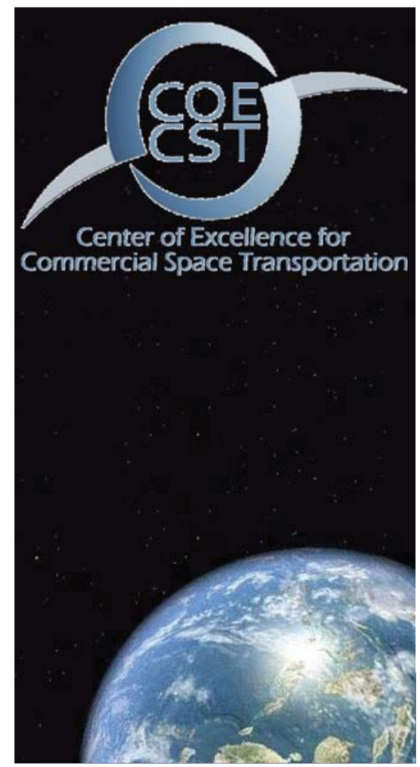
COE CST 3rd Annual Technical Meeting:

Task 255: Validation of Non-Invasive Biomedical Monitoring in Centrifuge-Simulated Suborbital Spaceflight

Richard Jennings, MD, MS
Tarah Castleberry, DO, MPH

Baylor College of Medicine — utmb Health Aerospace Medicine

October 30th, 2013



Disclaimers

- Will discuss off-label use of commercially-available physiologic monitoring device, Equivital EQ01-1000 (Hidalgo Ltd., Cambridge, United Kingdom)
- Hidalgo Ltd provides technical expertise and materials to investigators for the purpose of research

Disclaimers

- NASTAR Center partners with UTMB to provide no-cost centrifuge time for research
  - 112 days
  - Value of contribution: 3.4 million
- No other financial relationships to disclose

Overview

utmb Health Aerospace Medicine

- Team Members
- Purpose of Task
- Research Methodology
- Results
- Conclusions
- Next Steps
- Contact Information

Team Members

utmb Health Aerospace Medicine

- **PI: Richard Jennings, MD, MS; Tarah Castleberry, DO, MPH** (UTMB Aerospace Medicine)
- **Co-I: James Vanderploeg, MD, MPH** (UTMB Aerospace Medicine)
- **Co-I: Rebecca Blue, MD, MPH** (UTMB Aerospace Medicine)
- **Student: Alejandro Garbino, MD, PhD** (Baylor College of Medicine)
- **Industry Partner: Brienna Henwood** (NASTAR Center)
- **Program Manager: Ken Davidian** (FAA)
- **Technical Monitor: Henry Lampazzi**

Purpose of Task

- Purpose:
  - Identify the utility of a commercial, non-invasive, biomedical monitoring device to support operational monitoring needs in a centrifuge-simulated suborbital spaceflight experience.

NASTAR Center

Study Hardware

http://cdn.medgadget.com/wp-content/uploads//2013/01/Equivital-belt-large.jpg

http://vivonoetics.com/wp-content/uploads/2012/04/SEM02-300x210.jpg

Research Methodology

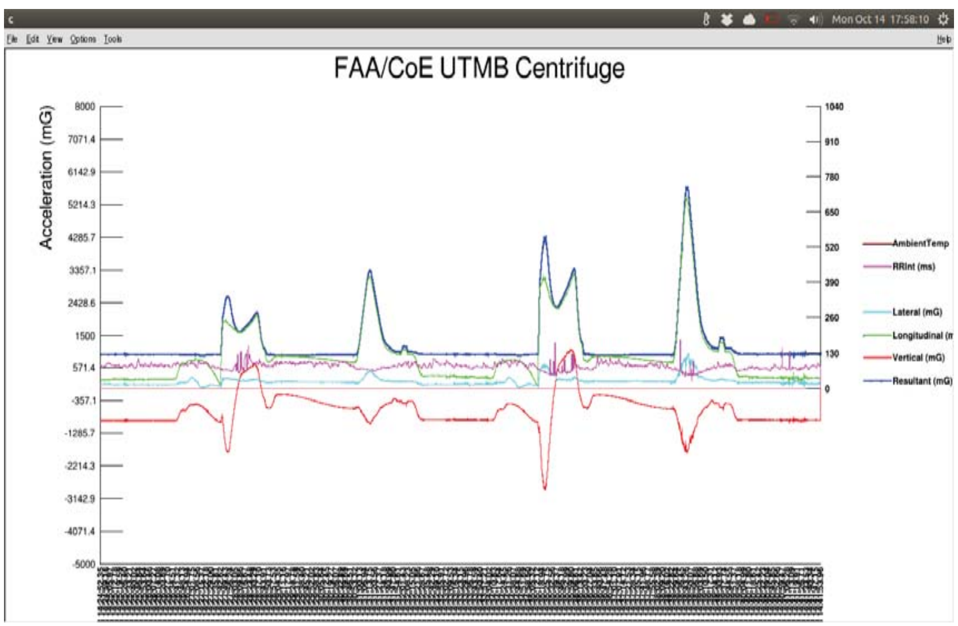
- Physiological parameters, including:
  - Heart rate
  - Respiratory rate
  - Pulse Oximetry
  - Tri-axial acceleration
- Physiologic data were synchronized with standard electrocardiogram monitoring for validation

Research Methodology

- Instrumented subjects underwent 7 centrifuge runs over two days
  - Day 1 consisted of two +Gz runs (peak=+3.5Gz) and two +Gx runs (peak=+6.0Gx)
  - Day 2 consisted of three runs approximating suborbital spaceflight (combined +Gx and +Gz).

Results

- The device performed well during the centrifuge profiles, providing hemodynamic data with little disruption of signal
- Accelerometer data were reliably synchronized with centrifuge acceleration profiles and served as excellent run-timing markers for hemodynamic data



Conclusion

- Despite the significant acceleration exposures, the monitoring system performed well and provided accurate and reliable hemodynamic monitoring of subjects
- Limitations of the device include difficulty in identifying altered electrocardiographic morphology due to the off-nominal electrode placement, cumbersome analysis techniques, and limited harness size to accommodate larger subjects.

Next Steps

- Complete training and evaluation using the NASTAR centrifuge
- Perform data analysis
- Publish results

COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013

Center of Excellence for Commercial Space Transportation

Contact Information

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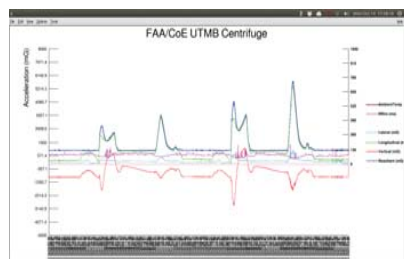
Task 256: Tolerance of Centrifuge-induced G-force by Disease State



Project At-A-Glance
- University: The University of Texas Medical Branch
- Principal Investigator: Tarah Castleberry, DO, MPH
- Student Researchers: Alejandro Garbino, MD, PhD

Relevance to Commercial Spaceflight Industry
- Commercial spaceflight participants (SFPs) represent a population with potentially significant medical problems that may warrant in-flight medical monitoring
- Commercial SFPs may be hesitant to wear highly invasive, obtrusive monitoring equipment

Statement of Work
- Identify the utility of a commercial, non-invasive, biomedical monitoring device to support operational monitoring needs in a centrifuge-simulated suborbital spaceflight experience
- Volunteers wearing the monitoring device experienced G-forces simulating a commercial spaceflight.

Status
- Complete evaluation using the NASTAR centrifuge

Future Work
- Perform data analysis
- Publish results

COE CST Third Annual Technical Meeting (ATM3)
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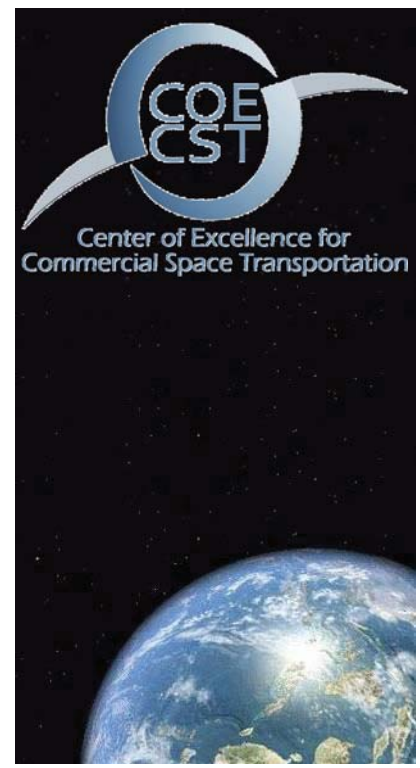
COE CST 3rd Annual Technical Meeting:

Task 256: Tolerance of Centrifuge-induced G-force by Disease State

James Vanderploeg, MD, MPH

October 30th, 2013



Disclaimers

- Will discuss off-label use of commercially-available physiologic monitoring device, Equivital EQ01-1000 (Hidalgo Ltd., Cambridge, United Kingdom)
- Hidalgo Ltd provides technical expertise and materials to investigators for the purpose of research

Disclaimers

- NASTAR Center provided centrifuge time to UTMB at no charge under the FAA COE CST relationship
- No other financial relationships to disclose

Overview

utmb Health Aerospace Medicine

- Team Members
- Purpose of Task
- Research Methodology
- Results
- Conclusions
- Next Steps
- Contact Information

Team Members

utmb Health Aerospace Medicine

- **PI: James Vanderploeg, MD, MPH** (UTMB Aerospace Medicine)
- **Co-I: Rebecca Blue, MD, MPH** (UTMB Aerospace Medicine)
- **Co-I: Tarah Castleberry, DO, MPH** (UTMB Aerospace Medicine)
- **Co-I: Charles Mathers, MD, MPH** (UTMB Aerospace Medicine)
- **Co-I: Johnené Vardiman, LCDC** (UTMB Aerospace Medicine)
- **Student: James Pattarini, MD, MPH** (UTMB Aerospace Medicine)
- **Student: David Reyes, MD, MPH** (UTMB Aerospace Medicine)
- **Student: Robert Mulcahy, MD** (UTMB Aerospace Medicine)
- **Brienna Henwood** (NASTAR Center)
- **Program Manager: Ken Davidian** (FAA)
- **Technical Monitor: Henry Lampazzi**

NASTAR Center

Purpose of Task

utmb Health Aerospace Medicine

- Purpose:
  - Evaluate subjects with defined disease states under the G-loads expected during commercial space flights using centrifuge-induced G-forces
  - Disease States
    - Controlled cardiovascular/coronary disease
    - Controlled hypertension
    - Controlled diabetes
    - Pulmonary disease
    - Spinal disease or injury

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Research Methodology

utmb Health Aerospace Medicine

- Volunteers were recruited for participation based upon their suitability for each of five disease categories (heart disease, lung disease, back or neck problems, diabetes, hypertension) or a control group.
- Subjects underwent 7 centrifuge runs over two days.

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Research Methodology

utmb Health Aerospace Medicine

- Day 1 consisted of:
  - Two +Gz runs (peak=+3.5Gz)
  - Two +Gx runs (peak=+6.0Gx)
- Day 2 consisted of three runs approximating suborbital spaceflight profiles
  - Combined +Gx and +Gz
  - Peak +6.0Gx/+4.0Gz

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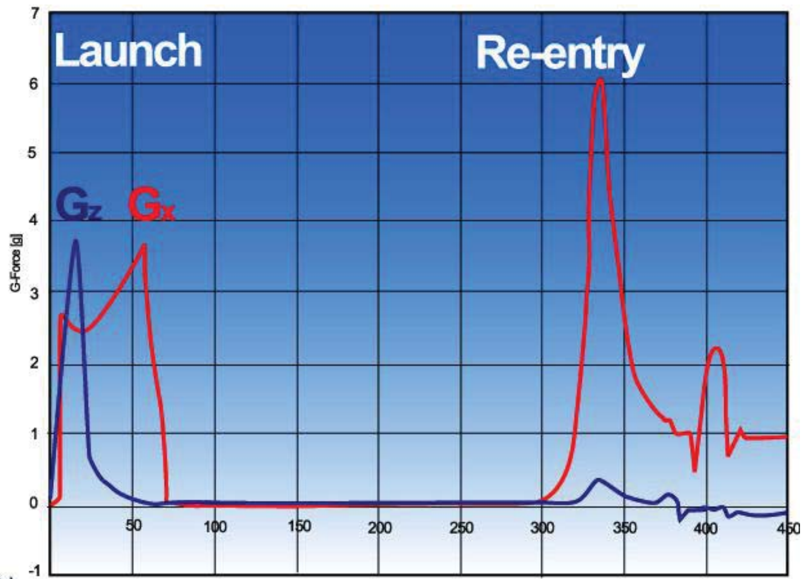
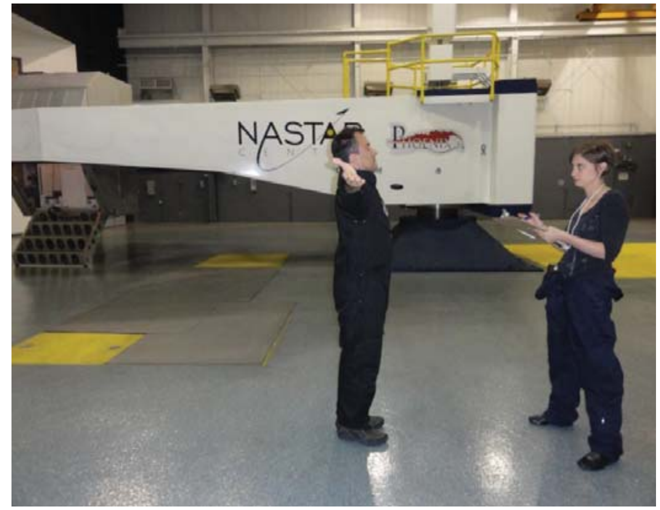

Launch
Re-entry
Gz
Gx
G-Force [g]
7
6
5
4
3
2
1
0
-1
50
100
150
200
250
300
350
400
450


NASTAR

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Research Methodology

utmb Health
Aerospace Medicine

- Data collected included:
  - Blood pressure
  - Electrocardiogram
  - Pulse oximetry
  - Neurovestibular exams
  - Post-run questionnaires regarding:
    - Motion sickness, disorientation, grey-out, and other symptoms.

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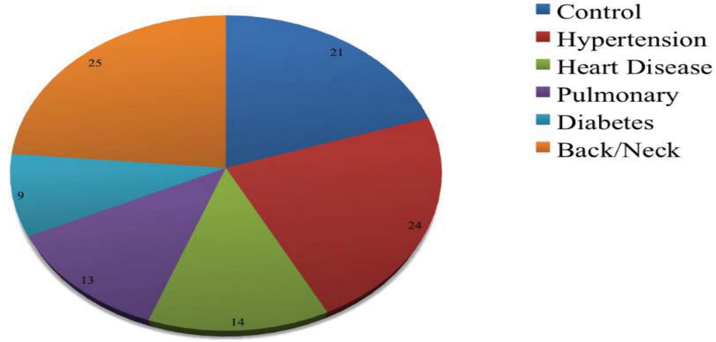
Past Medical History of Participants



Results

- A total of 77 subjects have participated thus far in centrifuge trials
  - Age range 22-73 (average 45)
  - Average BMI 26, range 18.9-40.7
- 84 subjects by study completion (115 data points)

Results

- The most common cause for disqualification was severe and uncontrolled medical or psychiatric disease.
- Two subjects voluntarily withdrew from the second day of testing for anxiety reasons
- Despite significant medical history, no subject has experienced significant adverse or abnormal physiological responses to centrifuge profiles.

Conclusion

- Results thus far suggest that most individuals with well-controlled medical conditions can withstand acceleration forces involved in launch and landing profiles of commercial spaceflight vehicles.
- Further investigation will help determine which medical conditions or devices present significant risks during suborbital flight and beyond.

Next Steps

- Complete training and evaluation using the NASTAR centrifuge
- Perform data analysis
- Publish results

COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013

Contact Information

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COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013

Task 256: Tolerance of Centrifuge-induced G-force by Disease State

Project At-A-Glance
- University: The University of Texas Medical Branch
- Principal Investigator: James Vanderploeg, MD
- Student Researchers: James Pattarini, MD
  David Reyes, MD, Robert Mulcahy, MD

Relevance to Commercial Spaceflight Industry
- There is little to no data on how individuals with chronic disease will perform in a high-performance environment such as commercial spaceflight. This study will provide data on how individuals with chronic disease respond to G-force

Statement of Work
- Characterization of responses of individuals with common medical conditions to G-force
- Development of risk mitigation strategies for individuals with those medical conditions

Status
- Complete training and evaluation using the NASTAR centrifuge

Future Work
- Perform data analysis
- Publish results
- Develop optimal acceleration training protocols for passengers

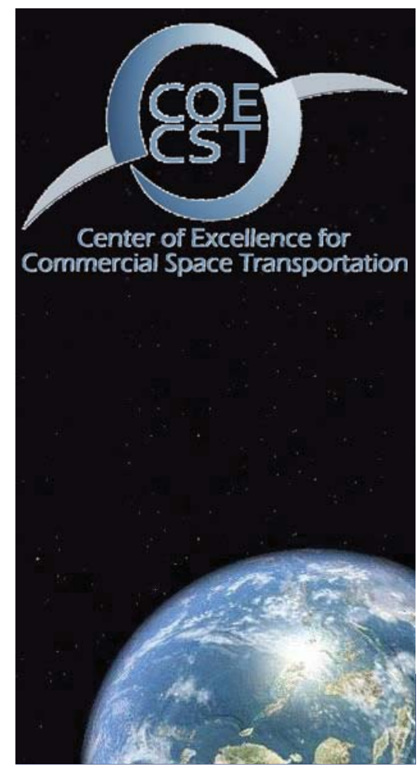
COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013

COE CST Third Annual Technical Meeting:

Commercial Spaceflight Operations Curriculum Development (Task 257)

George Born

October 29th 2013



Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results or Schedule & Milestones
- Next Steps
- Contact Information

Team Members

- **George H. Born** – Director Emeritus, Colorado Center for Astrodynamics Research
- **Bradley Cheetham** – Graduate Research Assistant, CU Boulder, Aerospace Engineering Sciences
- **Juliana Feldhacker** – Graduate Research Assistant, CU Boulder, Aerospace Engineering Sciences
- **Jon Herman** – Graduate Research Assistant, CU Boulder, Aerospace Engineering Sciences

Industry Partners

Recently Added Industry Partners

Lab software/operations insight

Industry guest lecture

Lecture content & best practices

Industry guest lecture

Purpose of the Task

To develop graduate level curriculum that will serve as a bridge between academic theory and commercial applications and to prepare students to become real-world problem solvers.

COE Objectives

Research
- Student research projects investigate current constraints and explore potential solutions

Training
- Preparing students to enter industry with commercial perspective

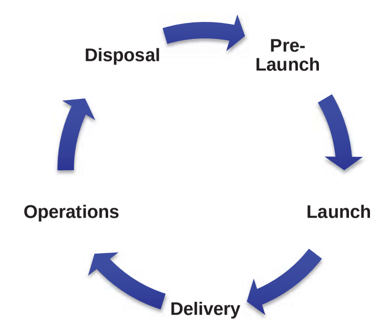
Outreach
- Educating academia about developments in commercial space

Approach

Objectives:
- Develop one-semester course
- Develop one-semester lab
- Refine content based on student and industry feedback
- Standardize and establish Graduate Certificate
- Increase collaboration between academia and industry

Curriculum Scope

- Full mission lifetime
- Transfer knowledge
  - Industry ↔ Academia
  - Established ↔ Emerging
- Provide context



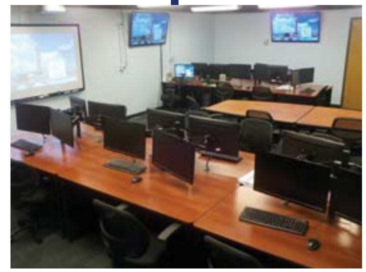
Operations Lab

Guiding principles:

- Push the state-of-the-art for education
- Extensively involve industry
- Apply theories to real-world challenges
- Assist research
- Enable other courses
- Exhibit research

Entirely constructed with University cost-share

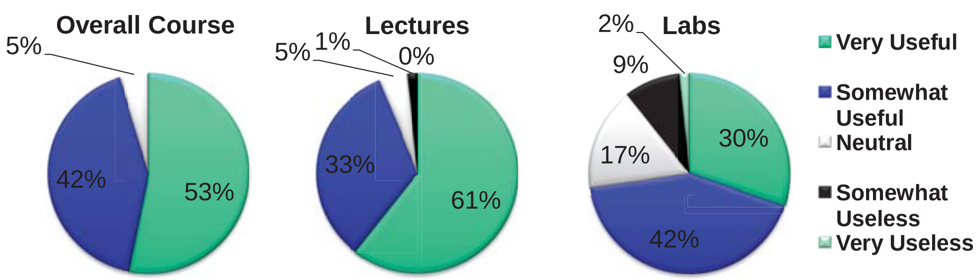
Lab Complete



Results or Schedule/Milestones

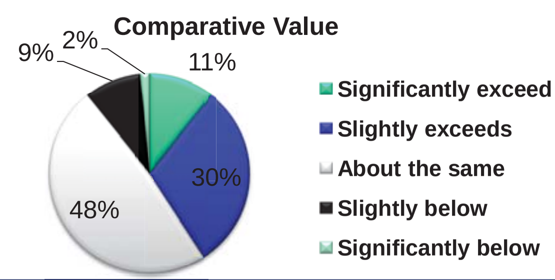
- Lecture offered: fall 2011, 2012, 2013
- Lab offered: spring 2013, spring 2014
- Total students registered: 81

- Student feedback



Results

- Industry feedback incorporated into all content
- Student feedback incorporated where possible
  - Changes to course lay-out
  - Changes to lab assignments
- Value proposition to students



Next Steps

- Spring 2014 – Lab offered
- Certificate Development
- Broaden impact via distance learning and collaboration
  - Currently engaged with Kansas University and University of Southern California

Contact Information

- George Born

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- Bradley Cheetham

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ccar.colorado.edu/CSO

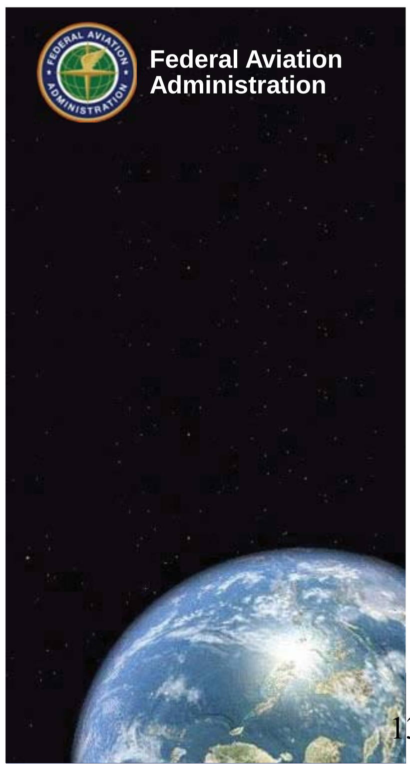
Analysis Environment for Safety of Launch and Re-Entry Vehicles

Task 258

Juan J. Alonso and Francisco Capristan
Department of Aeronautics and Astronautics
Stanford University

FAA COE for CST Technical Meeting

October 29, 2013



Overview

- Team Members
- Purpose of Task
- Research Methodology
  - -Current Approach
    - Trajectory Development
    - Safety Assessment Tool
    - Inverse Problem
- Results / Progress to Date
  - -Uncertainty Effects on Ec
- Conclusions / Future Work

Team Members

- PI: Juan J. Alonso, Aero & Astro, SU
- Francisco Capristan, Aero & Astro, Graduate Student, SU
- Paul Wilde, FAA
- Program Manager: Ken Davidian

Purpose of Task/Goals

- To provide the FAA and the community with an independent ground safety analysis capability for launch and re-entry vehicles that is based on tools of the necessary fidelity.
- To develop and establish quantitative safety metrics appropriate for variety of commercial space transportation vehicles.
- To validate the resulting tool with existing and proposed vehicles so that the resulting tool/environment can be confidently used.
- To increase the transparency of the safety assessment of future vehicles via a common analysis tool that is entirely open source and, thus, streamline the licensing process for a variety of vehicle types.

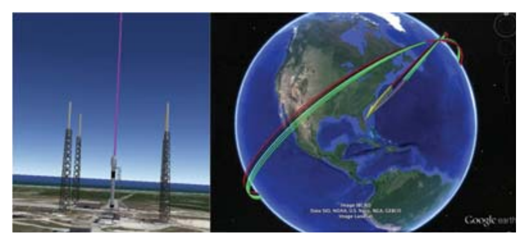
Research Methodology

- Currently the FAA uses procedures and tools to assess the ground safety of future commercial launch and re-entry vehicles that are based on traditional launch systems. There are concerns with potential diversity of future systems.
- Some uncertainty effects in ground safety assessment methodologies are not well understood. Thus, there might be important safety metric data currently being ignored.
- Safety issues include:
  - Human rating.
  - Acceptable probability of failure.
  - How to account safety risks not associated with component, sub-system, and system failure (unknown unknowns).
  - Safety assessment modeling is nondeterministic.

Trajectory Development

Stanford Program to Optimize Trajectories (SPOT)
- In house 3-DOF trajectory code that uses a pseudospectral collocation method.
- Python code with a few fortran modules.
- Available optimizers:
  - SNOPT (commercial)
  - IPOPT (open source)
- Aerodynamics : CD as a function of Mach number
- MISSILE DATCOM used to obtain aerodynamic data

Trajectory perturbation (Thrust offset, wind, etc) performed with SPOT's trajectory propagation capabilities



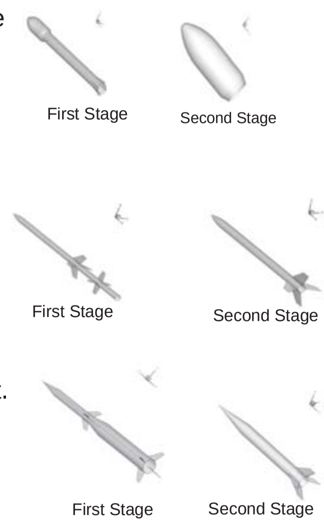
Sample Trajectory

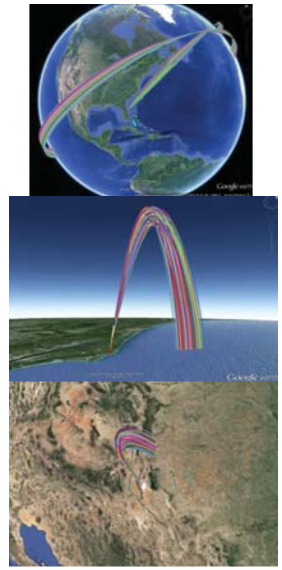
Sample Trajectories

Falcon 9 type vehicle to the ISS orbit

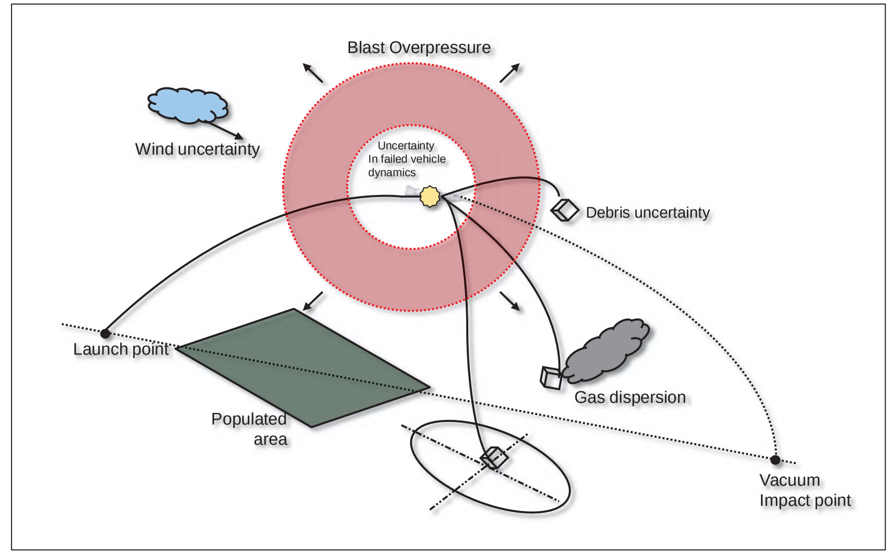
Stratos II Sounding Rocket. ~60 km Altitude

SONDA III Sounding Rocket. ~600 km altitude





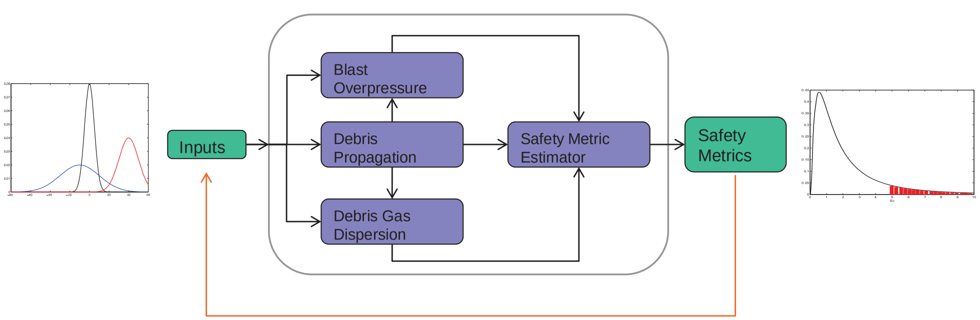
Safety Assessment Tool



Safety Analysis Environment Sketch

Safety Assessment Tool

- Main focus is on safety on the ground (expected casualty measures).
- There are 3 main modeling modules.



Inverse Problem

- We are in the process of understanding the input parameter combinations that lead to worst case scenarios (tails of casualty expectation distribution).
- Results obtained by solving the reverse problem could be used to inform licensing restrictions, or influence design.

** MORE DETAILS COMING UP IN AIAA SCITECH 2014 "Analysis Environment for Safety Assessment of Launch and Re-entry Vehicles"

Safety Assessment ToQN

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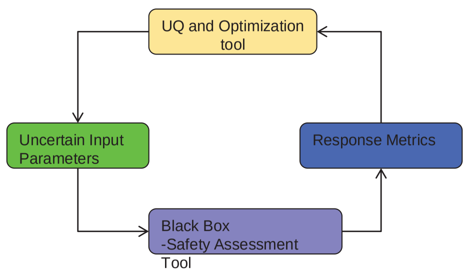
- c
- E c

Inverse Problem

- Currently using Uncertainty Quantification(UQ) and Optimization toolkits:
  - Dakota
    - Provides algorithm for design optimization, UQ, sensitivity analysis, etc.
    - Open source project actively being developed at Sandia National Labs.
  - Openturns
    - It is a scientific library usable as a Python module dedicated to the treatment of uncertainties.

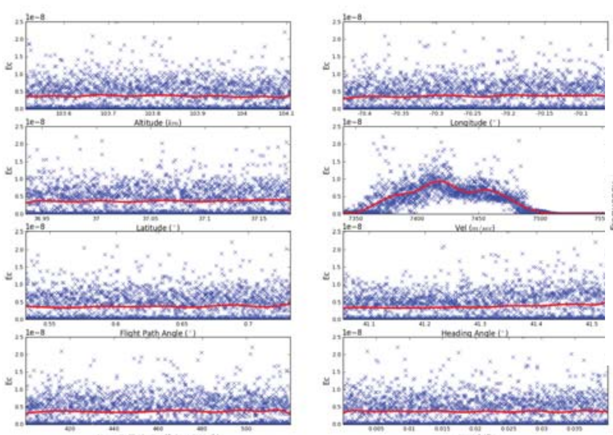


Inverse Problem

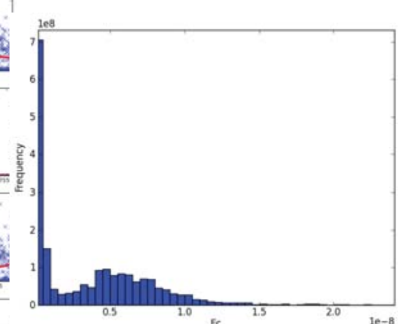
- Initial Attempts to solve the inverse problem include exploring the use of different sensitivity analysis methods:
  - Sobol Indices:
    - Ranks the variance contribution of the uncertain inputs.
    - Useful for understanding the central dispersion of the variable of interest, presents limitations when concerned with extreme values (tails of distribution).
  - FORM/SORM:
    - Allow us to rank the importance of the inputs with respect to some realization (e.g. exceeding a threshold).
    - Results for highly non-linear functions that have multiple most probable points must be interpreted with caution.
  - Efficient Global Reliability Analysis:
    - Based on surrogate-based global optimization, which exploits special features of Gaussian processes.
  - Cobweb Graph:
    - Enables to visualize all the combinations of the input variables which lead to a specific range of the output variable.

Results - Uncertainty Effects

- Uncertainty effects on Ec:
  - Space Shuttle (STS-111) on trajectory failure at t = 497 sec.
  - Mean ballistic coefficient = 100 lb/ft^2.



Relationship between inputs and Ec

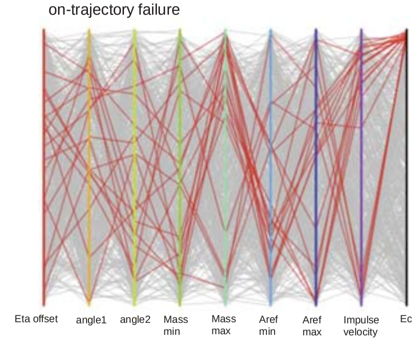


Ec Distribution

Results - Cobweb Graph

Calculation for a Falcon 9 type vehicle to the ISS.
- On trajectory failure at 5 and 15 seconds after liftoff.
- Only 1 group in the debris catalog considered.

Results for a single debris group at a 5 second on-trajectory failure



Results for a single debris group at a 15 second on-trajectory failure

Results suggest that different parameter combinations dominate the results in the tails of the output distribution

Conclusions

- A debris propagation tool has been implemented and successfully automated to generate thousands of Monte Carlo evaluations.
- Debris propagation tool is capable of using different debris catalog depending on time and/or distance travelled.
- Sheltering model included in the Ec calculation.
- First version of the safety environment tool completed (debris propagation, gas dispersion, blast overpressure models, and safety metric estimator) and validated.
- SPOT, an in-house trajectory optimization code, can provide baseline trajectories.
- An initial assessment indicates that the current methodologies to solve the inverse problem are not appropriate for our current ground safety formulation.

Ongoing and Future Work

- Further investigate how input uncertainties affect Ec calculations.
- Further validation of modeling tools.
- Perform safety assessment (including sensitivities) for an entire trajectory.
- Identify parameters of interest to solve the inverse problem.
- Identify/modify methodologies to solve the inverse problem.
- Demonstrate inverse solutions for input to licensing process.

Contact Information

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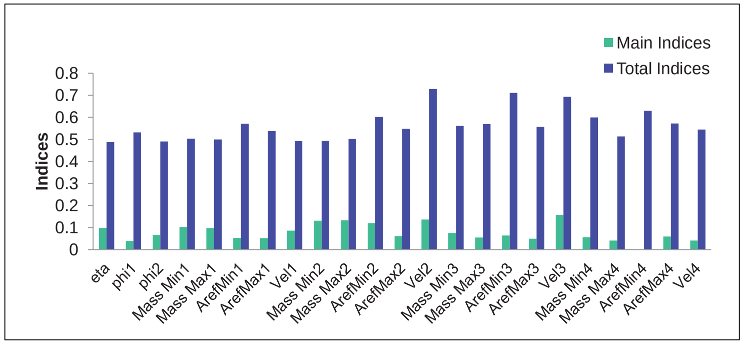
- Francisco M. Capristan fcaprist@stanford.edu

Backup Slides

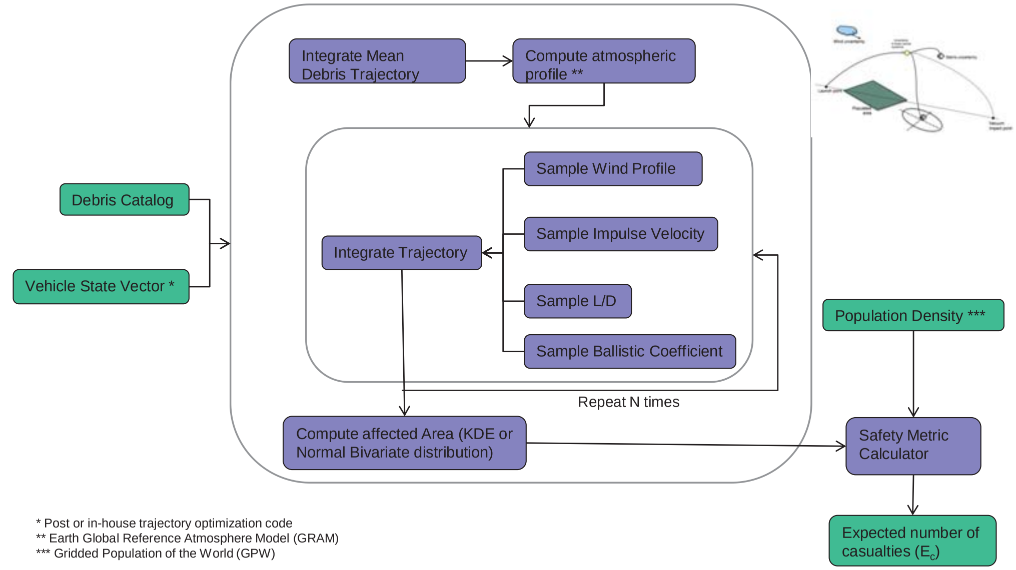
Sobol Indices Calculation

Calculation for a Falcon 9 type vehicle to the ISS.

- On trajectory failure 10 seconds after liftoff.
- Debris catalog scaled from the Space Shuttle's debris catalog.

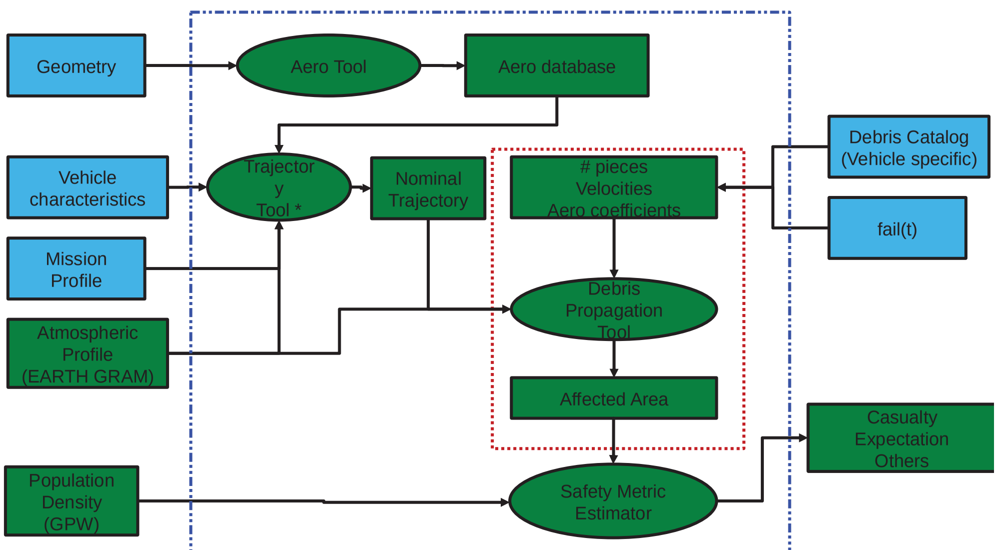


Analysis Environment: Debris Propagation



* Post or in-house trajectory optimization code
** Earth Global Reference Atmosphere Model (GRAM)
*** Gridded Population of the World (GPW)

Debris Modeling



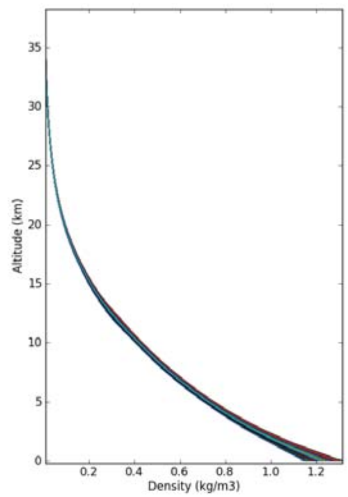
* Access to POST or Stanford Trajectory Optimization Program (STOP)

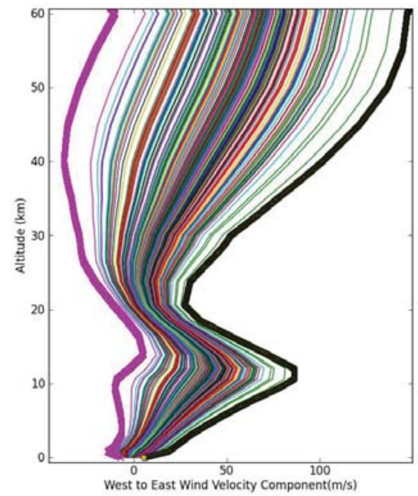
Debris Modeling

- The following assumptions/considerations were made to the debris dispersion tool :
  - Spherical/Oblate rotating Earth.
  - Debris pieces have constant mass.
  - Debris pieces treated as point masses.
  - Lift and drag coefficients functions of Mach number.
  - Explosion effects simulated by giving impulse velocities to the debris.
  - Earth Gram used to obtain atmospheric profiles.
  - Wind effects in all 3 orthogonal directions are considered.
  - Malfunction turns not implemented.
  - Affected ground area obtained by using Kernel Density Estimation or assuming a Normal Bivariate distribution

Debris Propagation

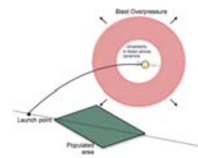
Uncertainty in atmospheric parameters



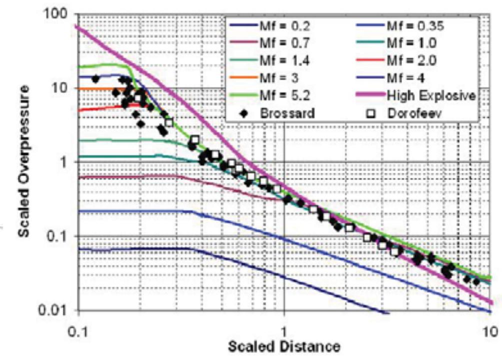


Analysis Environment: Blast Overpressure

- Blast Overpressure is one of the main threats associated with catastrophic booster failure leading to explosion.
- The Baker-Strehlow-Tang curves are used because of their ease of use and good agreement with experiments in the supersonic and subsonic regimes.



$E_i = \eta_p m_p E_{TNT}$ $\bar{P} = \frac{p - p_0}{p_0}$ $\bar{R} = \frac{R}{E_i / p_0^{1/3}}$

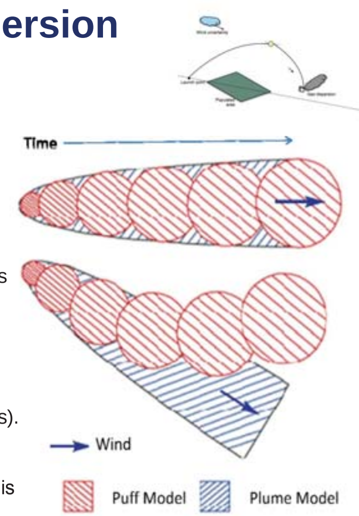


p_0 atmospheric pressure
p absolute peak pressure
R stand-off distance
E_{TNT} blast energy per unit mass of TNT
E_T blast energy
η_p yield factor
m_p propellant mass

Blast Overpressure Modeling Enhancements for Application to Risk Informed Design of Human Space Flight Launch Abort Systems. Scott Lawrence, and Donovan Mathias

Analysis Environment: Gas Dispersion

- The most common air dispersion models are Plume and Puff types.
- Modeling systems considered :
  - CALPUFF => Puff
  - AERMOD => Plume
- AERMOD :
  - Steady state model which assumes that a plume disperses in the horizontal and vertical directions.
  - Plume follows the wind direction in a straight line.
  - Valid Range up to 50 km from the source.
- CALPUFF :
  - Uses discrete puffs emitted from sources.
  - Puffs can follow a curved trajectory (due to changing winds).
  - Valid Range up to 200~300 km from the source.
- Due to complexities in CALPUFF's input parameters, AERMOD is used in our modeling environment.
  - Studies suggests that CALPUFF and AERMOD return comparable results for dispersion near the sources.



*Integrated Environmental Solutions White Paper – Puff and Plume Models

Technical Approach

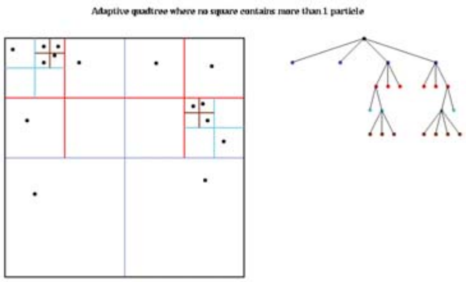
Risk area debris formulation

$X_i = [Latitude_i, Longitude_i]^T$

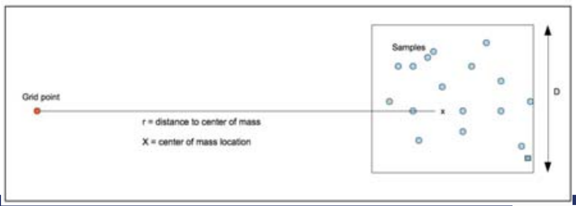
Normal Bivariate	Kernel Density
$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$	$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$
$S = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})(X_i - \bar{X})^T$	$S = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})(X_i - \bar{X})^T$
$\hat{f}(x) = \frac{1}{2\pi\sqrt{det(S)}} e^{\frac{1}{2}(x-\bar{X})^T S^{-1}(x-\bar{X})}$	$\begin{bmatrix} S_1 & 0 \\ 0 & S_2 \end{bmatrix} = U^{-1} SU$ Compute eigenvalues and eigenvectors
	$U = \begin{bmatrix} s_x & -s_y \\ s_y & s_x \end{bmatrix}$
	$[P_i \ \ Q_i] = X_i^T U$ Compute h from P and Q
	$h = 1.06\left(min\left(\sigma, \frac{IQR}{1.34}\right)\right) n^{-1/5}$
	$H_2 = U \begin{bmatrix} h_1^2 & 0 \\ 0 & h_2^2 \end{bmatrix} U^{-1}$
	$\hat{f}(x) = \frac{1}{2\pi n\sqrt{det(H_2)}} \sum_{i=1}^{n} e^{\frac{1}{2}(x-X_i)^T H_2^{-1}(x-X_i)}$

Procedure suggested in "Range Safety Application of Kernel Density Estimation". Gary Cionek, et al.

Kernel Density Estimation via Adaptive Quadtrees



$$\hat{f}(x)=\frac{1}{2\pi n\sqrt{det(H_2)}}\sum_{i=1}^{n} e^{\frac{-1}{2}(x-X_i)^T H_2^{-1}(x-X_i)}$$



Quadtree formulation

$$\frac{D}{r} < q$$

$$\hat{f}(x)=\frac{1}{2\pi n\sqrt{det(H_2)}}\sum_{k=1}^{Nr} n_k e^{\frac{-1}{2}(x_{cm}-X_i)^T H_2^{-1}(x_{cm}-X_i)}$$

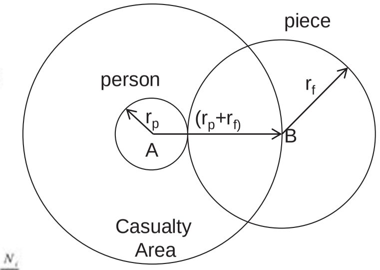
Expected Casualty Calculation

A_C : Casualty area
A_f : fragment projected area
r_p : person radius

$$A_C=\pi\left(\sqrt{\frac{A_f}{\pi}}+r_p\right)^2$$

E_C : Casualty Expectation
P_{Iij} : probability that the jth piece of debris will land in A_i
N_i : number of people
A_i : Area of interest

$$E_C=\sum_{i=1}^{n}\sum_{j=1}^{m} P_{Iij} A_{Cij} \frac{N_i}{A_i}$$



Casualty Area Calculation

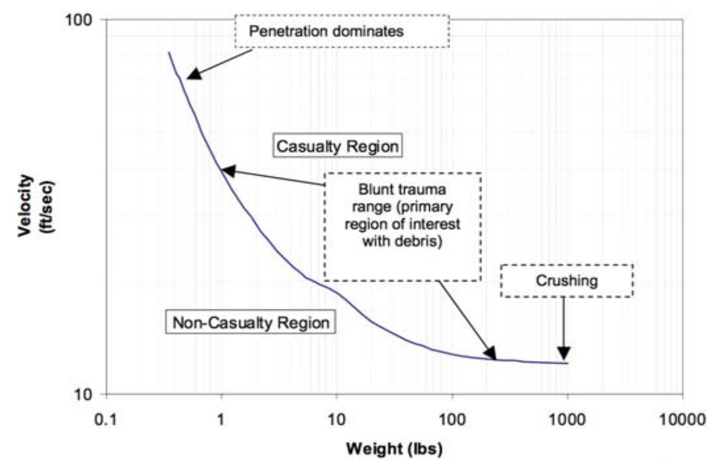
* "A Hazard Model for Exploding Solid-Propellant Rockets"
J.C. McMunn, et al.

Ec Calculation

- The following assumptions/considerations were made in the Expected Casualty (safety metric) calculation:
  - Population divided in square grid cells, and uniformly distributed within each cell.
  - No bouncing debris considered.
  - An empirical formula is used to calculate debris piece lethality.
  - Gridded Population of the World used for population density

Ec Calculation

- Debris piece lethality assessment



* "Estimation of Space Shuttle Orbiter Reentry Debris Casualty Area" Jon D. Collins, Randolph Nyman, and Isaac Lottati

Example Distribution of Sheltering

Census Category (Occupation)	Open	Wood-Roof	Wood-1st	Wood-2nd	Steel-Roof	Steel-1st	Steel-2nd	Concrete	Concrete-1st	Concrete-2nd	Composite	Light Metal	Tile-Roof	Tile-1st	Tile-2nd	Car
Management occupations (other than farm managers)		11.7	6.5	1.8	7.7	6.4	10.9	9.0	7.0	9.0		20.0	5.6	3.0	0.3	1.0
Farm managers	33.0	19.0	1.0								13.0	17.0				17.0
Farming, fishing, and forestry occupations	50.0	4.8	0.3		0.5			0.5			5.0	5.0	4.8	0.3		29.0
Installation, maintenance, and repair occupations	20.0	24.9	4.6	0.5	7.2	4.7	5.1	6.8	4.4	4.8		1.0	0.7	0.3	0.1	15.0
Production occupations		3.2	1.6	0.2	10.8	2.9	0.3	15.4	4.2	0.4	50.0	5.0	3.2	1.6	0.2	1.0
Supervisors, transportation and material moving workers	30.0										50.0					20.0

Scenario	s_2	e_2	d	v
Weekday Daytime Summer	0.05	0.9	0.25	0.05
Weekday Daytime Winter	1	0.9	0.1	0.07
Weekday Night	0	0.05	0.01	0.005
Weekend Daytime Summer	0	0.2	0.4	0.06
Weekend Daytime Winter	0.02	0.2	0.1	0.07
Weekend Night	0	0.01	0.01	0.005

*Tables from "Large Region Population Sheltering Models for Space Debris Risk Analysis. Eric W.F Larson"

Safety Metric Estimator

.Expected Casualty Formulation

$$P_{I_{ij}} = f(\vec{r}, \vec{v}, a\vec{er}o)$$
$$A_{C_{k_r}} = g(m) \quad , r \geq 1$$

$$E_{1k}(\vec{A_{C_k}}, \vec{r}, \vec{v}, a\vec{er}o) = \sum_{i=1}^{n}\sum_{j=1}^{m}(P_{k_{Iij}}[A_{C_{k_0}}\rho_{ij}c_0 + \sum_{r=1}^{\#roofs}(A_{C_{k_r}}\rho_{ij}c_r)])$$

$$E_k(\vec{r}, \vec{v}, a\vec{er}o) = \sum_{i=1}^{n}\sum_{j=1}^{m}(P_{k_{Iij}}[E(A_{C_{k_0}})\rho_{ij}c_0 + \sum_{r=1}^{\#roofs}E(A_{C_{k_r}})\rho_{ij}c_r])$$

$$E(A_{C_{k_r}}) = \int_0^{\infty} g(m)p(m)\,dm \quad , r \geq 1$$

$P_{I_{k_{ij}}}$ => *PDF on the ground for debris group k (from KDE or Normal distribution assumption)*
$A_{C_{k_0}}$ => *Casualty area (debris piece projected area for people in the open)*
$A_{C_{k_{1...R}}}$ => *Casualty Area for different roof types*
c_r => *fraction of people in different shelter categories*
ρ_{ij} => *Population Density*
$k =$ *debris group*

Safety Metric Estimator

.Sheltering Formulation

$$E_{1k}(\vec{A_{C_k}}, \vec{r}, \vec{v}, a\vec{er}o) = \sum_{i=1}^{n}\sum_{j=1}^{m}(P_{k_{Iij}}[A_{C_{k_0}}\rho_{ij}c_0 + \sum_{r=1}^{\#roofs}(A_{C_{k_r}}\rho_{ij}c_r)])$$

$$\vec{c} = e_1e_2O\vec{o} + s_1s_2\vec{q} + (1 - e_1e_2 - s_1s_2)[(1-d-v)H\vec{h} + (0 \ \ 0 \ldots v \ \ d)^T]$$

Variable	Description
e_1	Fraction of people who are employed
e_2	Fraction of those employed who are at work
o (vector)	Fraction of people who are at work in each occupation category
O (matrix)	Fraction of people in each sheltering class by occupation
s_1	Fraction of people who are students
s_2	Fraction of students who are at school
q (vector)	Fraction of people at school in each sheltering class
d	Fraction of people not at work or school who are outside
v	Fraction of people not at work or school who are in vehicles
h (vector)	Fraction of people in each housing type
H (matrix)	Fraction of people in each sheltering class by housing type

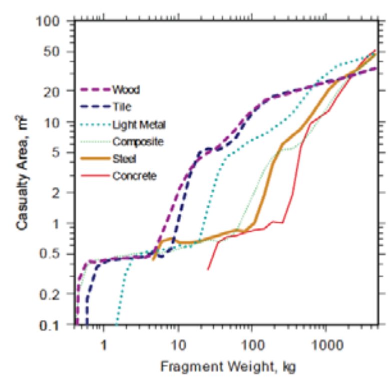
*Formulation from "Large Region Population Sheltering Models for Space Debris Risk Analysis. Eric W.F Larson"

Safety Metric Estimator

.Roof Models

- Casualty Area of Roof Penetration Models

$$E_{1k}(\vec{A_{C_k}}, \vec{r}, \vec{v}, a\vec{er}o) = \sum_{i=1}^{n}\sum_{j=1}^{m}(P_{k_{Iij}}[A_{C_{k_0}}\rho_{ij}c_0 + \sum_{r=1}^{\#roofs}(A_{C_{k_r}}\rho_{ij}c_r)])$$



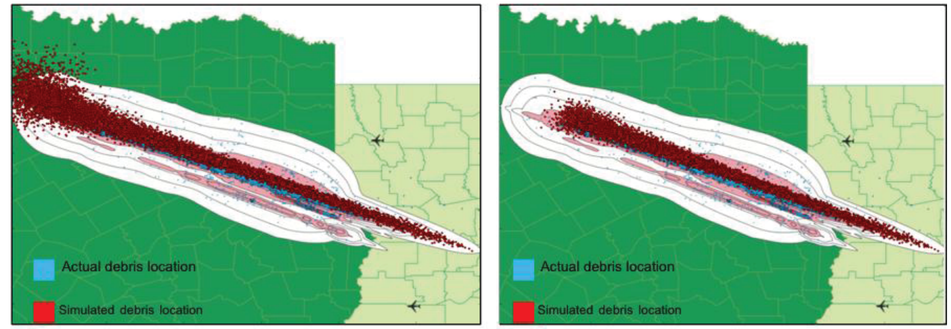
*from "Large Region Population Sheltering Models for Space Debris Risk Analysis. Eric W.F Larson"

Validation Test Cases

- Two test cases have been simulated:
  - STS-107 (Columbia) accident simulations
  - STS-111 over-flight of Eurasia simulations
- Experimental data available for STS-107
- Other computations available for STS-111
- Results of current framework compare favorably with existing data:
  - Debris impact locations
  - Expected casualty numbers
  - Sensitivities

Columbia Accident Simulations

- Breakup during re-entry
- Debris catalog from Columbia Accident Investigation Board (CAIB) report.
- 11 debris groups considered (groups by ballistic coefficient and projected area).
- More than 80,000 debris pieces recovered over more than 10 counties.

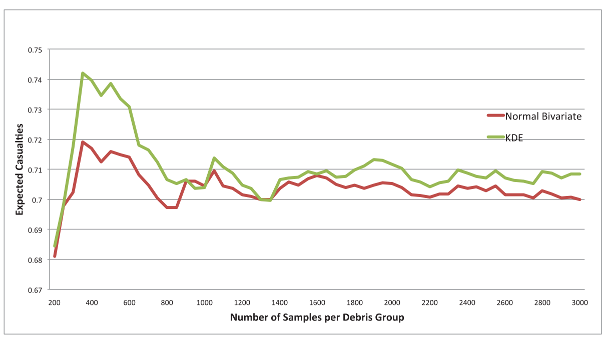


All simulated pieces | Lethal simulated debris pieces

Debris Location. From CAIB report Volume II Appendix D.16

Columbia Accident Simulations

- Expected casualties convergence for normal bivariate, and kernel density estimation.
- Population density from Gridded Population of the World (GPW)



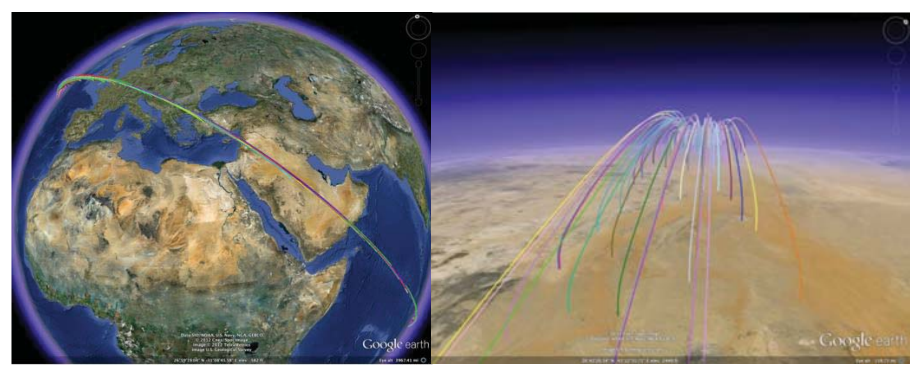
Casualty Expectation Convergence

	% People in the open	E_c
CAIB Report*	10	0.08
CAIB Report*	20	0.14
CAIB Report*	30	0.21
Simulation	18.7	0.31
Simulation	100	0.71

*Results from Columbia Accident Investigation Board

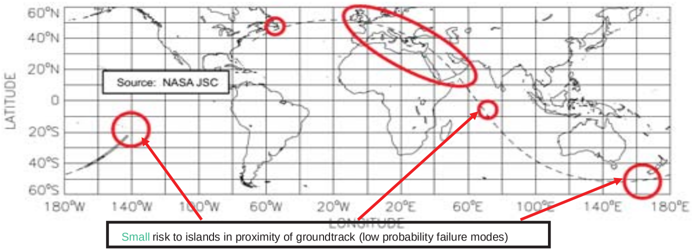
STS-111Over-Flight of Eurasia Simulations

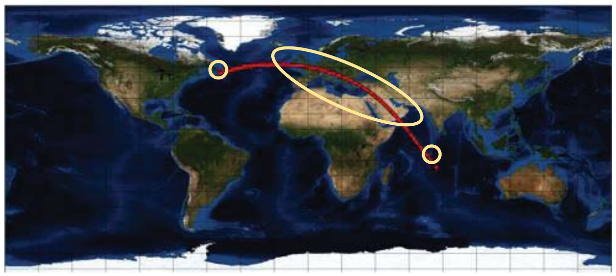
- Stage II, on trajectory, orbiter failures.
- Reentry breakup altitude ~ 250,000 ft.
- Failure times 490-500 seconds.
- Orbiter debris catalog from Columbia accident.
- 3-sigma trajectories provided by Paul Wilde.



Simulated Debris Trajectories

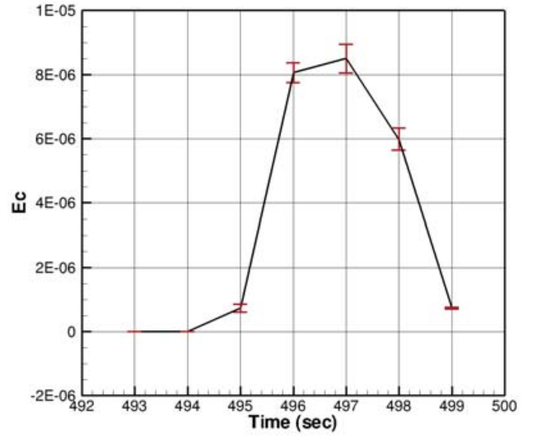
STS-111Over-Flight of Eurasia Simulations





Simulated Debris Impact Location

STS-111 Over-Flight of Eurasia Simulations and UQ



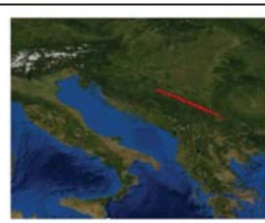
Casualty Expectation vs. Flight Time with 99% Confidence Intervals

Ec values reported by ACTA range from 2.8e-6 to 4.6e-6.

- Differences in results probably due to sheltering, guidance and performance, and wind uncertainty.

STS-111Over-Flight of Eurasia Simulations and UQ

- Uncertainty effects on risk area determination:
  - On trajectory failure at t = 497 sec.
  - Ballistic coefficient = 100 lb/ft^2.

Debris Location spread due to uncertainties in initial debris velocity	
Debris location spread due to uncertainties in : • Ballistic coefficient. • L/D. • Wind. • Atmospheric density.	

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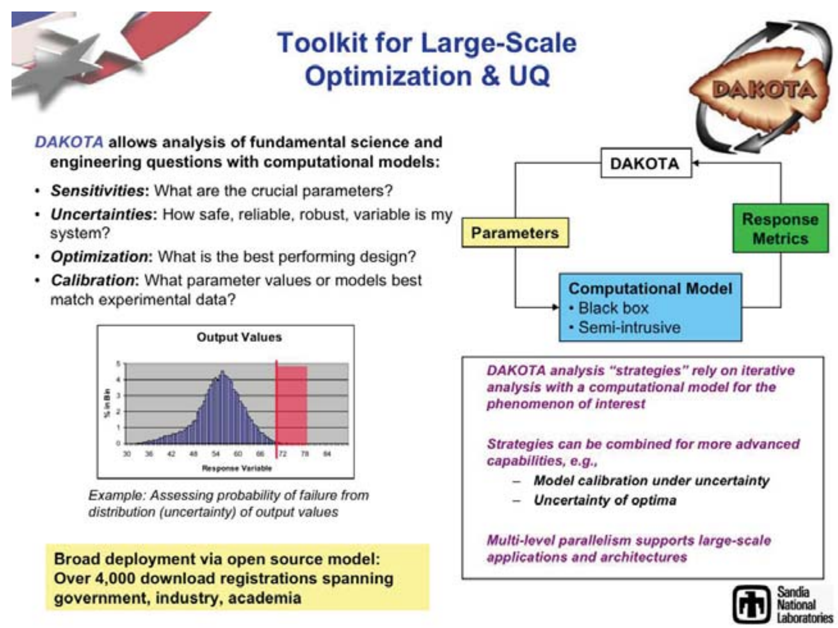


** Slide from http://dakota.sandia.gov/papers/DAKOTA_oneslide.pdf

Sensitivity Analysis

- SOBOL INDICES
  - The main effect sensitivity index (S_i) corresponds to the fraction of the uncertainty in the output, Y , that can be attributed to input xi alone. The total effects index (T_i) corresponds to the fraction of the uncertainty in the output, Y , that can be attributed to input xi and its interactions with other variables.

$$S_i = \frac{Var_{x_i}[E(Y|x_i)]}{Var(Y)} \qquad T_i = \frac{E(Var(Y|x_{-i})}{Var(Y)} = \frac{Var(Y) - Var(E[Y|x_{-i}])}{Var(Y)}$$

Main	Total	Variable
-8.95E-03	1.19E-01	Altitude
1.62E-04	1.16E-01	Longitude
-2.08E-03	1.19E-01	Latitude
6.60E-01	9.96E-01	Velocity
1.03E-02	2.70E-01	Flight Path Angle
2.07E-02	1.84E-01	Heading Angle
-3.83E-03	1.19E-01	Mean Ballistic Coefficient
-2.41E-03	1.11E-01	Max L/D

Falcon 9 Type Vehicle

- 3 DOF trajectory generated using SPOT.
- Debris catalog obtained by scaling the some components of the Space Shuttle debris catalog.
- Only considering Ec due to inert pieces of debris.

Falcon 9 type launch vehicle trajectory to ISS orbit

Sensitivity Analysis

- Test case for:
  - T fail = 10 sec. Mean BC = [40 45]. STD BC = [2 7].
- SOBOL INDICES
  - The main effect sensitivity index (S_i) corresponds to the fraction of the uncertainty in the output, Y , that can be attributed to input xi alone. The total effects index (T_i) corresponds to the fraction of the uncertainty in the output, Y , that can be attributed to input xi and its interactions with other variables.

	Time of Launch	Thrust Magnitude	Thrust Angle 1	Thrust Angle 2	Mean Ballistic Coefficient	STD Ballistic Coefficient	Upper Bound Impulse Velocity
Main	-0.0258834	-0.0218401	0.0516547	-0.0105059	-0.00785064	0.0034845	0.304994
Total	0.588063	0.529558	0.378294	0.639112	0.513613	0.290565	0.974261

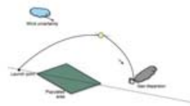
Interactions between variables

	Time of Launch	Thrust Magnitude	Thrust Angle 1	Thrust Angle 2	Mean Ballistic Coefficient	STD Ballistic Coefficient	Upper Bound Impulse Velocity
Time of Launch	0	0.0434299	0.158467	0.0465927	0.0162967	0.149093	0.0834008
Thrust Magnitude	0.0434299	0	0.037148	0.0282799	0.0100992	0.0574975	0.0986086
Thrust Angle 1	0.158467	0.037148	0	-0.0309172	-0.0147603	0.0592488	-0.0359259
Thrust Angle 2	0.0465927	0.0282799	-0.0309172	0	0.0123546	0.194605	0.161345
Mean Ballistic Coefficient	0.0162967	0.0100992	-0.0147603	0.0123546	0	0.112971	0.0374759
STD Ballistic Coefficient	0.149093	0.0574975	0.0592488	0.194605	0.112971	0	0.0888075
Upper Bound Impulse Velocity	0.0834008	0.0986086	-0.0359259	0.161345	0.0374759	0.0888075	0

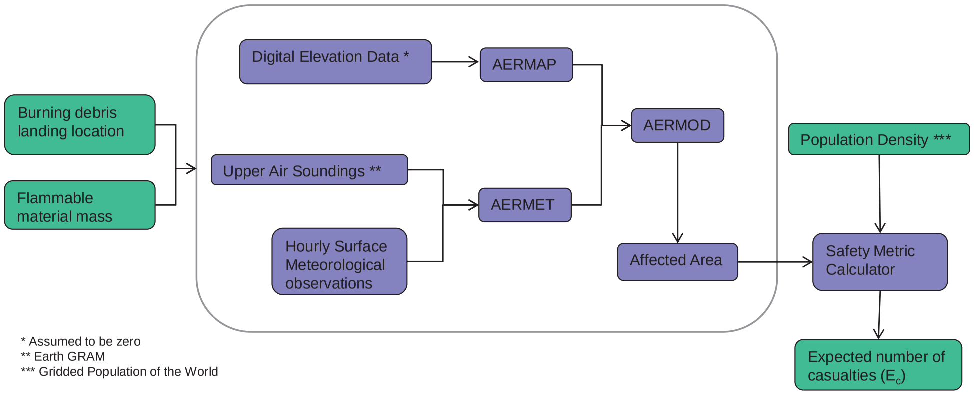
Available Trajectories

Reentry scenario: Apollo Capsule

Analysis Environment: Gas Dispersion



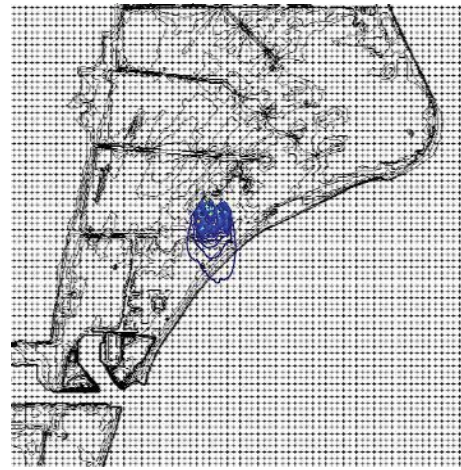
- Currently using AERMOD (Atmospheric Dispersion Modeling):
  - Tool used by the U.S Environmental Protection Agency (EPA) for regulation purposes.
  - It incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated sources, and both simple and complex terrain.

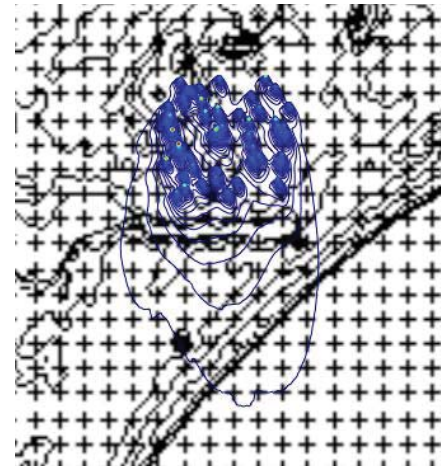


* Assumed to be zero
** Earth GRAM
*** Gridded Population of the World

Gas Dispersion Simulation

- Sample gas dispersion case (add more details: location, test case made up, wind profiles, etc, etc)
  - 50 pieces of burning debris



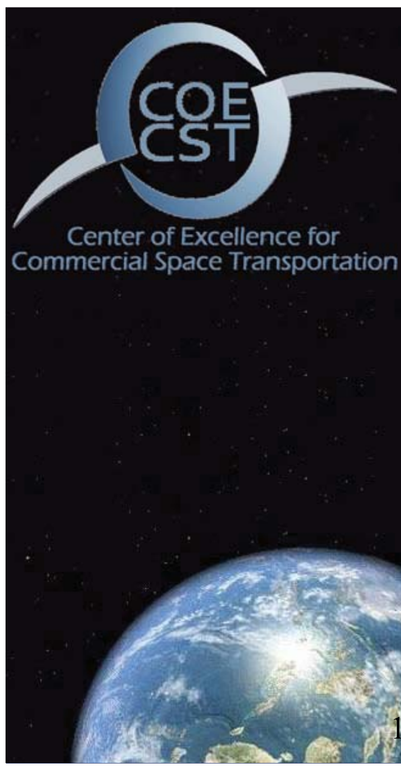


COE CST Third Annual Technical Meeting: Nonlinear Structural Models Task 293

Dr. A. Keith Miller and Dr. Warren Ostergren

NEW MEXICO TECH

29 October2013



Overview

- Team Members
- Task Objective
- Research Methodology
- Results to Date
- Next Steps
- Contact Information

Team Members

- **PIs:** Dr. A. Keith Miller, Associate Professor of Mechanical Engineering, NMT
  Dr. Warren Ostergren, Associate Professor & Chair of Mechanical Engineering, NMT
- **Students**: Mr. Joshua Mendoza, MS MENG (May 2013), Mr. Lance Hernandez, BS MENG (May 2014)
- **Research Partners:** Sandia National Laboratories
- **Industry Partners:** United Launch Alliance, Ball Aerospace

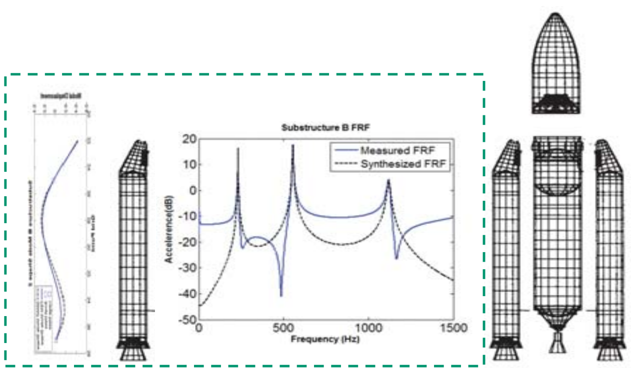
Task Objective

Develop computational tools that improve the capability to determine the performance and safety margins of commercial space vehicles. The focus is to construct non-linear system-level models. The models are constructed by computationally combining reduced-order finite element models of substructure components directly with experimentally-derived modal substructure components.

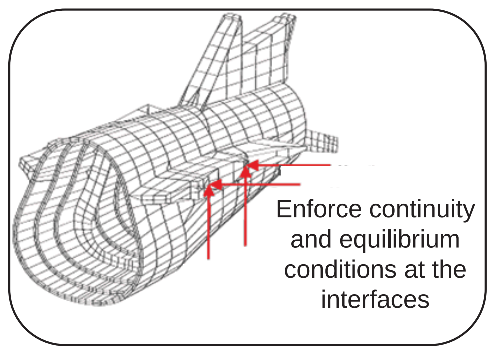
SUBSTRUCTURING

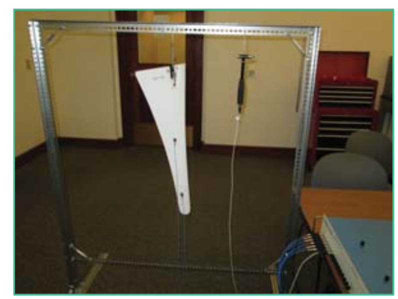
Research Methodology

Develop system-level non-linear structural dynamic models by computationally coupling FEA and experimentally derived components.



Produce reduced-order models of each substructure

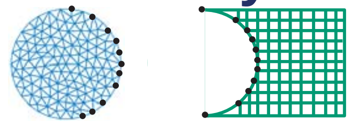




Fixed interface FEA "testing"

Free interface modal "analysis"

Static Augmentation Modes for Improved Accuracy



$$[\mathbf{T}]_1 = [\mathbf{\Phi}]_k + [\mathbf{\Phi}]_{static} = \begin{bmatrix} \phi_{11} & \cdots & \phi_{1k} \\ \phi_{21} & \cdots & \phi_{2k} \\ \vdots & \ddots & \vdots \\ \phi_{n-11} & \cdots & \phi_{n-1k} \\ \phi_{n1} & \vdots & \phi_{nk} \end{bmatrix} + \begin{bmatrix} g_{11} & g_{12} & \cdots & g_{1b} \\ g_{21} & g_{22} & \cdots & g_{2b} \\ \vdots & \vdots & \ddots & \vdots \\ g_{n-11} & g_{n-12} & \cdots & g_{n-1b} \\ g_{n1} & g_{n2} & \cdots & g_{nb} \end{bmatrix}_{static}$$

Fixed Interface Boundary Nodes

Constraint Modes
Craig-Bampton

Attachment Modes
MacNeil-Coppolino

Free Interface Boundary Nodes

Inertia-Relief Modes
Benfield-Hruda

Residual Modes
Martinez-Miller-Carne

Results to Date

Developed Matlab™ based modal parameter extraction algorithms based on rational fraction polynomials and global RFP Method

Presented at 1[st] IMAC Conference, Orlando, FL — November, 1982

PARAMETER ESTIMATION FROM FREQUENCY RESPONSE MEASUREMENTS USING RATIONAL FRACTION POLYNOMIALS

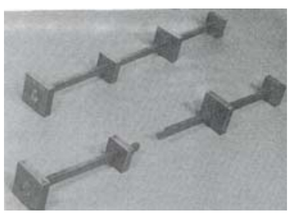
Mark H. Richardson & David L. Formenti
Structural Measurement Systems, Inc.
San Jose, California

Presented at 3[RD] IMAC Conference, Orlando, FL — January, 1985

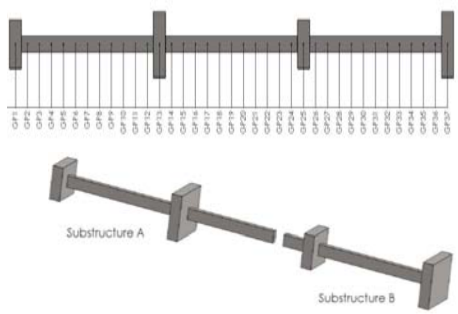
Global Curve Fitting of Frequency Response Measurements using the Rational Fraction Polynomial Method
by
Mark H. Richardson and David L. Formenti
Structural Measurement Systems
San Jose, California

Method yields either real, normal modal data or complex modal data

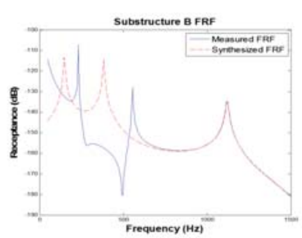
Results to Date



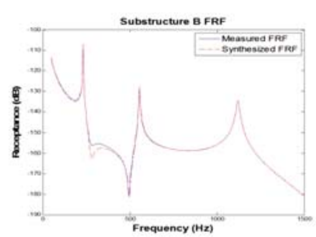
Muli-component test beam



Codes written by Josh Mendoza, 2012 - 2013

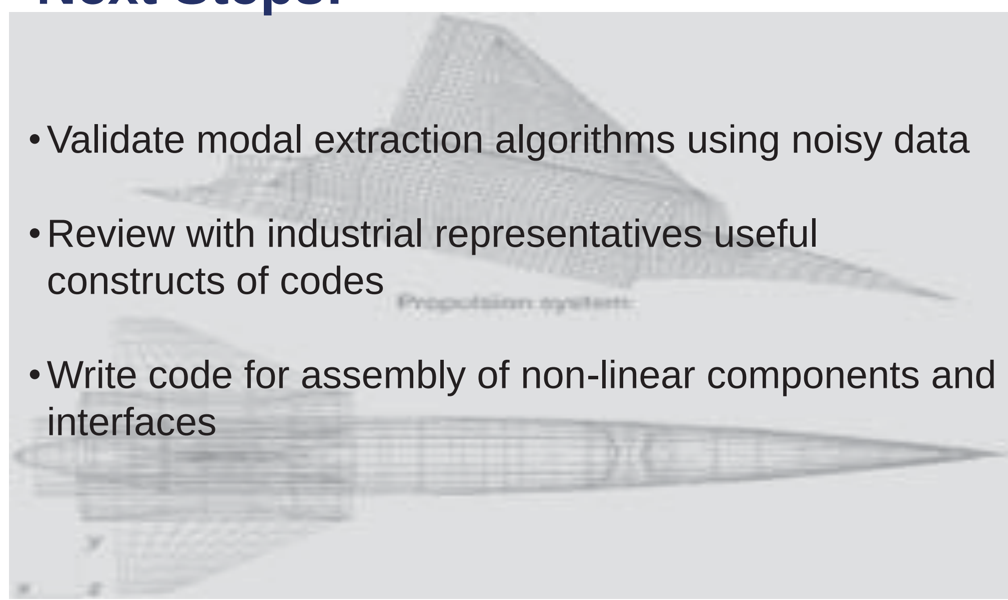


FRF Fitting with zero computational modes



FRF Fitting with two computational modes

Next Steps:



- Validate modal extraction algorithms using noisy data
- Review with industrial representatives useful constructs of codes
- Write code for assembly of non-linear components and interfaces

Contact Information

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COE CST 3rd Annual Technical Meeting:

Task 294:Development of Minor Injury Severity Scale for Orbital Human Space Flight

Richard T. Jennings, MD, MS
Tarah L. Castleberry, DO, MPH

October 30th, 2013

Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results
- Next Steps
- Contact Information

Team Members

- **PI: Richard Jennings, MD** (UTMB Aerospace Medicine)
- **PI: Tarah Castleberry, DO** (UTMB Aerospace Medicine)
- **Co-I: Eric Kerstman, MD** (Wyle Integrated Science and Engineering)
- **Co-I: Jonathan Clark, MD** (Center for Space Medicine, Baylor College of Medicine)
- **Student/Resident: James Cushman, MD** (UTMB Aerospace Medicine)
- **Program Manager:** Ken Davidian (FAA)
- **Technical Monitor:** Henry Lampazzi

Purpose of Task

- FAA COE-CST Task 294
  - Minor injuries of small consequence on the ground may have a large operational impact if they were to occur in space.
  - A Minor Injury Severity Scale (MISS) for human space flight (HSF) was developed for identification of unacceptable injuries that could disrupt HSF operations.

Research Methodology

- Systematic literature review on existing injury scoring systems which were used to create the MISS
  - PubMed
  - MedLine
  - Google Scholar

Results

- Injury Severity Scoring is a process by which complex and variable patient data is reduced to a single number. This value is intended to accurately represent the patient's degree of critical illness. In truth, achieving this degree of accuracy is unrealistic and information is always lost in the process of such scoring. As a result, despite a myriad of scoring systems having been proposed, all such scores have both advantages and disadvantages.

Outcome = Anatomic Injury + Physiologic Injury + Patient Reserve

GLASGOW COMA SCORE

The Glasgow Coma Score (GCS) is scored between 3 and 15, 3 being the worst, and 15 the best. It is composed of three parameters : Best Eye Response, Best Verbal Response, Best Motor Response, as given below:

Best Eye Response (4)	Best Motor Response (6)	Best Verbal Response (5)
1. No eye opening	1. No motor response	1. No verbal response
2. Eye opening to pain	2. Extension to pain	2. Incomprehensible sounds
3. Eye opening to verbal command	3. Flexion to pain	3. Inappropriate words
4. Eyes open spontaneously	4. Withdrawal from pain	4. Confused
	5. Localizing pain	5. Oriented
	6. Obeys Commands	

Note that the phrase 'GCS of 11' is essentially meaningless, and it is important to break the figure down into its components, such as E3 V3 M5 = GCS 11. A Coma Score of 13 or higher correlates with a mild brain injury, 9 to 12 is a moderate injury and 8 or less a severe brain injury.; Teasdale G., Jennett B., Lancet 1974; 81-83.

Results: Injury scales

ABBREVIATED INJURY SCALE

- The Abbreviated Injury Scale (AIS) is an anatomical scoring system first introduced in 1969. Since this time it has been revised and updated against survival so that it now provides a reasonably accurate ranking of the severity of injury. The latest incarnation of the AIS score is the 1998 revision.

Injury	AIS Score
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Unsurvivable

Copes WS, Sacco WJ, Champion HR, Bain LW, "Progress in Characterising Anatomic Injury", In Proceedings of the 33rd Annual Meeting of the Association for the Advancement of Automotive Medicine, Baltimore, MA, USA 205-218

Injury Scales

INJURY SEVERITY SCORE (ISS) & NEW INJURY SEVERITY SCORE (NISS)

The Injury Severity Score (ISS) is an anatomical scoring system that provides an overall score for patients with multiple injuries. Each injury is assigned an AIS and is allocated to one of six body regions (Head, Face, Chest, Abdomen, Extremities (including Pelvis), External). Only the highest AIS score in each body region is used. The 3 most severely injured body regions have their score squared and added together to produce the ISS score.

An example of the ISS calculation is shown below:

Region	Injury Description	AIS	Square Top Three
Head & Neck	Cerebral Contusion	3	9
Face	No Injury	0	!
Chest	Flail Chest	4	16
Abdomen	Minor Contusion of Liver Complex Rupture Spleen	2 5	! 25
Extremity	Fractured femur	3	!
External	No Injury	0	!
		Injury Severity Score:	50

The ISS score takes values from 0 to 75. If an injury is assigned an AIS of 6 (unsurvivable injury), the ISS score is automatically assigned to 75. The ISS score is virtually the only anatomical scoring system in use and correlates linearly with mortality, morbidity, hospital stay and other measures of severity. Its weaknesses are that any error in AIS scoring increases the ISS error. Many different injury patterns can yield the same ISS score and injuries to different body regions are not weighted. Also, as a full description of patient injuries is not known prior to full investigation & operation, the ISS (along with other anatomical scoring systems) is not useful as a triage tool.

Baker SP et al, "The Injury Severity Score: a method for describing patients with multiple injuries and evaluating emergency care", J Trauma 14:187-196;1974

Results: MISS

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Anatomic (A)

Site	Score
Brain (CNS)	3
Spinal Cord (CNS)	3
Sensory (Eyes/Ears)	2
Spine	2
Chest/Pulmonary	2
Abdomen/Pelvis	2
Cardiovascular	2
Extremity	1
Nerve (PNS)	1
Skin	1
Psych	1

Functional Impairment (FI)

System	Score
Musculoskeletal	0/1/2/3
Neurologic	0/1/2/3
Pain	0/1/2/3

0= none, 1= mild, 2= moderate, 3= severe

Diagnosis/Treatment (Dx/Tx)

Diagnosis/Treatment	Score
Diagnostic testing required	0/1/2/3
Treatment required	0/1/2/3

0= none, 1= minimal, 2= moderate, 3=extensive

Total MISS Score= Adding Anatomic + Functional Impairment + Dx/Tx Range = 1-18 per injury

MISS Examples

[illegible]

[illegible]

[illegible]

[illegible]

MISS Examples

[illegible]
- [illegible]
- [illegible]
- [illegible]

[illegible]

[illegible]
- [illegible]
- [illegible]
- [illegible]
- [illegible]

[illegible]

Proposed Limits for Total MISS

Pre-Flight: 1 = Go
2 = Go/No Go
≥ = No Go

In-Flight: 1-2 = Go
3 = Go/No Go
≥4 = No Go

Anatomic	Skin/Extremity	Large or Sensory Organ	CNS Insult
Functional Impairment	Mild	Moderate	Severe
Diagnosis/Treatment	None/Mild	Moderate	Extensive
	↓	↓	↓
	GO	Expert Consultation	NO-GO

Conclusion

- While there is no substitute for clinical judgment by the aerospace medicine physician, the MISS could serve as a general guideline and rationale for Go/No-Go decision-making for HSF. This system may serve as a way to classify injuries in both crew and space flight participants such that appropriate response decisions can be made before and during flight.

Next Steps

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- Manuscript editing
- Publish results

Contact Information

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Task 294:Development of Minor Injury Severity Scale for Orbital Human Space Flight

Project At-A-Glance
- University: The University of Texas Medical Branch
- Principal Investigator: Richard T. Jennings, MD, MS
  Tarah Castleberry, DO, MPH
  - Co-I: Eric Kerstman, MD, MPH
  - Co-I: Jonathan Clark, MD, MPH
- Student Researchers: James Cushman, MD, MPH

Anatomic	Skin/Extremity	Large or Sensory Organ	CNS Insult
Functional Impairment	Mild	Moderate	Severe
Diagnosis/Treatment	None/Mild	Moderate	Extensive
	↓	↓	↓
	GO	Expert Consultation	NO-GO

Relevance to Commercial Spaceflight Industry

Minor injuries of small consequence on the ground may have a large operational impact if they were to occur in space.

A Minor Injury Severity Scale (MISS) for human space flight (HSF) was developed for identification of unacceptable injuries that could disrupt HSF operations.

Statement of Work
- Investigate and develop a Minor Injury Severity Scale (MISS) for Orbital Human Space Flight (HSF).

Status
- Completed literature review and MISS development

Future Work
- Manuscript editing
- Publish results

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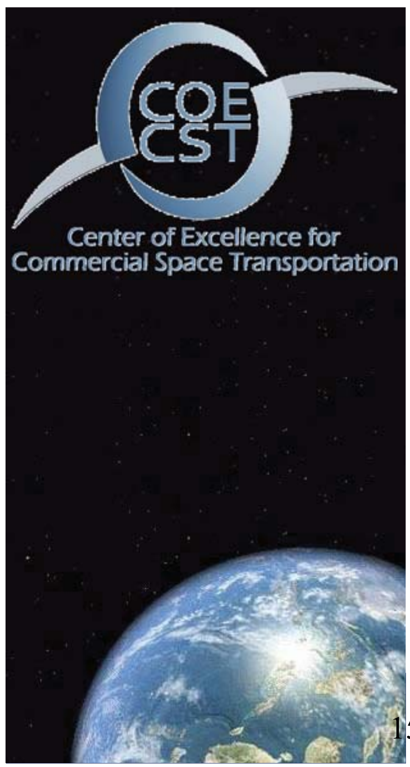
COE CST 3rd Annual Technical Meeting:

Task 295:Effects of EMI and Ionizing radiation on Implantable Medical Devices

James M. Vanderploeg, MD, MPH

Baylor College of Medicine · utmb Health Aerospace Medicine · National Space Biomedical Research Institute

October 30th, 2013



Overview

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- Team Members
- Purpose of Task
- Research Methodology
- Results
- Next Steps
- Contact Information

Team Members

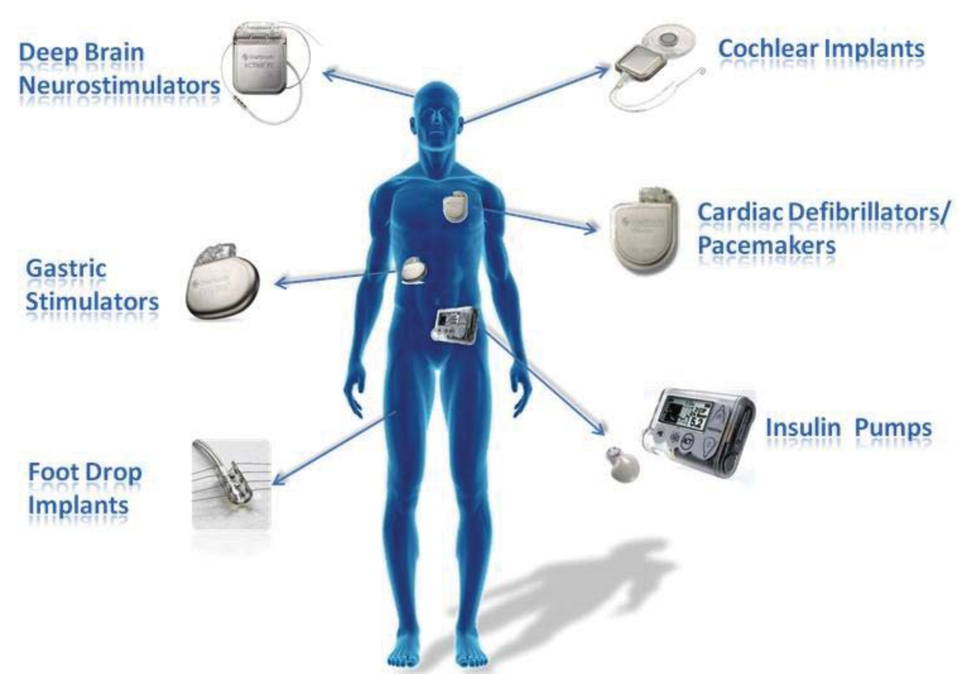
- **PI: James Vanderploeg, MD** (UTMB Aerospace Medicine)
- **Co-I: Tarah Castleberry, DO** (UTMB Aerospace Medicine)
- **Resident: David Reyes, MD** (UTMB Aerospace Medicine)
- **Steven McClure** (NASA Jet Propulsion Laboratory)
- **Jeffery Chancellor** (Center for Space Medicine, Baylor College of Medicine)
- **Nicholas Stoffle** (NASA Johnson Space Center, Space Radiation Analysis Group)
- **Program Manager:** Ken Davidian (FAA)
- **Technical Monitor:** Henry Lampazzi

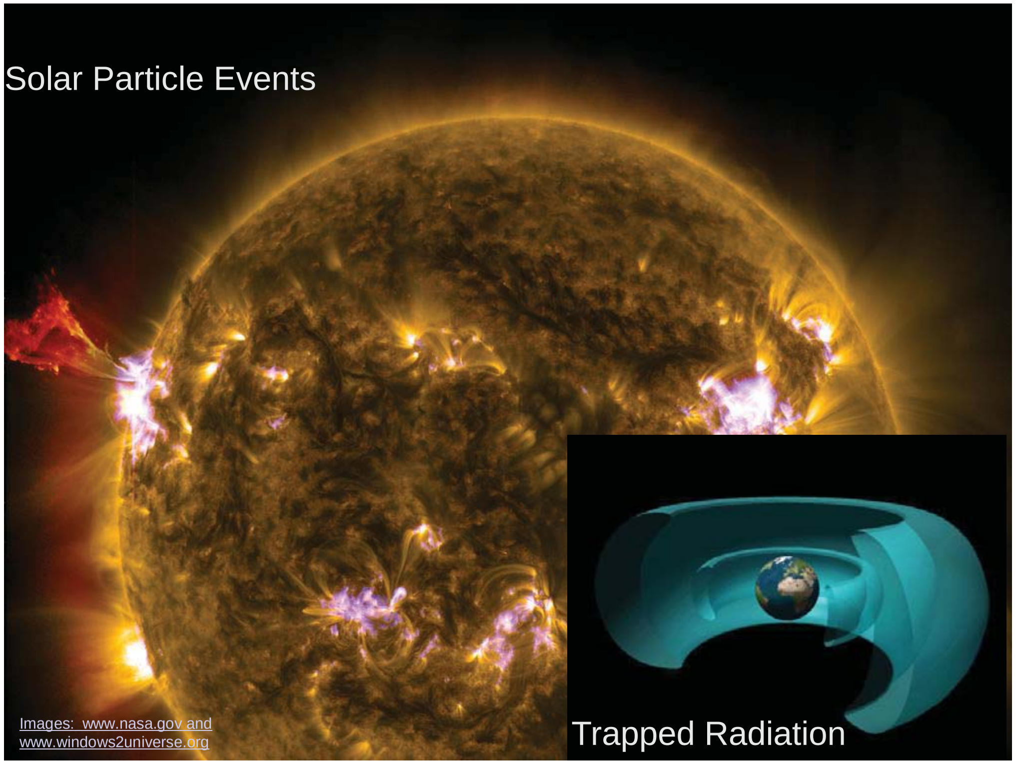
Purpose of Task

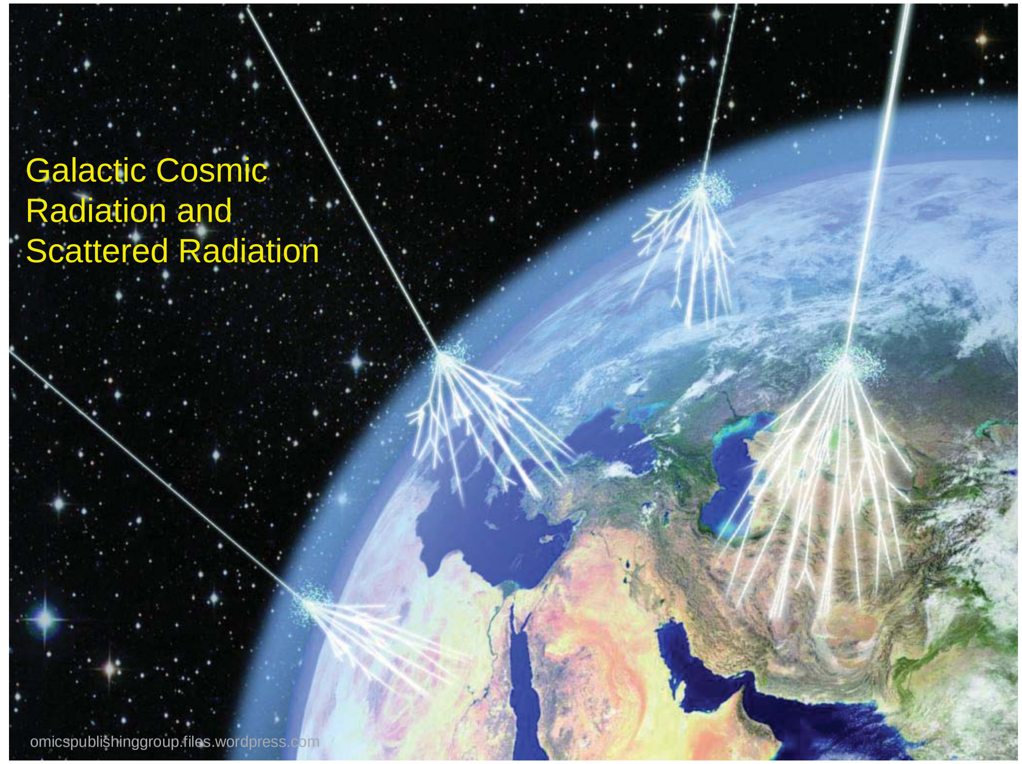
- Investigate known effects of radiation environments on the performance of implanted medical devices (IMDs)
- Extrapolate impacts on function of IMDs in commercial spaceflight participants flying at suborbital and LEO altitudes

Rationale

- Commercial spaceflight participants may have varying degrees of health and potentially significant medical problems
- The effect of solar and galactic radiation on IMDs is unknown, particularly on the internal components, electronics, and function of the device itself







Research Methodology

- Systematic literature review for human studies involving EMI and effects of diagnostic and therapeutic radiation on IMDs
  - PubMed
  - MedLine
  - Google Scholar

Results

- Effects of EMI on IMDs
  - Transient
  - <6” distance

Nonmedical EMI Sources

Table 1. Possible Sources of Electromagnetic Interference From Nonmedical Sources

Source	Possible Effect(s)
Cell phones	None
Security gates	EMI sensing
EAS systems	EMI sensing
Taser	Rapid pacing (shunting of electrical activity to the lead tip); EMI sensing
Magnets (speakers, headphones, jewelry clasps)	Magnet mode
iPods	Interference with ECG recording systems
Other (microwaves)	None

Abbreviations: EAS, electronic article surveillance; ECG, electrocardiographic; EMI, electromagnetic interference.

Clin. Cardiol. 35, 5, 276–280 (2012)
J. Misiri et al: EMI interactions with ICDs: Part I
Published online in Wiley Online Library (wileyonlinelibrary.com)
DOI:10.1002/clc.21998 © 2012 Wiley Periodicals, Inc.

Results

- Effects of radiation on IMDs
  - Diagnostic (CT scan) – transient effects, ~10mGy
  - vs. Therapeutic (tumor treatment) – High-energy can cause device malfunction at doses as low as 40mGy
  - vs. Space Environment – Suborbital effect low
  - Transient, Cumulative
  - Single event upset (SEUs) – alter memory, but can effect device function

Single Event Effects

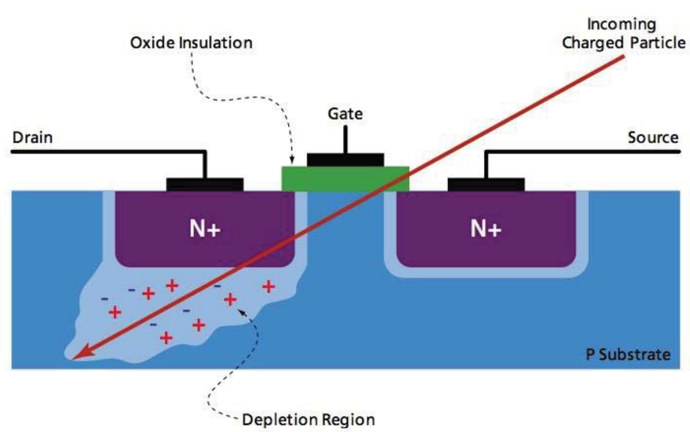
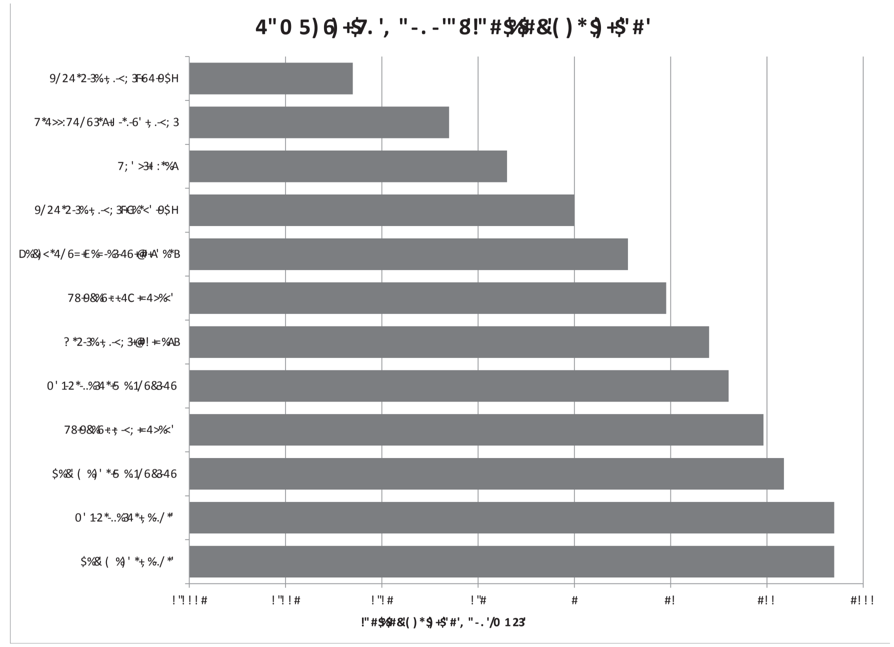


Figure 1: **Charged Particle Causing an SEU**

Microsemi Corp (2010), *Single-event upsets (SEUs) and medical devices*, Microsemi Corp White Paper, Irvine, CA, December 2010.



Results

Mission Type	Radiation Relative to Earth Surface	Possible Dose	IMD Effects
Round Trip, Cross-Country Flight (12 Km)	Radiation Belts – not encountered SPE – slight increase, latitude dependent GCR – minimal additional from ground levels	0.05 mGy	Very low rate of SEU
Suborbital (100 Km)	Radiation Belts – not encountered SPE – slight increase, latitude dependent GCR – minimal additional from ground levels	0.00034 – 0.0026 mGy (no SPE) [1] 0.2 – 1 mGy (large SPE) [1]	Very low rate of SEU due to very short exposure time
Orbital (ISS orbit at ~400 Km)	Radiation Belts – orbit dependent SPE – significant increase GCR – increased	3 – 25 mGy/ 10 days [1] 0.18 to 2.1 mGy per day 1.8 to 21 mGy / 10 days [2] 250 mGy / 100 days [2]	Rate of SEU or other effects dependent on duration of mission. Malfunction likely if > 10 days Eventual failure possible for long-duration flights

Conclusion

- While significant radiation exposure in suborbital flight is unlikely, multi-day orbital exposures could approach levels of radiation exposure associated with potential device malfunction. Individuals with IMDs should experience few, if any, radiation-related device malfunctions during suborbital flight, but could have problems with radiation exposures associated with longer, orbital flight.

COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013
Center of Excellence for Commercial Space Transportation

Next Steps

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- Manuscript editing
- Publish results

COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013
Center of Excellence for Commercial Space Transportation

Contact Information

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COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013
Center of Excellence for Commercial Space Transportation

Task 295:Effects of EMI and Ionizing radiation on Implantable Medical Devices

Project At-A-Glance

- University: The University of Texas Medical Branch
- Principal Investigator: James Vanderploeg, MD, MPH
- Student Researchers: David Reyes, MD, MPH

Relevance to Commercial Spaceflight Industry

- Commercial spaceflight participants (SFPs) represent a population with potentially significant medical problems, including use of Implantable Medial Devices (IMDs)

Statement of Work

- Investigate known effects of radiation environments on the performance of implanted medical devices (IMDs)
- Extrapolate impacts on function of IMDs in commercial spaceflight participants flying at suborbital and LEO altitudes

Status

- Completed literature review and preliminary manuscript

Future Work

- Review by radiation specialists
- Publish results

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Baylor College of Medicine

BACKUP SLIDES

COE CST Third Annual Technical Meeting (ATM3)
October 28-30, 2013
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Response of CIED to EMI

Table 2. Possible Clinical Responses to Electromagnetic Interference Depend on Device and Patient Characteristics

Device/Patient	Possible Observed Responses
Device type	
Pacemaker: ventricular channel	Asynchronous pacing due to activation of noise algorithms; safety pacing (pacing at short AV intervals); inhibition of ventricular pacing; magnet mode
Pacemaker: atrial channel	Asynchronous pacing; inhibition of atrial pacing; mode switch; magnet mode
ICD	Inappropriate antitachycardia therapy; magnet mode
Patient characteristics	
Pacemaker-dependent patient	Inhibition of pacing could cause slow heart rates and result in dizziness, syncope, etc.; inappropriate tracking could lead to fast paced rates and rapid heart rates; inappropriate sensing of EMI by an ICD could lead to inappropriate antitachycardia therapy, such as pacing or a shock.
Non–pacemaker-dependent patient	Inhibition of pacing generally does not cause symptoms; inappropriate tracking could lead to fast paced rates and rapid heart rates; asynchronous pacing can cause palpitations and rarely may lead to initiation of arrhythmias; inappropriate sensing of EMI by an ICD could lead to inappropriate antitachycardia therapy, such as pacing or a shock.

Abbreviations: AV, atrioventricular; EMI, electromagnetic interference; ICD, implantable cardioverter-defibrillator.

Clin. Cardiol. 35, 5, 276–280 (2012)
J. Misiri et al: EMI interactions with ICDs: Part I
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Medical EMI effects

Table 1. Recommendations to Minimize Electromagnetic Interference in Medical Settings

Electrosurgery
1. Maximize distance between site of monopolar electrosurgery and the CIED. Consider bipolar electrosurgery if required near the CIED. 2. Use the minimum power settings required for adequate electrosurgery. 3. For monopolar electrosurgery, place the return electrode at a site where the current path is kept as far as possible from the CIED. Often, the thigh on the leg contralateral to the CIED will be the best location. 4. For surgeries below the umbilicus, often no specific procedures are required for CIEDs. However, in some cases (patients with ICD or who are pacemaker dependent), reprogramming or magnet application may be considered. 5. Procedures above the umbilicus are more likely to be associated with EMI, and reprogramming or magnet application may be required, particularly if the patient has an ICD or is pacemaker dependent. 6. Using short bursts of electrosurgery may be required if inhibition is observed. 7. Continuously monitor the patient with plethysmography or arterial pressure. 8. After the surgery, address any preoperative programming changes that were made, and consider interrogation for any surgery with a higher likelihood of EMI.
MRI (see Table 2)
LVAD
1. Surgeons implanting the HeartMate II LVAD should be notified and be aware of possible loss of ICD telemetry in some types of ICDs. 2. Interrogate before and immediately after LVAD implantation. 3. If there is loss of ICD telemetry, metal shielding and/or implanting an ICD from a different manufacturer may be required.
Radiation therapy
1. Avoid direct irradiation of the CIED. 2. Consider relocation of the device if it is within the radiation field. 3. Review with the manufacturer the susceptibility of the device to radiation effects. 4. Establish the pacemaker dependency of the patient. 5. Shield the pulse generator if possible. 6. The absorbed dose to be received by the ICD should be estimated before treatment. 7. Continuously monitor the patient's ECG. 8. Consider intermittent testing of the CIED during and after radiation therapy.
Cardioversion
1. Use an anterior-posterior patch position, with the patches positioned as far from the CIED as possible (>8 cm). 2. Evaluate CIED function after cardioversion.
TENS
1. Assess the likelihood and patient risk of TENS for CIED interaction: location of TENS, pacemaker dependency, ICD vs pacemaker. 2. Perform initial supervised testing of TENS use with monitoring to evaluate for interference. 3. Set pacemaker sensing polarity to bipolar. 4. Program OFF impedance-based sensors such as minute ventilation. 5. Place the TENS electrodes close to each other and perpendicular to the device leads. 6. Avoid treatment in the chest area; TENS can often be done safely in the lower extremities.
Radiofrequency ablation, lithotripsy, ECT
1. Generally, no specific programming is required. 2. It is reasonable to have a magnet available. 3. Cardiac monitoring is reasonable, particularly in those patients who are pacemaker dependent.

Abbreviations: CIED, cardiovascular implantable electronic device; ECG, electrocardiogram; ECT, electroconvulsive therapy; EMI, electromagnetic interference; ICD, implantable cardioverter-defibrillator; LVAD, left ventricular assist device; MRI, magnetic resonance imaging; TENS, transcutaneous electrical nerve stimulation.

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Guidelines for MRI and CIED

Table 2. Summary of Different Guidelines for the Use of Magnetic Resonance Imaging in Patients With Cardiovascular Implantable Electronic Devices

	AHA Scientific Statement	ESC Position Paper	ACR Guidance Document
Patient selection	Should not be performed in pacemaker-dependent patients or patients with ICDs unless there are "highly compelling circumstances"; discouraged in non–pacemaker-dependent patients unless there is a "strong clinical indication"	Pacemaker-dependent patients (very high risk), ICD patients (high risk), non–pacemaker-dependent patients (low risk)	CIEDs are a relative contraindication to MRI; MRI should be performed on a "case-by-case and site-by-site basis."
MRI considerations	Lowest RF power levels, weakest/ slowest necessary gradient magnetic fields	Field strength <1.5 T; limit SAR — no SAR >2 W/kg; minimize number/ length of sequences; send/receive coils preferred to surface coils	None given
Preoperative CIED evaluation	Interrogate the CIED; program to asynchronous pacing for pacemaker-dependent patients; disable tachycardia therapy in ICD patients	Interrogate the CIED; program to asynchronous pacing for pacemaker-dependent patients; disable tachycardia therapy in ICD patients; program to bipolar sensing; disable special algorithms (eg, rate adaptation)	No specific recommendations
Intraoperative	Monitor heart rhythm and vital signs; audio and visual contact; crash cart available; appropriate personnel available	ECG and pulse oximetry; audio and visual contact; crash cart available; ACLS-certified personnel available; CIED programmer available	ECG and pulse oximetry; crash cart available; radiology and cardiology personnel available
Postoperative CIED evaluation	For any ICDs and pacemaker-dependent patients, interrogate the CIED and reprogram to original parameters; for non–pacemaker-dependent patients, reprogram as needed	Reinterrogate the CIED and reprogram to original parameters if required; interrogate the CIED at 1 week and 3 months	Reinterrogate the CIED; interrogate the CIED again 1–6 weeks after the MRI

Abbreviations: ACLS, advanced cardiac life support; ACR, American College of Radiology; AHA, American Heart Association; CIED, cardiovascular implantable electronic device; ECG, electrocardiography; ESC, European Society of Cardiology; ICD, implantable cardioverter-defibrillator; MRI, magnetic resonance imaging; RF, radiofrequency; SAR: specific absorption rate.

324 Clin. Cardiol. 35, 6, 321–328 (2012)
J. Misiri et al: EMI interactions with ICDs: Part II
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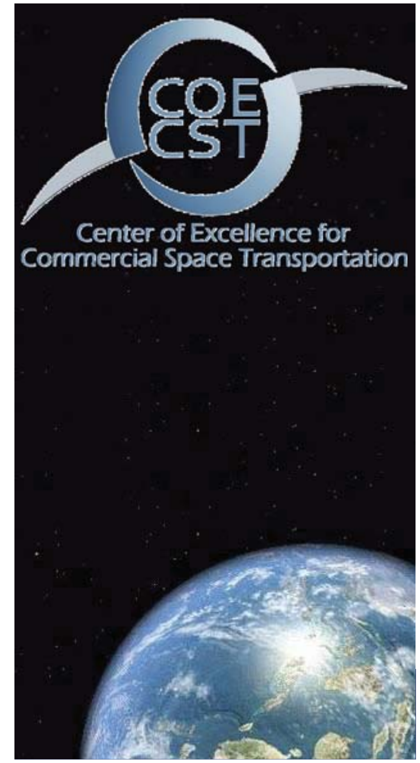
COE CST Third Annual Technical Meeting: Task 298: Integration and Evaluation of ADS-B Payloads

Pat Hynes

October 29, 2013



Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results or Schedule & Milestones
- Next Steps
- Contact Information

Team Members

- PIs: Patricia Hynes, New Mexico State University
- Co-Investigator: Nick Demidovich, FAA, AST-300, Regulations and Analysis Division
- Co-Investigator: Laura Boucheron, New Mexico State University
- Student: Joshua Michalenko, Electrical & Computer Engineering, New Mexico State University
- Industry Partners: Jason R. Armstrong, TriSept Corporation and Dave Edwards, Mitre

Purpose of Task

- Purpose- NMSU and the FAA will launch an Automatic Dependent Surveillance – Broadcast (ADS-B) on a rocket from Spaceport America
- Objectives- ADS-B has the potential to enable routine, seamless access to the National Airspace (NAS) by reusable launch vehicles (RLV)
- Goal- Long term goal is to mature the ADS-B system by flying it repeatedly in space, using flight data to make future versions lightweight and affordable

Research Methodology

- FAA will request truth data (acceleration) from Up Aerospace payload on SL6 on board avionics (IMU)- still not available
- Dr. Boucheron will do comparative analysis from ADS-B captured data transmitted from SL 6 and captured by ADS-B receiver equipment against flight data WSMR radar already on hand and data from SL6 on board avionics (IMU) if possible, the latter are available flight data WSMR already on hand

Research Methodology (cont)

- Dr. Boucheron will perform comparative data analysis from SL-7 & SL 8 from ADS-B data transmitted from those flight and captured against flight data from WSMR radar. She will assess if it is feasible to create a post-flight trajectory using ADS-B messages containing only time of transmission and time of arrival that have been received at multiple independent sites- still not available

Results or Schedule/Milestones

- Code infrastructure is developed and ready to analyze the additional data as soon as we receive it from Nick Demidovich

Next Steps

- Receive data from SL-7 (C-band radar and WSMR radar data from Nick Demidovich)

Contact Information

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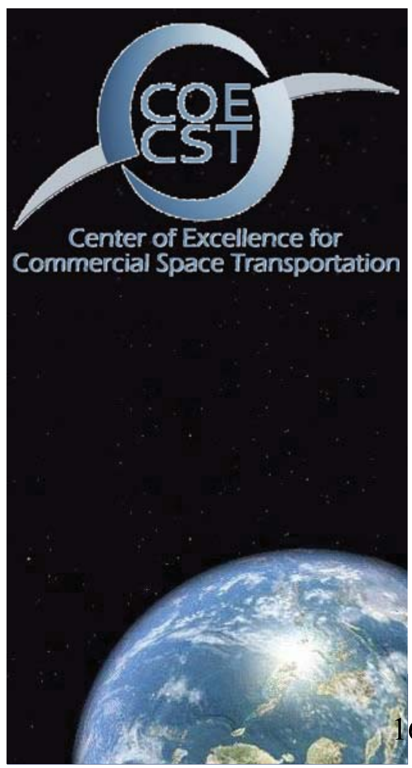
COE CST Third Annual Technical Meeting:

Task 299: Nitrous Oxide Composite Case Testing

PI: Warren Ostergren
Co-PIs: Michael Hargather
Robert Abernathy
Andrei Zagrai

October 29, 2013



Overview

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- Contact Information

Team Members

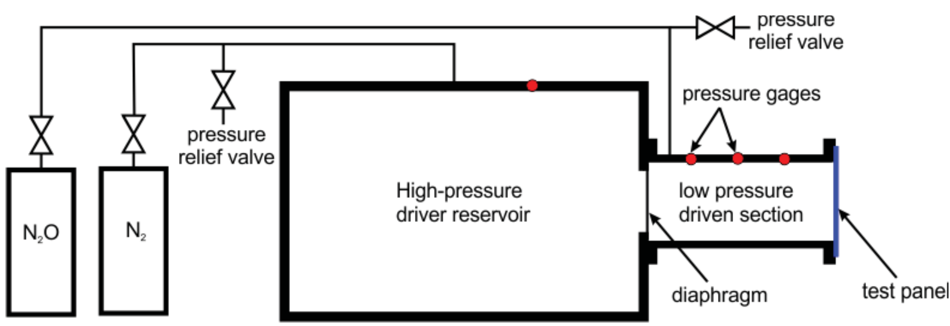
- PI: Warren Ostergren, Associate Professor of Mechanical Engineering, NMT
- Co-PIs:
  - Michael Hargather, Assistant Professor
  - Robert Abernathy, Computational Analyst, Energetic Materials Research and Testing Center (EMRTC)
  - Andrei Zagrai, Associate Professor
- Test Engineer
  - Paul Giannuzzi, Research Engineer, EMRTC
- Students:
  - Jesse Tobin – MS in Mechanical Engineering
  - Steven Bayley – BS in Mechanical Engineering

Purpose of Task

- Develop an understanding of fragmentation hazards from composite tanks used for fuel/oxidizer storage
- Objectives:
  - Test composite panels to understand fragmentation hazards
  - Develop methods to predict fragmentation conditions
  - Develop standard test procedures for composite materials under shock and high-rate loading
  - Develop analytical and computational models to compare to experiments
- Goals
  - Provide data to help set guidelines for safe distances during launch of commercial vehicles
  - Establish standard test procedures for high-rate loading of composites

Research Methodology

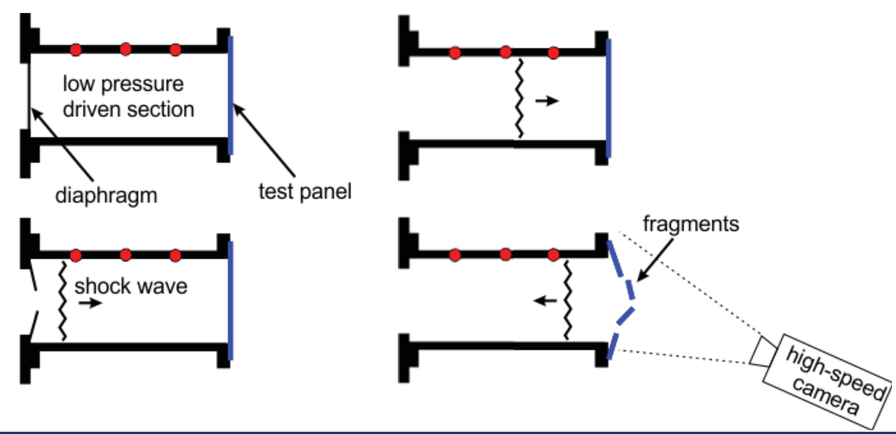
- Test flat panels of composite materials under dynamic, shock loading produced with a diaphragm rupture



- Benchmark facility with aluminum plates
  - Aluminum is used in lined composite tanks
  - Modeling of aluminum can be performed simply

Research Methodology

- High-pressure reservoir pressure = 3000 psi
- Low-pressure section represents the fuel tank, P = 750 psi
- Composite test panel on end of driven section will be fractured



Research Methodology

- Tests will be performed at EMRTC on the NMT campus
  - Initial tests with aluminum panels as benchmark
  - Follow on tests with composite panels
- Data recorded:
  - Pressure measurements in low-pressure section to measure shock loading and dynamic pressure
  - High-speed video showing fragmentation of test panels
  - Acoustic emission measurements on the test panel surface
  - All data synchronized to allow analysis of dynamic failure
- Computational simulations will be performed in CTH
  - Pressure-time history on test panels
  - Estimation of fragmentation/deformation regimes

Results or Schedule/Milestones

- Test fixture currently under construction
  - High-pressure section ready
  - Low-pressure section in final machining stages
  - Pressure gages and all instrumentation have been obtained
- Instrumentation being tested in laboratory
- Composite material selection
  - Obtained samples of composite N_2O tank materials
  - Selection of representative material in progress

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Results or Schedule/Milestones

- Testing expected to begin in December
  - Initial aluminum panel tests expected to be complete by mid-January
  - Initial four tests of composite material to be complete by end of March
- Initial computer simulations have begun
  - Computational model of entire system
  - Accurate model for aluminum

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Next Steps

- Testing to be performed starting in December
- Computational model of aluminum tests complete before testing commences
- Long term:
  - Selection of a variety of composite materials to represent wide range of variables
  - Incorporation of data from composite tests into computational model
  - Test of full composite N_2O tank
- Establish safety standards for dynamic loading of composite tanks

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