Center of Excellence for
Commercial Space Transportation

Federal Aviation Administration Center of Excellence for Commercial Space Transportation

Year 4 Annual Report

Volume 2. Annual Technical Meeting Presentations

December 31, 2014

Florida Institute of Technology
Florida State University
NM State University
New Mexico Tech
Science • Engineering • Research • University
Leland Stanford Junior University
University of Colorado
University of Central Florida
University of Florida
utmb Health

www.coe-cst.org

COE CST YEAR 4 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 4 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 fourth Annual Technical Meeting in October 2014 held 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 fourth Annual Technical Meeting in October 2014 held in Washington, DC.

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

- "COE CST 5 Year Review (Year 4) Briefing" presented by Dr. Patricia Watts, Program Director FAA Centers of Excellence.
- "COE CST Fourth Annual Technical Meeting (ATM4) Overview and Status" presented by Mr. Ken Davidian, FAA Program Manager for the Center of Excellence for Commercial Space Transportation.
- "Advanced ADS-B Prototype for Commercial Space: Status Update and Future Opportunities" presented by Mr. Richard S. Stansbury, Embry Riddle Aeronautic University (Affiliate Member).

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

- Task 185 "Unified 4D Trajectory Approach for Integrated Traffic Management" presented by Tom Colvin and Juan Alonso of Stanford University (SU).
- Task 186 " Space Environment MMOD Modeling and Prediction" presented by Alan Li and Sigrid Close of Stanford University (SU).
- Task 186 " Mitigating Threats Through Space Environment Modeling/Prediction" presented by Tim Fuller-Rowell and Catalin Negrea of University of Colorado, Boulder (CU).
- Task 187 "Space Situational Awareness" presented by D.J. Scheeres and In-Kwan Park of University of Colorado, Boulder (CU).
- Task 220 "Update" presented by Patricia C. Hynes, Ph.D. of New Mexico State University (NMSU).
- Task 257 "Commercial Spaceflight Operations Curriculum Development" presented by George H. Born and Bradley Cheetham of University of Colorado, Boulder (CU).
- Task 184 "Human-Rating of Commercial Spacecraft" presented by Professor David Klaus, Christine Chamberlain, and Roger Huang of University of Colorado, Boulder (CU).
- 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 228 "Magneto-Elastic Sensing for Structural Health Monitoring" presented Andrei Zagrai and Warren Ostergren of New Mexico Institute of Mining & Technology (NMT).
- 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 for Space Debris Mitigation" presented by Norman Fitz-Coy of University of Florida (UF).
- Task 244 "High Temperature Pressure Transducers" presented by William Oates and Justin Collins of Florida State University (FSU).
- Task 244 "Autonomous Rendezvous and Docking" presented by Penina Axelrad of University of Colorado, Boulder (CU).

- Task 253 “ Ultrahigh Temperature Composites for Thermal Protection Systems (TPS)” presented by Hungjiang Yang of University of Central Florida (UCF).
- Task 258 “Analysis Environment for Safety of Launch and Re-Entry Vehicles” presented by Francisco Capristan and Juan Alonso of Stanford University (SU).
- Task 293 “Nonlinear Structural Models” presented by Dr. A. Keith Miller, Dr. Warren Ostergren, and Mr. Lance Hernandez of New Mexico Institute of Mining & Technology (NMT).
- Task 298 “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).
- Task 306 "Advanced ADS-B Prototype for Commercial Space: Status Update and Future Opportunities" presented by Mr. Richard S. Stansbury of Embry Riddle Aeronautic University.
- Task 307 "Flight Test of Communications in Space via Commercial Satellite Networks on Suborbital Spacecraft: Implications for Space Traffic Management" presented by M. Brian Barnett of SatWest.
- Task 311 "Robust and Low-Cost LED Absorption Sensor for Simultaneous, Time-Resolved Measurements of CO and CO_2" presented by Dr. Subith Vasu, Dr. Jayanta Kapat, Dr. Bill Partridge Jr., Kyle Thurmond, and Zachary Loparo of University of Central Florida (UCF).
- Task 193 “Research Roadmap 2.0” presented by Professor Scott Hubbard, Jonah Zimmerman, and Andrew Ow of Stanford University (SU).
- Task 193 “Role of COE CST in EFP ” presented by George H. Born and Bradley Cheetham of University of Colorado, Boulder (CU).
- Task 304 “Definition and Delimitation of Outer Space" presented by Dr. Ram S. Jakhu and Andrea DiPaolo of McGill University (MU).
- Task 305 “Industrial Analysis of Orbital and Suborbital Commercial Space Transportation” presented by Scott Benjamin of Florida Institute of Technology (Florida Tech).

Center of Excellence CST

The FAA Air Transportation Center of Excellence
for
Commercial Space Transportation

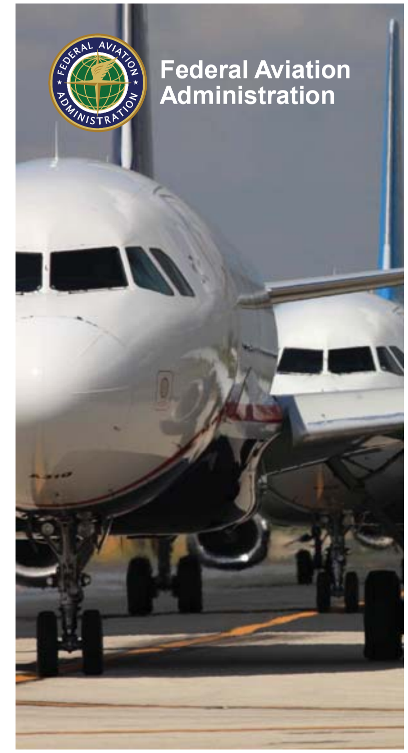
5 Year Review (Year 4)

Presented by: Patricia Watts, Program Director FAA Centers of Excellence

Presented to: COE CST Members

Date: October 29, 2014

Location: Washington, DC



COE CST 5-Yr Review (Year 4)

AGENDA

Part 1 – Patricia Watts

Administrator, Jane Garvey, with Congressman Mica
COE GA Dedication, Washington, DC

- **Review/Evaluation Process &Topics**
- **Funding Summary**
- **Academic Production**

COE CST 5-Yr Review (Year 4)

AGENDA (continued)

Part 2 – Ken Davidian

- **Projects - Open**
- **Significant Research Results**

Overview: DOT/FAA Grants Authority

- **DOT:** 92 Grants Programs ~ **$60 B** (vs. Contracts $ 6 B)
  2 Centers Programs
  - UTCs
  - COEs

- **FAA:** Authority for Major Grants Program
  1. Airway Science
  2. AIP
  3. Aviation Research
  4. <u>COE – P.L. 101-508 ~$500 M / LOE</u>

Enacted to enhance FAA's access to resources and research capabilities and facilities available at colleges, universities, and other organizations and institutions by establishing COEs on behalf of AOA

DOT - The Secretary's RAISE Award

Recognizing Aviation and Aerospace Innovation in Science and Engineering

Nominations Open until December 30, 2014
Award will be presented to individuals or teams at the high school and university level (under graduate & graduate) to recognize extraordinary achievements that have a significant impact on the future of aviation and aerospace.

Full announcement and application details at:
www.faa.gov/go.coe

Contact:
Patricia Watts, Ph.D
FAA Centers of Excellence Program Office
Phone: (609) 485-5043 or
Email: patricia.watts@faa.gov

2013 Award Recipient
Lieutenant Kyle Smith (USAF)
with Secretary Anthony R. Foxx

COE Legislative Authority – P.L. 101-508

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 <u>shall include, but not be limited to,</u> the conduct of research concerning airspace and airport planning and design, the air transportation environment, aviation safety and security, the <u>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</u>.… each <u>center may make contracts with nonprofit research organizations and other appropriate persons</u>.…"

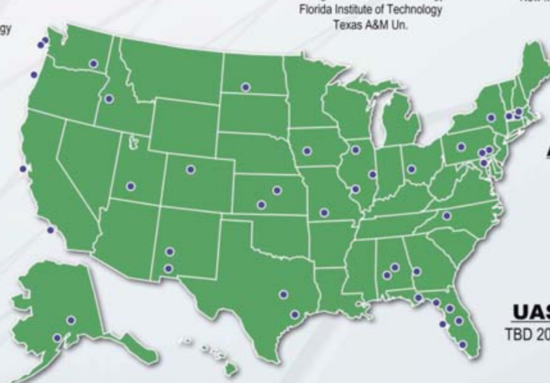
FAA Centers of Excellence Teams

Alternative Jet Fuels & Environment
Washington State Un. (Lead)
Massachusetts Inst. of Tech (Co-Lead)
Boston Un.
Georgia Institute of Technology
Missouri Un. of Science & Technology
Oregon State University
Pennsylvania State Un.
Purdue Un.
Stanford Un.
Un. of Dayton
Un. of Hawaii
Un. of Illinois
Un. of North Carolina – CH
Un. of Pennsylvania
Un. of Tennessee
Un. of Washington

Noise and Emissions Mitigation (PARTNER)
MIT (Lead)

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

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



Airliner Cabin Environment-Intermodal Research (ACER/Rite)
Auburn Un. (Admin Lead)
Kansas State Un. (Tech Lead)
Harvard Un.
Purdue Un.
Boise State Un.
Rutgers Un.

General Aviation (CGAR)
Embry Riddle Aeronautical Un. (Lead)

Operations Research (NEXTOR)
UMD (Lead)

Airworthiness Assurance (AACE)

UAS
TBD 2015

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.

Airport Technology
Un. of Illinois (Lead)

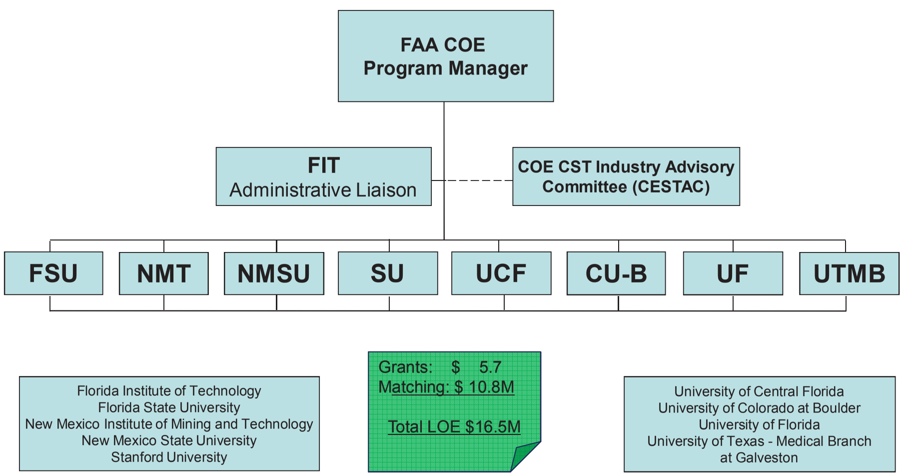
COE Funding – Levels of Effort

2015-2020	Unmanned Aircraft Systems	HQ	$ 500K
2014 –2019	**Alternative Jet Fuels & Environment (AJF&E)***	HQ	$ 8M
2012 – 2017	**General Aviation Research (PEGASAS)***	TC	$ 6M
2010 – 2015	**Commercial Space Transportation (CST)***	HQ	$ 16.5M
	===		
2004 – 2014	**Research in the Intermodal Transport Environment (RITE)***	HQ	$ 45M
2004 – 2015	**Advance Materials (JAMS)***	TC	$ 47M
2003 – 2014	**Aircraft Noise and Emissions Mitigation (PARTNER)***	HQ	$ 112M
2001 – 2013	**General Aviation (CGAR)***	TC	$ 39M
	===		
1997 – 2007	Airworthiness Assurance (AACE)	TC	$ 124M
1996 – 2007	**Operations Research (NEXTOR) Self-Sufficient****	HQ	$ 45M
1995 – 2013	**Airport Technology (CEAT) Self-Sufficient****	TC	$ 42M
1992 – 1996	Computational Modeling of Aircraft Structures (CMAS)	TC	$ 10M
		Total	**$ ~500 M**

* COE Operational = 7   ** Independently Operated = 2

PART 1 – P. Watts
COE CST Phase I Evaluation

COE for Commercial Space Transportation (CST)



COE CST Industry Advisory Committee (CESTAC)

JHR Consulting
The Tauri Group
Florida Institute of Technology
Space Florida
Spaceworks Enterprises
National Aerospace Training and Research Center (NASTAR)
Jacobs Technology, Inc.
Boeing Space Exploration
Scitor
Ball Aerospace
Lockheed Martin Space Systems Company
United Launch Alliance (ULA)
Commercial Spaceflight Federation
Wyle
ACTA
Space Systems Loral
SATWEST, LLC

CST 5-Yr Review Process

- **Evaluation Input Provided by:**
  - University PIs
  - Industry Sponsors and Advisory Board Members
  - COE Students
  - FAA Technical Monitor(s)
- **Focus of Assessment:**
  - Legislative Requirements
  - FAA & Sponsor Funded Technical Projects
  - Fiscal Activities
  - COE Research, Management & Overall Activities

CST Specific Assessment Topics

- **COE Research Agenda**
  - Impact
  - Relevance to the Industry
  - Benefits to the Aviation Community and to the FAA
- **Extent to Which the COE Has Met Goals**
  - **FAA's**
    - Research Outcomes & Technology Transfer
  - **Congressionally Defined**
    - Outreach and *Information Dissemination*
    - *Education & Training* NextGen of Scientists – Evidence of Student Learning
    - *Geographic Equity*
    - *Matching Contributions*

Gregory D. Winfree
Deputy Administrator, RITA w/
Bradley Cheetham, Un. of Colorado at Boulder
COE for Commercial Space Transportation

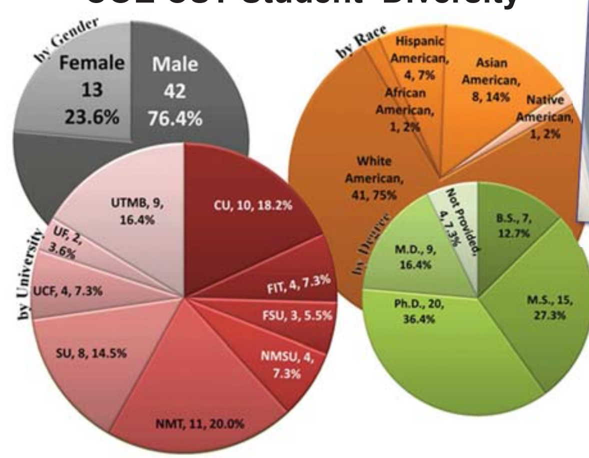
2012 DOT FAA COE
Student of the Year

COE CST Overall Funding Summary (2010 – 2014)

• **FAA Grant Funds Awarded:**	$5,620,140
• **Sponsors - Private Sector Matching Contributions:** (as of March, 2014 – Cash and In-Kind Excess of $5,236,845)	$10,856,985 (2:1)
• **Total Level of Effort:**	**$16,477,125**

COE CST Academic Production (2010 – 2014) -- Center Overall

COE CST Student Diversity



PART 2 – K. Davidian

Center of Excellence Benefits

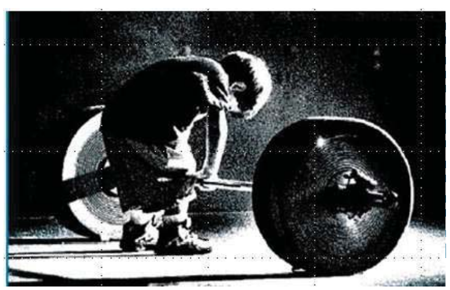
- **Promote** academic, government & industry scientific networks prepared to enhance the safety, security & efficiency of the national airspace system
- **Augment** government resources ($:$) and leverage funds through flexible and responsive public/private partnerships
- **Expand** the U.S. math & 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 mandates

Congressman Oberstar meets with COE Students & Faculty at TRB Council of University Transportation Centers Awards Ceremony celebrating the Outstanding Students of the Year

"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

Q and A



The Challenges of Serious Heavy Lifting

Scott Pipkins, Ph.D., George Donohue, Ph.D., Bruce Singer, Virgina Sahmi, Sarya Arluri, Ph. D., Patricia Watts, Ph.D., Chris Seher

COE University Members (1 of 3)

Andrew Leonard, UND
COE for General Aviation

2010 DOT FAA COE
Student of the Year

John Porcari
Deputy Sec. of Transportation w/
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
Oregon State University
Pennsylvania State University
Purdue University
Rensselaer Polytechnic Institute
Stanford University

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 w/
Bradley Cheetham, Un. of Colorado at Boulder
COE for Commercial Space Transportation

2012 DOT FAA COE
Student of the Year

Texas A&M University
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 Delaware
University of Florida
University of Illinois at Urbana Champaign
Un. of Medicine & Dentistry of NJ
University of Missouri at Rolla
University of North Dakota
University of North Carolina at Chapel Hill
University of Pennsylvania
University of Texas Medical Branch
University of Utah
University of Washington
Washington State University
Wichita State University

COE Co-Sponsors

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

FAA Air Transportation Centers of Excellence

Contact:

Patricia Watts, Ph.D.
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

Secretary of Transportation Rodney Slater and University of Illinois student Bill Vavrik, 1999 DOT COE Student of the year

FAA Air Transportation Centers of Excellence

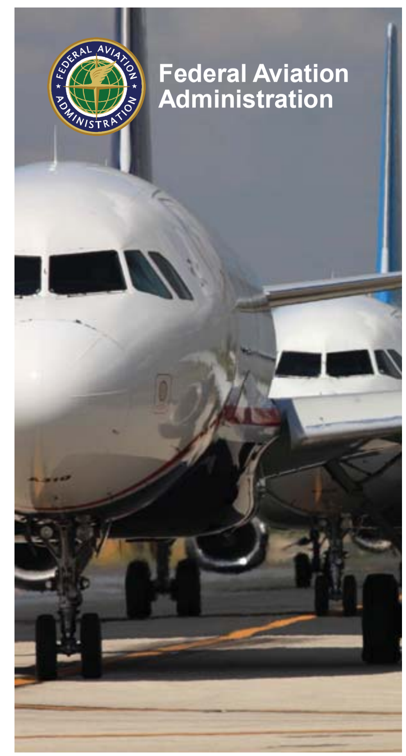
COE Organizational Structures

Government/Academic/Industry
Public/Private Partnerships

Part II

Presented by: Patricia Watts
FAA Centers of Excellence

Date: Tuesday, 23 September 2014 (12:30 PM)



FAA Air Transportation Centers of Excellence

FAA - ARA
FAA COE Program Management Office

	Computational Modeling of Aircraft Structures (CMAS)	Airport Technology (CEAT)	Operations Research (NEXTOR)	Airworthiness Assurance (AACE)
University Core Members	Rutgers/Georgia Tech	Un of Illinois/ Northwestern Un RPI	Un of Calif-Berkeley/MIT/Un. of MD/VPI	Iowa State & Ohio State Universities +30 Un Members
FAA Sponsors	1992-1996 Mandate AAR > ANG TC	1995-2010 AAR > ANG TC	1996-2007 ASD HDQ	1997-2007 AAR > ANG TC
Tasks Monitors Funds	27 Tasks 2 Task Monitors $10.3 M ($3M Earmark)	33 Tasks 3 Task Monitors $41.5 M*	41 Tasks 31 Task Monitors $44.7 M**	300 Tasks 30 Task Monitors $123.5 M**

* All dollar amounts indicated reflect grant awards and include matching funds.
** All dollar amounts indicated reflect grant awards, matching funds, other funding vehicles, and contracts.

FAA COEs – Active: Phase I

FAA-ANG
FAA COE Program Management Office

	Commercial Space Transportation (CST)	General Aviation Safety (PEGASAS)	Alt. Jet Fuels & Environment (AJF&E)	Unmanned Aircraft Systems (UAS)
University Core Members	FIT plus 8 Cores	PU plus 5 Core	MIT	
FAA Sponsors	2010 -2015 AST Hdq	2010 -2015 ANG-E TC	2012 – 2024 AEE Hdq	2015
Tasks Monitors Funds	43 Tasks 8 Task Monitors $13.7M*	5 Tasks 11 Monitors $5.6M*	1 Task 18 Task Monitors $1.3M*	TBD

* All dollar amounts indicated reflect grant awards and include matching funds.
** All dollar amounts indicated reflect grant awards, matching funds, other funding vehicles, and contracts.

FAA COEs – Active: In Phase Down

FAA-ANG
FAA COE Program Management Office

	General Aviation (CGAR)	Noise & Aviation Emissions (PARTNER)	Advanced Materials (JAMS)	Research in the Intermodal Transport Environment (ACER-RITE)
University Core Members	ERAU plus 4 Core	MIT plus 8 Core	WiSU & UW plus 10 Core	AU – HU – PU plus 3 Core
FAA Sponsors	2001-2012 AAR > ANG-E TC	2003 - 2013 AEE- Hdq w NASA /Tr Canada	2003 - 2015 ANG-E TC	2004 - 2014 AAM Hdq
Tasks Monitors Funds	101 Tasks 32 Task Monitors $39 M **	30 Tasks 7 Task Monitors $113 M **	20 Tasks 4 Task Monitors $47 M*	14 Tasks 3 Task Monitors $45 M + *

* All dollar amounts indicated reflect grant awards and include matching funds.
** All dollar amounts indicated reflect grant awards, matching funds, other funding vehicles, and contracts.

COE for Alternative Jet Fuels and Environment (AJF&E)

FAA COE Program Manager

COE Director
Ralph Cavalieri
Washington State University

COE CO-Director
R. John Hansman
Massachusetts Institute of Technology

Boston University
Georgia Institute of Technology
Massachusetts institute of Technology
Missouri University of Science & Technology
Oregon State University
Pennsylvania State university
Purdue University
Stanford University

University of Dayton
University of Hawaii
University of Illinois – UC
University of North Carolina – CH
University of Pennsylvania
University Tennessee
University Washington
Washington State University

COE for General Aviation Safety (PEGASAS)

FAA COE Program Manager

COE Director
William A. Crossley
Purdue University

FIT | GIT | ISU | OSU | TAMU

Purdue University
Florida Institute of Technology
Georgia Institute of Technology

Grants $2.8M
Matching $2.8M

Iowa State University
Ohio State University
Texas A&M
Plus 10 Affiliates

COE for Commercial Space Transportation (CST)

FAA COE Program Manager

FIT
Administrative Lead

COE CST Industry Advisory Committee (CESTAC)

FSU | NMT | NMSU | SU | UCF | CU-B | UF | UTMB

Florida Institute of Technology
Florida State University
New Mexico Institute of Mining and Technology
New Mexico State University
Stanford University

Grants: $5.7 M
Matching: $8M
Total LOE $13.7M

University of Central Florida
University of Colorado at Boulder
University of Florida
University of Texas - Medical Branch at Galveston

COE CST Industry Advisory Committee (CESTAC)

JHR Consulting
The Tauri Group
Florida Institute of Technology
Space Florida
Affiliate, Spaceworks Enterprises
National Aerospace Training and Research Center (NASTAR)
Jacobs Technology, Inc.
Boeing Space Exploration
Scitor
Ball Aerospace
Lockheed Martin Space Systems Company
United Launch Alliance (ULA)
Commercial Spaceflight Federation
Wyle
ACTA
Space Systems Loral
SATWEST, LLC

COE for Cabin and Intermodal Transportation (ACERite)

FAA COE Program Manager

COE Executive Director
Tony Overfelt – Auburn Un.

Industry Advisory Board

Auburn
Administrative Lead

KSU
Technical Co-Lead

BSU | HU | PU | RU

Auburn University
Boise State University
Harvard University

Grants: $23M
Matching: $28M
Total LOE: $51M

Kansas State University
Purdue University
Rutgers University of New Jersey

Joint COE for Advanced Materials (JAMS)

FAA COE Program Manager

- **Center Co-Director** John Tomblin — Industry Advisory Board
  - **WiSU** Co-Lead
    - NWU, PU, TU, UCLA, UCSD, UD
- **Center Co-Director** Mark Tuttle — Industry Advisory Board
  - **UW** Co-Lead
    - ECC, WSU, OSU, FIU, UU

Wichita State University
Northwestern University
Purdue University
Tuskegee University
University of California, Los Angeles
University of California, San Diego
University of Delaware

Grants: $24M
Matching: $24M

University of Washington
Edmonds Community College
Washington State University
Oregon State University
Florida International University
University of Utah

COE for Aircraft Noise & Aviation Emissions Mitigation (PARTNER)

Former Secretary of Transportation Norman Mineta & 2014's SOY Matthew Opliger (WSU) and Philip Wolfe (MIT)

FAA COE Program Manager

COE Center Director Ian Weitz

- **MIT** — Industry Advisory Board (100+ Members)
  - HU, PSU, PU, SU, UNC
  - MST, GIT, UI, BU, UPENN

Massachusetts Institute of Technology
Harvard University
Pennsylvania State University
Purdue University
Stanford University

Grants: $51M
Matching: $51M

University of North Carolina – CH
Missouri Science and Technology
Georgia Institute of Technology
University of Illinois
Boston University
University of Pennsylvania

FAA / NASA / Transport Canada COE for Aircraft Noise & Aviation Emissions Mitigation (PARTNER)

- Aerodyne Research, Inc.
- Aerospace Industries Association
- Airbus
- Air Line Pilots Association
- Air Transport Association of America
- Airports Council International - North America
- American Institute of Aeronautics and Astronautics
- Bay Area Air Quality Management District
- Bell Helicopter Textron, Inc.
- Boeing Commercial Airplanes Group
- Delta Air Lines, Inc.
- General Electric Aircraft Engines
- Gulfstream Aerospace Corporation
- Indiana Department of Transportation
- Lockheed Martin Aeronautics Company
- Logistics Management Institute
- Massachusetts Port Authority
- Metron Aviation, Inc.
- Metropolitan Washington Airports Authority
- National Organization to Insure a Sound-controlled Environment (N.O.I.S.E.)
- O'Hare Noise Compatibility Commission
- Palisades Citizens Association
- Pratt & Whitney
- Raisbeck Engineering
- Regional Airport Authority of Louisville and Jefferson County
- Rolls-Royce, plc
- San Francisco International Airport/Community Roundtable
- Sikorsky Aircraft Corporation
- United Parcel Service Airline
- United Technologies Pratt & Whitney
- Wyle Laboratories

COE for General Aviation (CGAR)

FAA COE Program Manager

COE Executive Director Steve Hampton

- ERAU
  - UAA, UAF, UND, WISU

Embry-Riddle Aeronautical University
University of Alaska at Anchorage
University of Alaska at Fairbanks
University of North Dakota
Wichita State University

LOE $38M

COE for Airworthiness Assurance Phase II - University Members

Arizona State University
Baylor University
Carnegie Mellon University
Embry-Riddle Aeronautical University
Florida International University
George Washington University
Iowa State University
Johns Hopkins University
Lehigh University
Mississippi State University
New Jersey Institute of Technology
North Carolina A&T State University
Northwestern University
Ohio State University
Ohio University
Pennsylvania State University

Purdue University
Rutgers University
Tuskegee University
University of Arizona
University of California at Berkeley
University of California at Los Angeles
University of California at Santa Barbara
University of Dayton
University of Maryland
University of Missouri at Columbia
University of North Dakota
University of Utah
University of Washington
Wayne State University
Wichita State University

COE for Operations Research - Partners and Affiliates (NEXTOR)

Core University Members

University of California-Berkley
Massachusetts Institute of Technology
University of Maryland
Virginia Tech
George Mason University

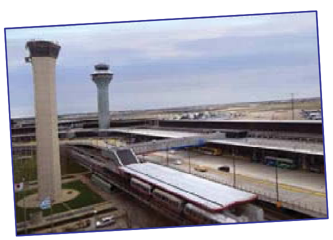
University Partners

Air Force Institute of Technology
Rensselaer
San Jose State University
University of Michigan
University of Minnesota
University of Rochester
University of Southern California
University of Texas at Austin

Industry Affiliates

The Boeing Company	Massachusetts Port Authority
California Department of Transportation	Metron Aviation, Inc.
Draper Laboratory	Northrop Grumman
Federal Express	Sabre
Honeywell	San Francisco International Airport
Leigh Fisher Associates	Seagull Technology
Logistics Management Institute	Southern California Association of Governments
Maryland Aviation Administration	Virginia Department of Transportation
Los Angeles World Airports	

COE for Airport Technology (CEAT)



FAA COE Program Manager

COE Executive Director
David Lange

UI

RPI

University of Illinois
Rensselaer Polytechnic Institute

LOE $41.5M

PUBLIC PARTNERS

O'Hare Modernization Program

City of Chicago

13

Joint Center for Computational Modeling of Aircraft Structures (RITE)

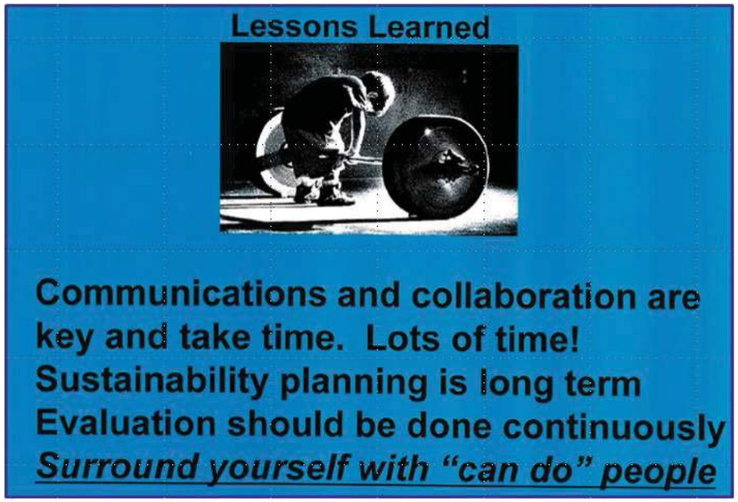
Dean Ellis Dill, Rutgers,
The State University of New Jersey

- Members Designated by Congress: $3M Directed –
  Operational 1993 through 1996

- Technology areas funded through matching grants:
  - Widespread Fatigue-Damage
  - Residual-Life and Residual-Strength Estimations
  - Mechanical and Composite-Patch Repairs
  - Life-Enhancement Methodologies
  - Discrete Source Damage

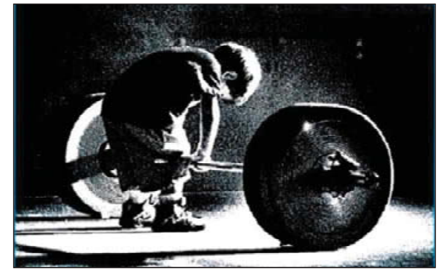
Rutgers University and Georgia Institute of Technology

Q + A



Q + A

Lessons Learned – GAM Grant Recipient



Communications and collaboration are key and take time. Lots of time!
Sustainability planning is long term.
Evaluation should be done continuously.
Surround yourself with "can do" people.

FAA Air Transportation Centers of Excellence

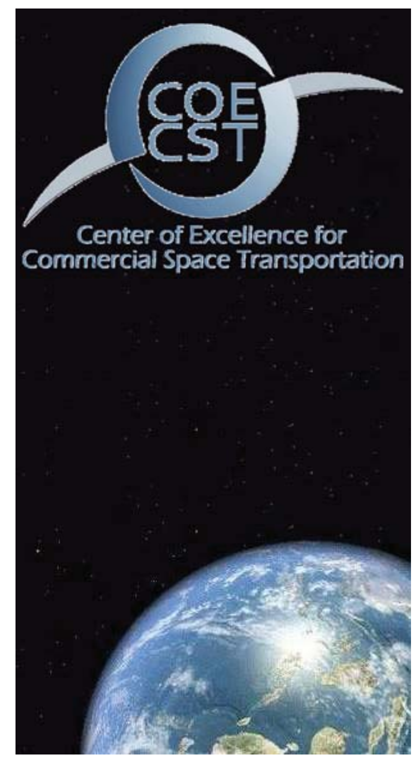
Contact:

Patricia Watts, Ph.D.
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

COE CST Fourth Annual Technical Meeting (ATM4): COE CST Overview & Status

Ken Davidian
COE CST ATM4 in Washington, DC
Wednesday, October 29, 2014



Agenda

- Overview
- Team Members
- Year 4 Organizational Highlights
- Administrivia
- Conclusion

AST Statutory Authority

Title 51 US Code Subtitle V, Ch. 509

- Regulate the commercial space transportation industry, only to the extent necessary, to ensure compliance with international obligations of the United States and to protect the public health and safety, safety of property, and national security and foreign policy interest of the United States
- Encourage, facilitate, and promote commercial space launches and re-entries by the private sector

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

Banner Competition

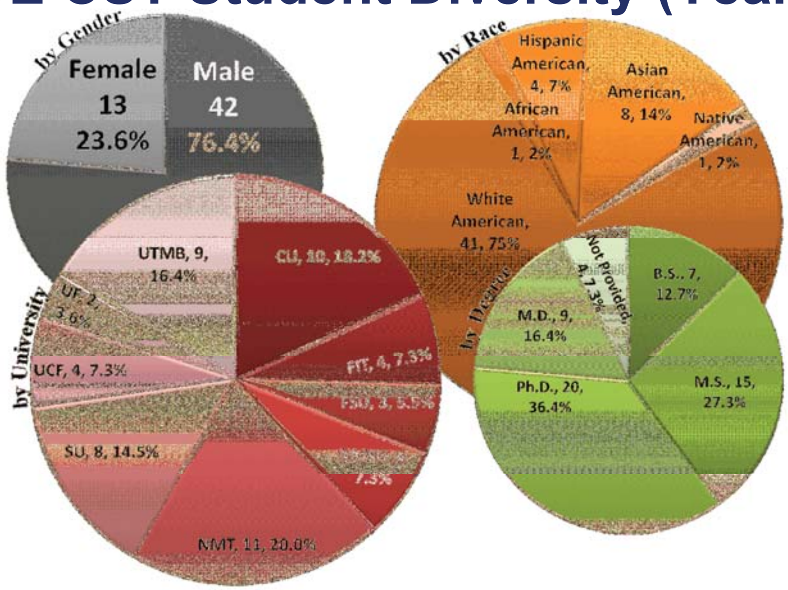
COE CST Fourth Annual Technical Meeting (ATM4)
October 29-30, 2014

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)

COE CST Fourth Annual Technical Meeting (ATM4)
October 29-30, 2014
Center of Excellence for Commercial Space Transportation

COE CST Student Diversity (Year 3)



COE CST Fourth Annual Technical Meeting (ATM4)
October 29-30, 2014
Center of Excellence for Commercial Space Transportation

FAA Center of Excellence for Commercial Space Transportation

COE CST Fourth Annual Technical Meeting (ATM4)
October 29-30, 2014
Center of Excellence for Commercial Space Transportation

COE CST Year 4 Supporters

Locked On Inc.
Paris Surgical Assoc.
Bachner Consultants Inc.
Digital Solutions
Marketing Consultant
Spaceport America Consultants
NM Space Development Foundation

Organizational Highlights

- **Previous Affiliate Members**: McGill University, Baylor, ERAU, NASTAR, Satwest, UN Lincoln
  - Associate Members: DLR, NASA ARC*
  - Potential New Affiliate/Associate Members: ASU, Berkeley, USC, NSI/DTU, UK, …
- **Fourth Annual Administrative Meeting (AAM4)** at FL TECH on April 22-23, 2014
- **Admin Transition from FAA to COE CST** to the Coordinating Committee Lead (FL TECH)

COE CST Fourth Annual Technical Meeting (ATM4)
October 29-30, 2014
Center of Excellence for Commercial Space Transportation

COE CST Year 3 Annual Reports

- Now available on the web at:
  - Exec Summary: bit.ly/COECSTYr3ExecSumm
  - Volume 1: bit.ly/COECSTYr3Vol1
  - Volume 2: bit.ly/COECSTYr3Vol2
  - Volume 3: bit.ly/COECSTYr3Vol3

COE CST Fourth Annual Technical Meeting (ATM4)
October 29-30, 2014
Center of Excellence for Commercial Space Transportation

COE CST Milestones Since ATM3

- April 22-23, AAM4, Melbourne, FL at FL TECH
- May 12-15, UTMB Awards at AsMA Conference

COE CST Fourth Annual Technical Meeting (ATM4)
October 29-30, 2014
Center of Excellence for Commercial Space Transportation

Body of Knowledge for Spaceport Operations

- April 16, 2014
- PI: Dr. Patricia Hynes, NMSU
- Partners: AIAA, ATK, Bachner Consultants, Inc., Ball Aerospace, Cimmaron Software Services, Digital Solutions, Marketing Consultant, National Space Grant Foundation, New Mexico Spaceport Authority, NMSU Space Development Foundation, SATWEST, Space News, Spaceport Sweden, Swedish Institute of Space Physics, Boeing CSSI, Dynetics, Jacobs Technology, Lockheed Martin, PSU Aerospace Engineering, Qinetiq, Space Works Enterprises, Spaceport America Consultants, Spaceworks, The Tauri Group, Webster University Space Programs, XCOR Aerospace


Body of Knowledge for Spaceport Operations

CENTER OF EXCELLENCE · COMMERCIAL SPACE TRANSPORTATION

About this collection

Today's space access systems do not employ standard systems allowing spaceports, ranges, and launch providers to interoperate in the seamless manner needed to stimulate a vibrant commercial space industry. This poses a challenge for the long term development of a commercial space transportation system. The development of a Framework for Spaceport Operations has shown that space launch sites, i.e. spaceports, consider that some of their operational activities, but not all, are similar to those of other spaceports.

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

Framework for Spaceport Operations

The information in this database is organized according to the Framework for Spaceport Operations. The Framework is composed of 10 top-level categories, each with multiple subcategories. The top-level categories are:

1.0 Airfield 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

Related Materials

Additionally, some of the categories have related materials attached to them. These are documents that don't necessarily belong in the Body of Knowledge, but are important for general informational purposes.

Related Materials

Subject Terms

The Body of Knowledge uses subject terms from the NASA Thesaurus, which are authorized for use in indexing and material retrieval by the NASA Scientific and Technical Information (STI) Program. The Library of Congress Subject Headings and Name Authorities were used for entities or concepts not covered in the NASA Thesaurus. Terms from the NASA Thesaurus are noted with (NASA).

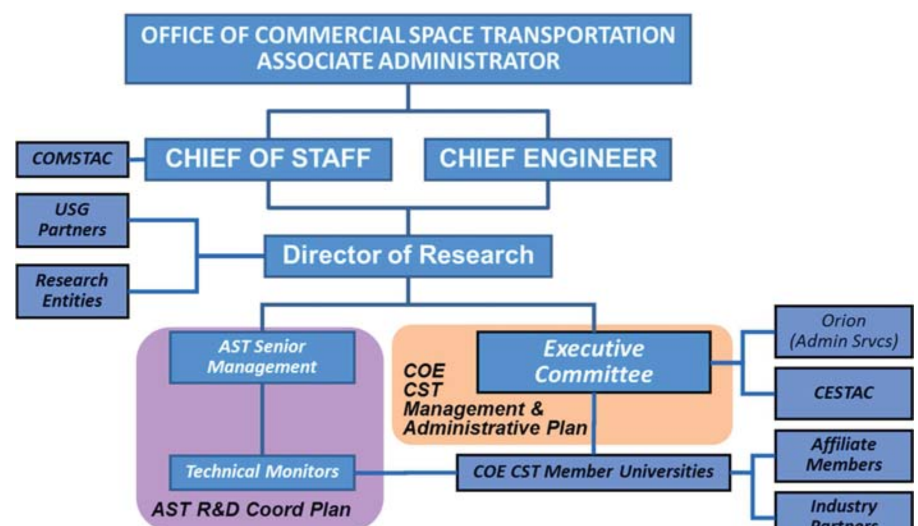
NM STATE UNIVERSITY Library

URL: contentdm.nmsu.edu:2011/cdm/landingpage/collection/NMSGCBOK

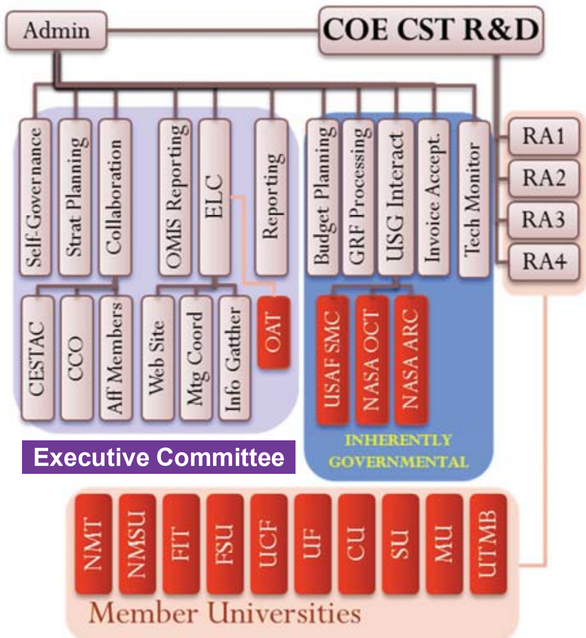
COE CST's Official Journal: New Space

COE CST @ ISPCS

COE CST Org Chart - Year 4



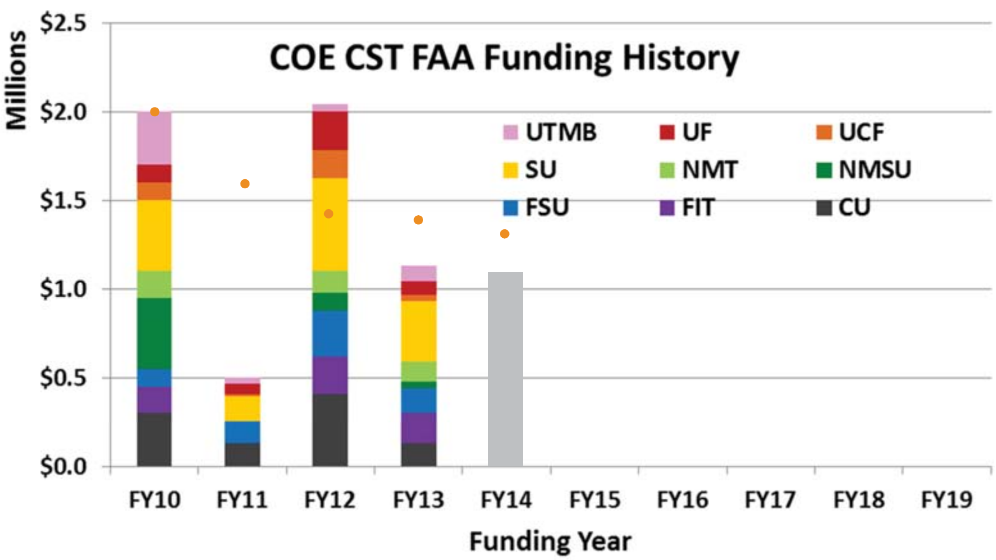
Year 4 COE CST Admin. Functional Diagram (with Orgs)



COE CST Metrics At-A-Glance

	Year 1	Year 2	Year 3	Year 4
# Tasks	25	33	26	~13
# PIs	27	24	29	~13
# Students	31	~29	55	~27
# Reports	0	~9	28	TBD
# Affil/Assoc Members	0/0	1/0	6/1	>6/1
Funding $6.63M (5 Yrs)	$2M (FY10)	$2.4M (FY11-12)	$1.13M (FY13)	$1.1M (FY14)

COE CST Funding Story, FY10-14



Conclusions

- COE CST Sets Standard for FAA COEs
- Strong Core Membership & Growing Affiliate, Associate Membership
- Many Highlights, Research Results, & Peer Recognition

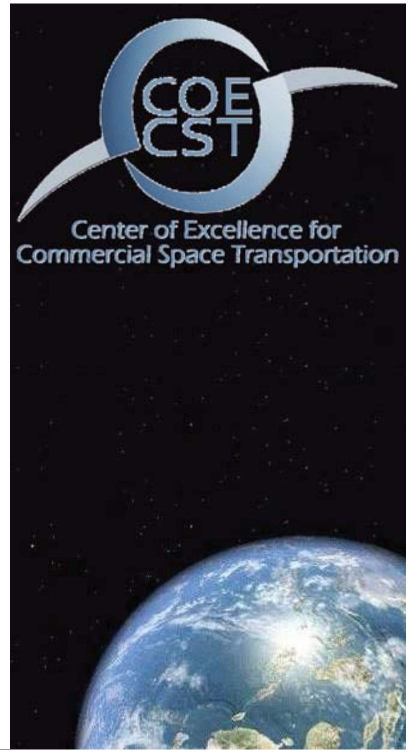
COE CST Fourth Annual Technical Meeting

Advanced ADS-B Prototype for Commercial Space: Status Update and Future Opportunities

Richard S. Stansbury

Brandon Neugebauer
Richard P. Day
Yosvany Alonso
Dominic Tournour

October 29-30, 2014
Washington, DC



Agenda

- Team Members
- Task Description
- SpaceLoft 8 Launch Campaign
- Follow-on work and conclusions

Team Members

- **People**
  - Principal Investigators: Richard S. Stansbury
  - Students: Brandon Neugebauer, Richard P. Day, Yosvany Alonso, and Dominic Tournour
  - FAA: Nick Demidovich, Chuck Greenlow, John Dinofrio, and others.
  - MITRE: Dave Edwards
- **Organizations**
  - Industry and Research Partners:
    - Terminal Velocity Aerospace, LLC.
    - NASA Flight Opportunities Program
      - Up Aerospace
      - Near Space Corporation

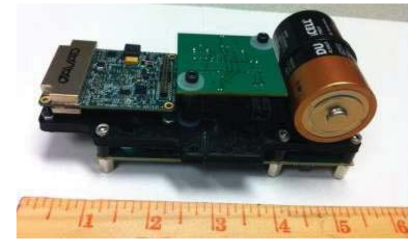
Purpose of Task

- Support of suborbital reusable launch vehicles (sRLVs) for commercial space transportation requires considerations for safe integration into the national airspace system (NAS)
- ADS-B technology is used for surveillance by air traffic control and situational awareness for pilots
- This research presents the potential for adaptation of existing ADS-B technology to support operations for sRLVs operations exceeding current technology limits (primarily altitude, velocity and acceleration)

MITRE UBR-TX

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

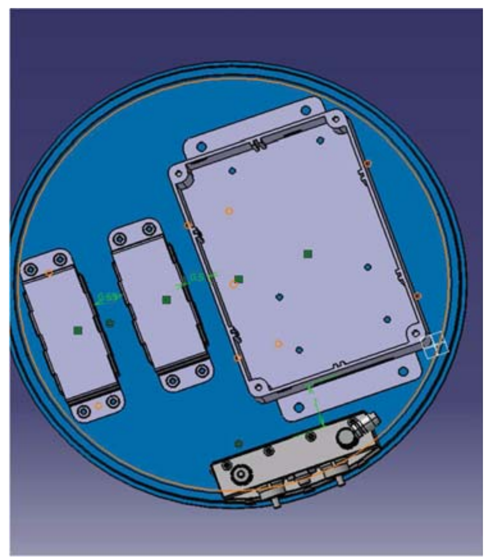
MITRE TECHNOLOGY APPLIED

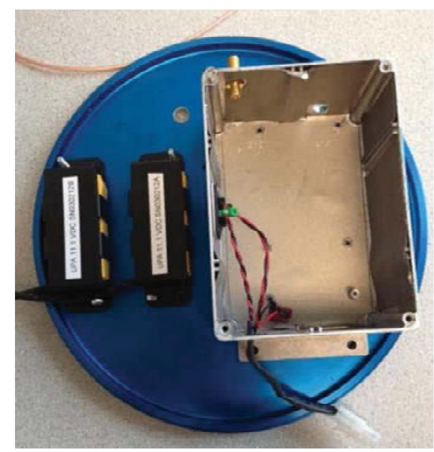


Parameter	Specification
Length	5.75" (14.6 cm)
Width	2.5" (6.35 cm)
Height	2.5" (6.35 cm)
Weight (UBR board, daughter board, GPS, battery, and enclosure)	790 g (27.9 oz)
Weight (cables, antennas, etc.)	85-300g est.
Nominal power Consumption	840mA @ 3VDC
Nominal battery capacity	7.75 Ah

INTEGRATION FOR SPACELOFT XL

PTS-10 Rocket Segment



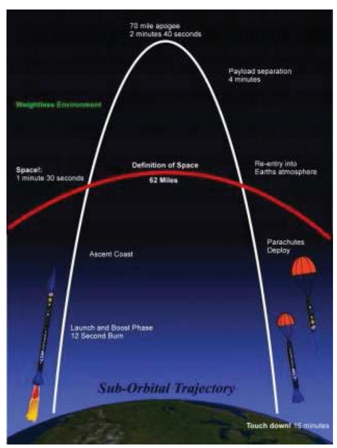


Vehicle Integration

SL-8 FLIGHT DATA AND ANALYSIS

SL-8 Flight Profile

Event	Time (seconds)
Launch	T + 0
Despin initiated	T + 55
Apogee (384,100 ft.)	T + 162
Payload separation	T + 240
Drogue deployment	T + 442
Chute Deployment	T + 452
Touchdown	T + 751



Flight Analysis

Phase of flight	Metric	Result
Full flight	% tracked by ADSB	73.8%
T + 62 (7 seconds post-despin initiation)	% of flight tracked by ADS-B	80.5
	Avg. time between message	1.27 s
	Max. time between message	8.00 s
	Max receivers tracking (FAA/Excelis Ground-based Transceivers GBTs only)	8
	Max receivers tracking (FAA GBTs and portable)	10
	Avg. latitude error	16.145E-05 deg.
	Avg. longitude error	9.170E-05 deg.
	Avg. altitude error (below 101,350 ft.)	54.31 ft.
After T+315 (descent and deceleration to less than 1000 ft./sec)	% of flight tracked by ADS-B	95.9%
	Avg. time between message	1.04 s
	Max. time between message	3.00 s

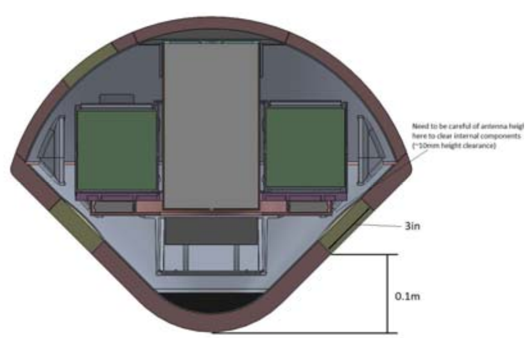
Performance vs. Success Criteria

Criteria	Pass / Fail	Comments
Broadcasts well-formed messages	Pass	ITT GBTs and two portable Garmin GDL 90 successfully parsed data
Vehicle tracking for 90% of flight	Fail	73.8% of full flight, 80.5% post-despin, and 95.9% on descent.
Characterization of data loss	Pass	Primary characterization of data loss was configuration onboard spacecraft and NOT ADS-B unit itself.
Correlated with other data sources	Pass	Utilized truth data from WSMR primary radar. Position/altitude accuracy measured.

FOLLOW-ON WORK AND CONCLUSION

Terminal Velocity Aerospace

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



Proposed Future Work

- Taking Advanced ADS-B to glass
  - Goal: identify gaps in current Advanced ADS-B implementation versus DO-282B standard and implement changes
- Dual antenna configuration
  - Goal: update Advanced ADS-B to meet DO-282B standard for dual antenna while ensuring sufficient transmit power to meet performance requirements
- Commercial Space Message Format for ADS-B
  - Goal: better express the state of a commercial spacecraft and bypass current limits for altitude and climb rate
- ADS-B for tracking of Cubesat
  - Goal: provide real-time low-cost tracking of LEO spacecraft, and demonstrate utilizing a free flying cubesat
  - Previous proposal through CASIS did not make it through first phase

Schedule

- Development of Advanced ADS-B Units
  - Preparing for future flights
    - NSC HASS, Q4 2014
    - SpaceShip2, TBA
    - Up Aerospace, SL10, TBD
  - Completing remaining ADS-B Units, 12/15/2014

- RED-4U
  - System integration, Q3 2014
  - System testing, Q4 2014

Questions?

Image courtesy of UpAerospace Inc.

Embry-Riddle Aeronautical University
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Chuck Greenlow, chuck.ctr.greenlow@faa.gov
John DiNofrio, john.dinofrio@faa.gov

MITRE
Dave Edwards, davee@mitre.org

Federal Aviation Administration

Unified 4D Trajectory Approach for Integrated Traffic Management

Tom Colvin & Juan Alonso
Stanford University

October 30 2014

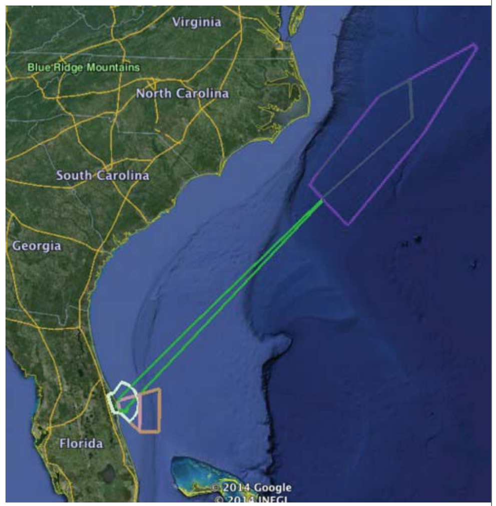
Outline

- What's the problem we want to solve?
- Compact Envelopes to the rescue
- Some Examples
- Quantify how great compact envelopes are
- Concluding thoughts and papers

What's The Problem?

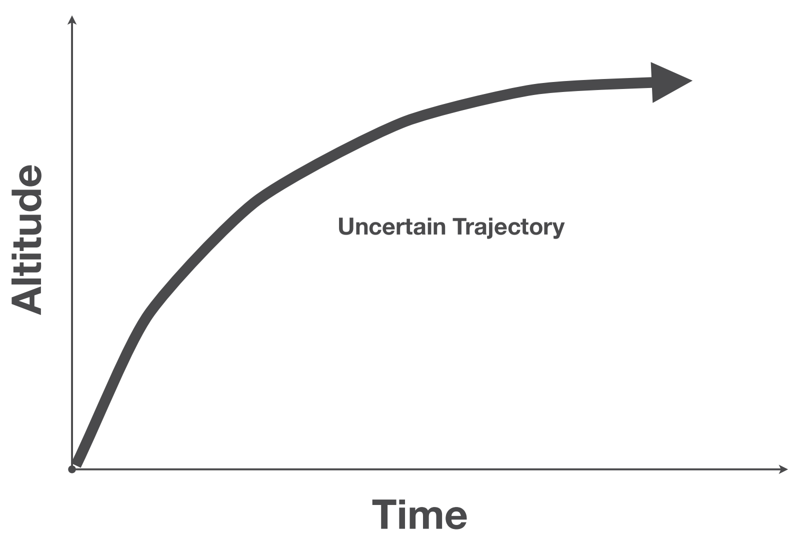
- Need launch architectures to ensure NAS users are safe.
- Current method uses SUAs, NOTAMs, etc and and is too big! Not altitude contoured, uses pre-existing shapes, conservative assumptions, range safety buffers, not dynamic.
- What level of safety?
- Unfair.
- Commercial space traffic in rising volume and launching from new ranges requires new ATM architectures.

Falcon9 March 1st 2013

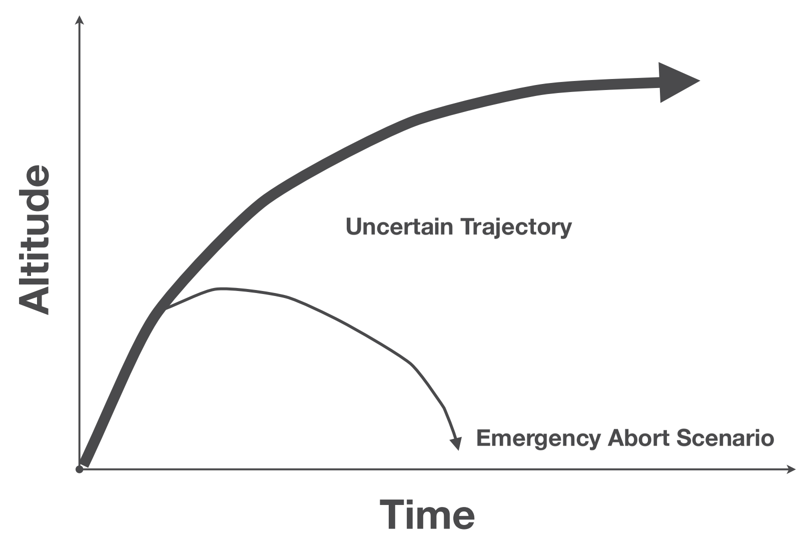


Compact Envelope Concept

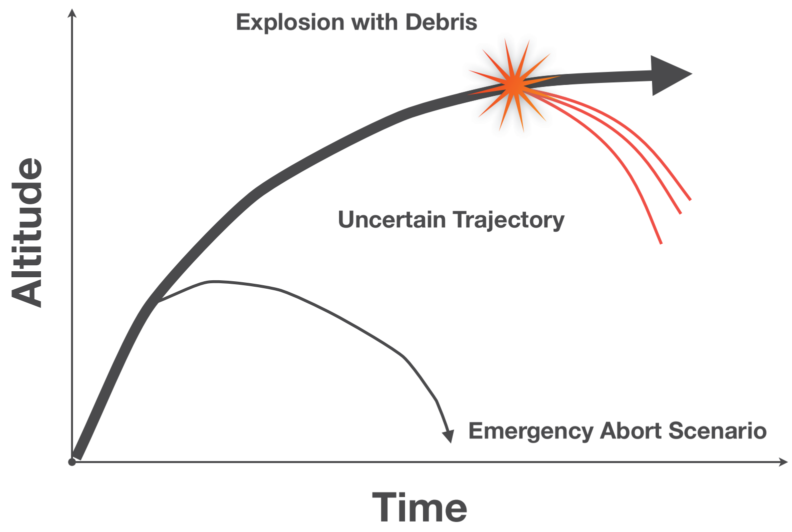
Compact Envelope Concept



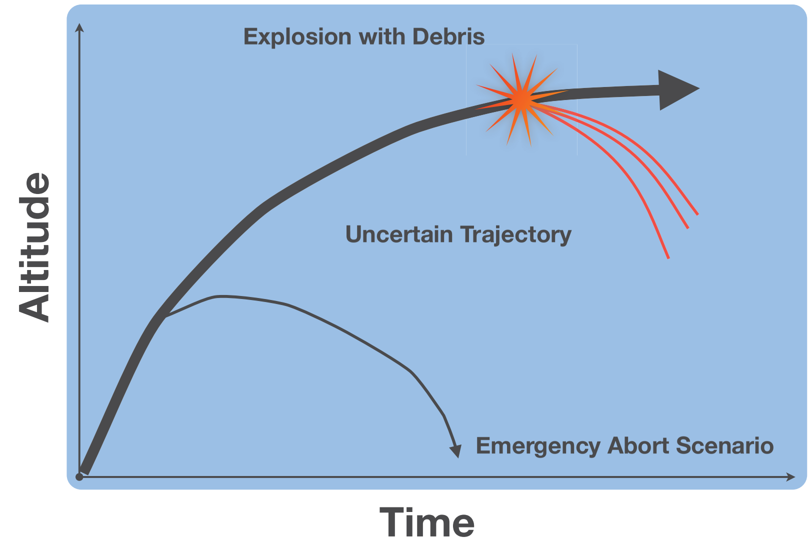
Compact Envelope Concept



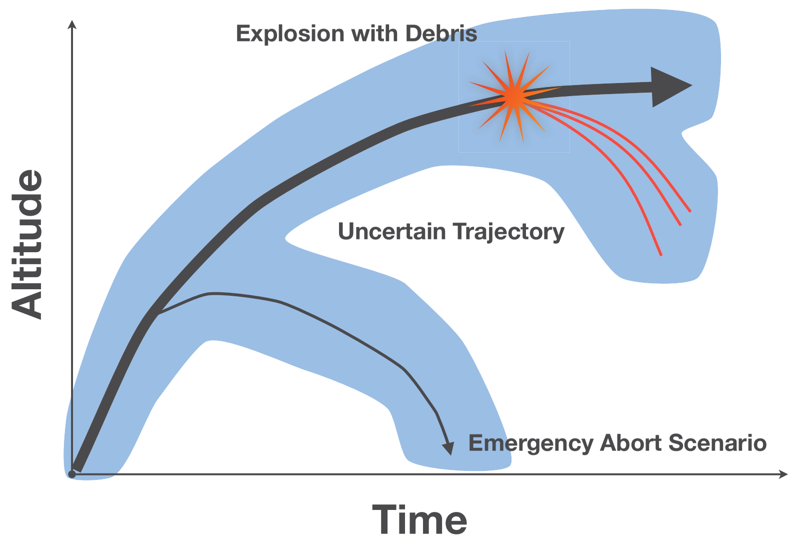
Compact Envelope Concept



Compact Envelope Concept

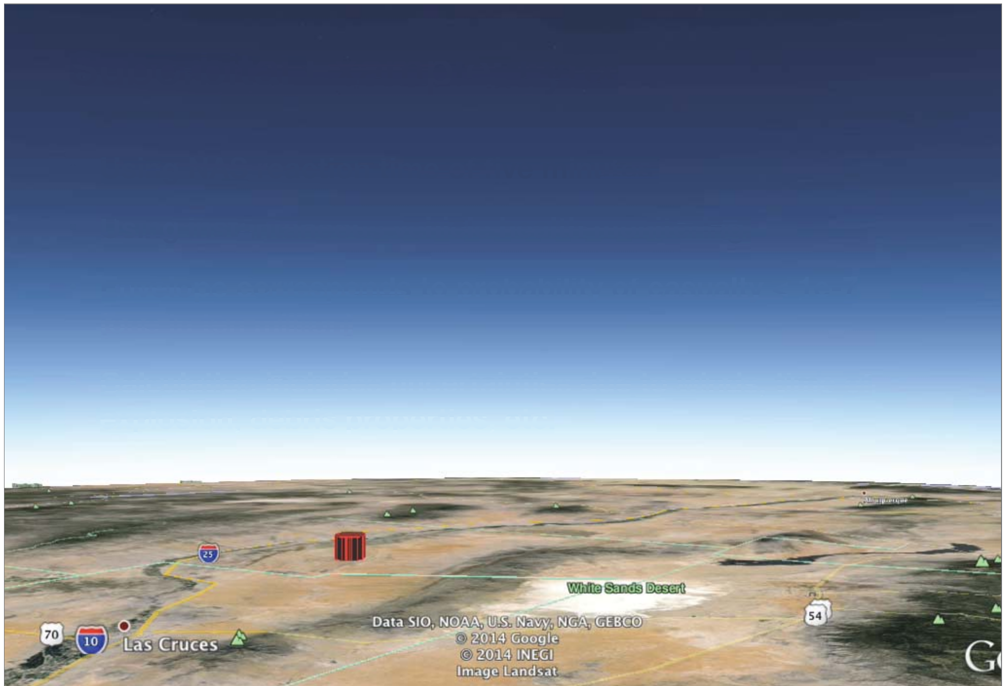


Compact Envelope Concept

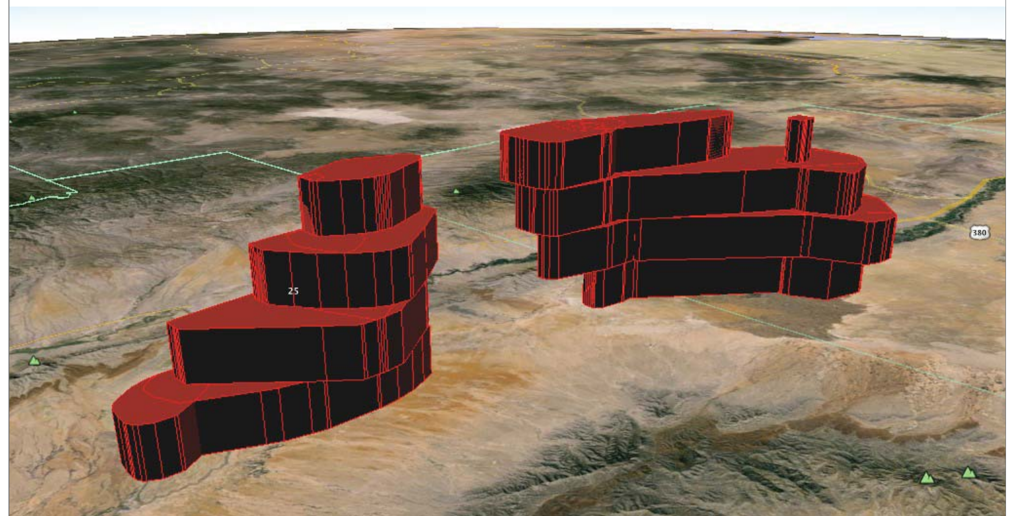


Suborbital Example: Lynx

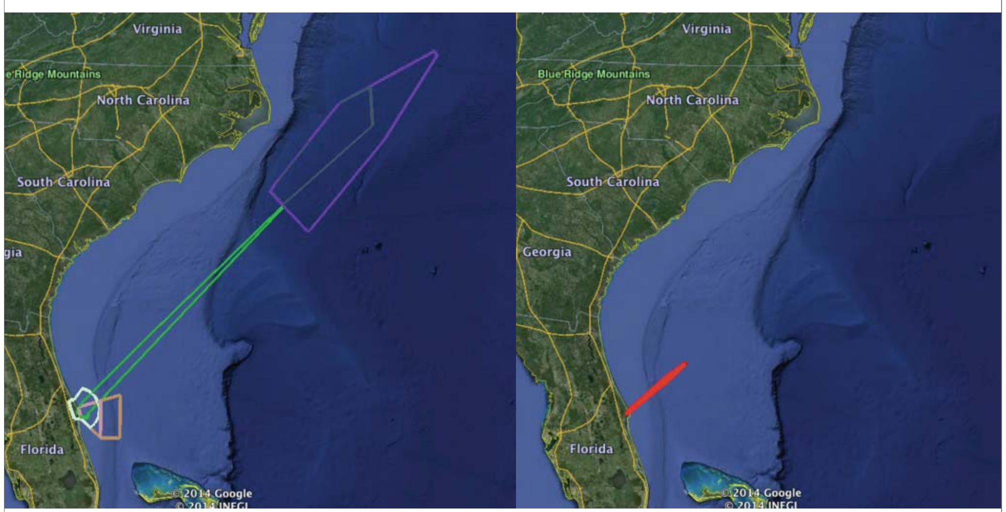
- Using NAS reaction time of five minutes.
- Using instantaneous vehicle health monitoring.
- Envelope corresponds to probability of casualty < 1e-7 (one in ten million)
- Calculation includes uncertainties due to winds, time of explosion, debris properties, etc.



Suborbital Example: Lynx (Another View)



Orbital Example: Falcon9



Orbital Example: Falcon9

	Actual SUAs	Compact Envelopes	Units
Flights Rerouted			#
Added Flight Time			Min
Added Flight Distance			N.M.
Added Fuel Burn			lbs

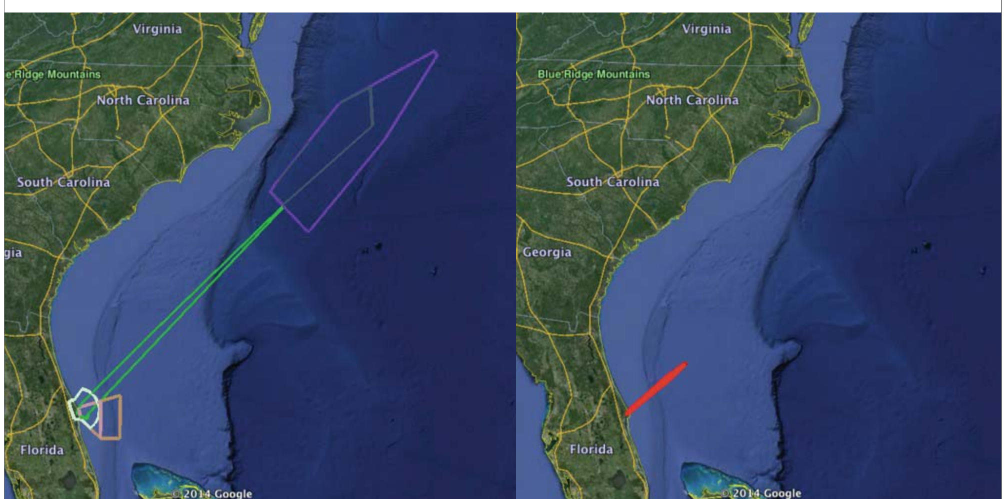
Orbital Example: Falcon9

	Actual SUAs	Compact Envelopes	Units
Flights Rerouted	45		#
Added Flight Time	537		Min
Added Flight Distance	2110.773		N.M.
Added Fuel Burn	22641.262		lbs

Orbital Example: Falcon9

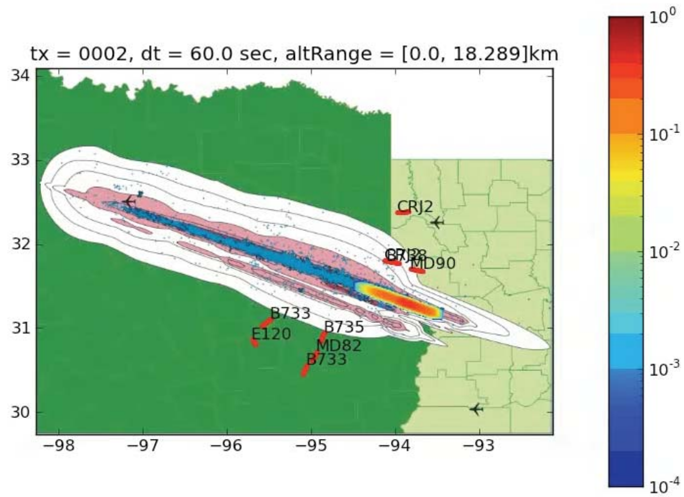
	Actual SUAs	Compact Envelopes	Units
Flights Rerouted	45	0	#
Added Flight Time	537	0	Min
Added Flight Distance	2110.773	0	N.M.
Added Fuel Burn	22641.262	0	lbs

Orbital Example: Falcon9



Reentry Example: Columbia

Reentry Example: Columbia



Conclusion

- I am developing a novel method, called Compact Envelopes, for keeping launch and reentry traffic safely separated from traditional air traffic.
- I have created a software environment to assess risk to aircraft from debris hazards and to create Compact Envelopes.
- Compact Envelopes incorporate probabilistic risks to generate a no-fly zone boundary that is contoured in space, dynamic in time, and quantifiably safe. Leverages NextGen!
- Preliminary validation against Columbia disaster case.
- Paper and talk at SciTech 2015 (January!).
- NAS-wide simulation in close collaboration with FAA and NASA.

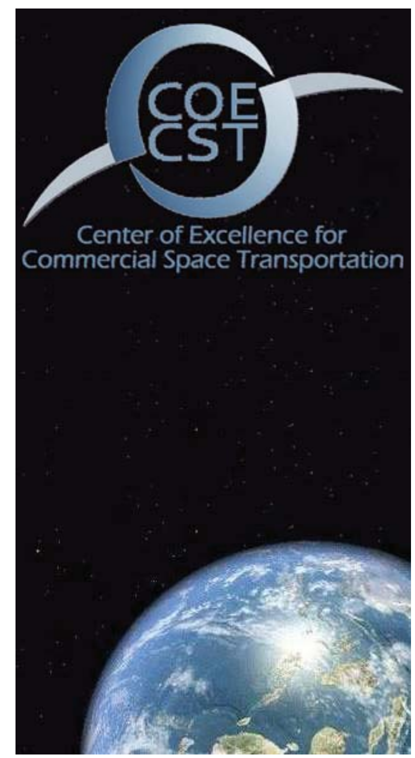
Thanks!

COE CST Fourth Annual Technical Meeting:

Space Environment MMOD Modeling and Prediction

Alan Li and Sigrid Close

October 29-30, 2014
Washington, DC



Overview

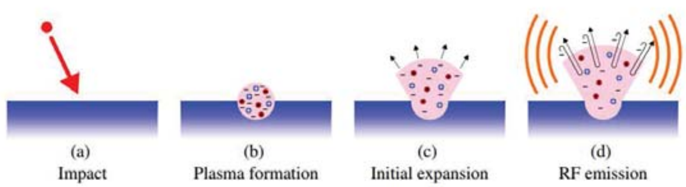
- Team Members
- Task Description
- Goals
- Results
- Conclusions and Future Work

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

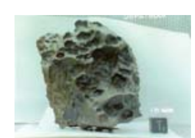
- **Spacecraft are routinely impacted by space debris and natural impactors**
  - Mechanical damage: “well-known”, larger (> 120 microns), rare
  - Electrical damage: “unknown”, smaller/fast, more numerous



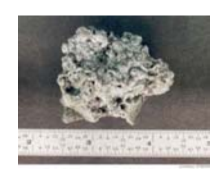
- **Goal: Characterize impactor population and provide predictive threat assessment**

Impactors

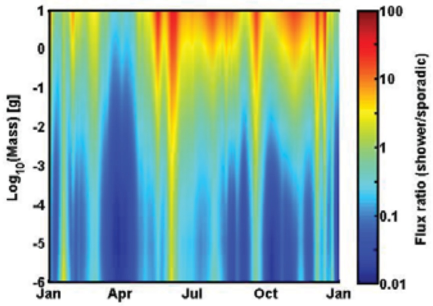
- **Meteoroids**
  - **Speeds**
    - 11 to 72.8 km/s (interplanetary)
    - 30-60 km/s (average)
  - **Densities**
    - ≤1 g/cm^3 (icy) or > 1 g/cm^3 (rocky/stony)
  - **Sizes**
    - < 0.3 m (meteoroid)
    - < 62 µm (dust)

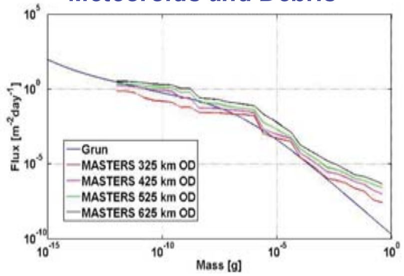


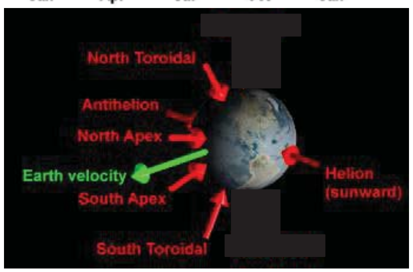
- **Space Debris**
  - **Speeds in LEO**
    - < 12 km/s
    - 7-10 km/s (average)
  - **Densities**
    - > 2 g/cm^3
  - **Sizes**
    - < 10 cm (small)

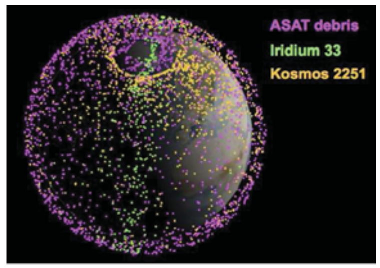


Flux



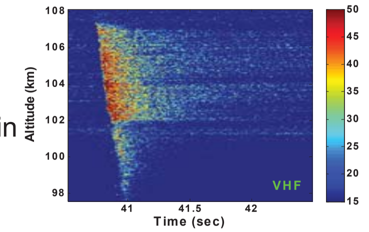






Methodology: Meteoroids

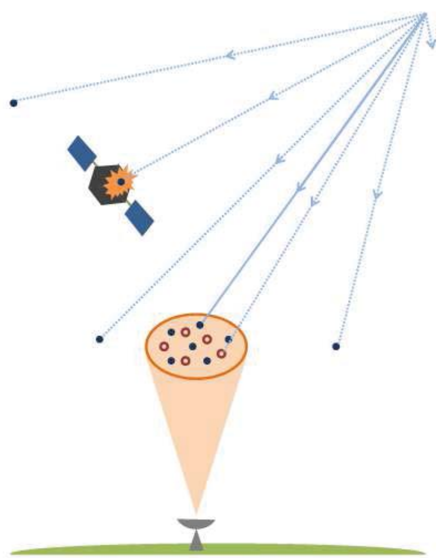
- **Atmospheric Plasma**
  - *Data*: ground-based radar
  - *Models*: Particle-In-Cell (PIC) for plasma development, Finite Difference Time Domain (FDTD) for EM interaction with plasma
  - *Deliverables*: energy flux, mass, bulk density, orbit prediction



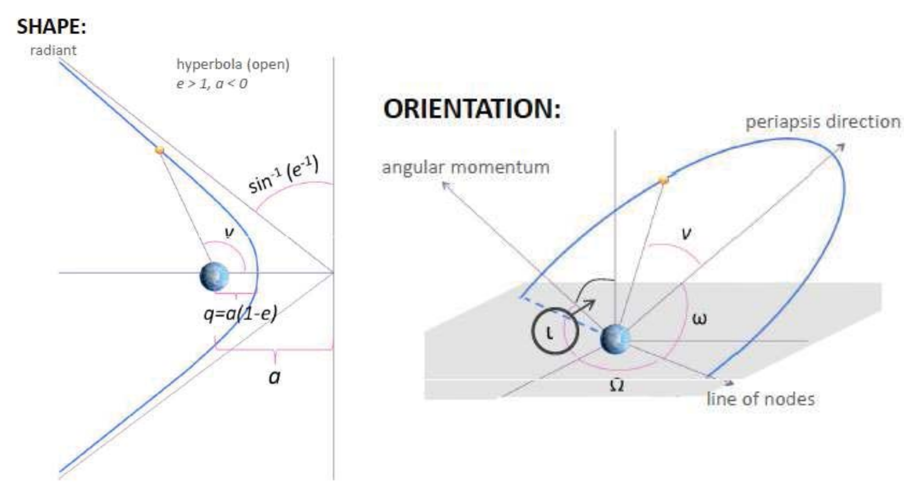
- **Impact Plasma**
  - *Data*: ground-based accelerators
  - *Models*: Computational Fluid Dynamics (CFD) for initial conditions, PIC for plasma development and RF emission
  - *Deliverables*: plasma composition, temperature, RF spectra

Atmospheric Data: Meteors

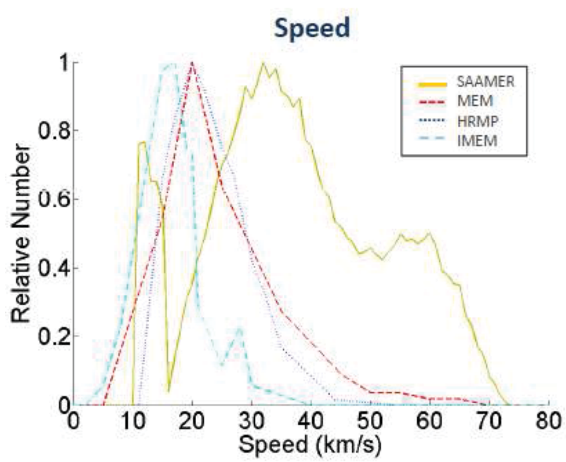
- **Radars**
  - ALTAIR
  - Arecibo Observatory
  - MIT Millstone
  - MU

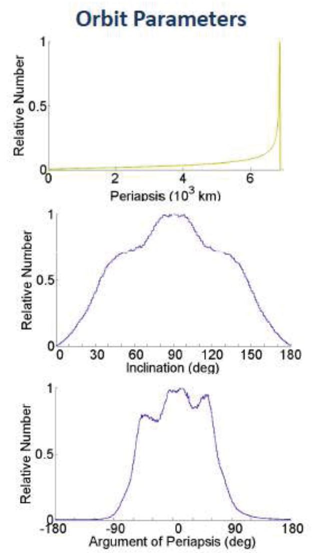


Orbit Determination



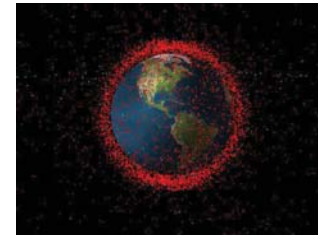
Meteoroids at LEO

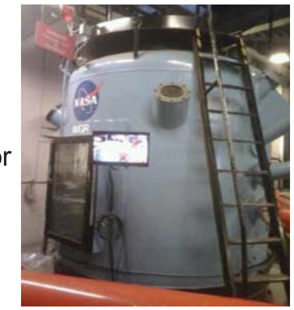




Methodology: Debris

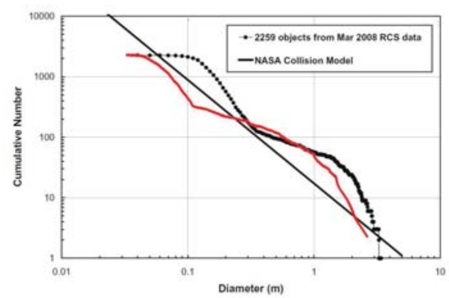
- **Remote Sensing**
  - *Data*: ground-based radar
  - Models: ORDEM for environment, LEGEND and MASTERS for collision and propagation
- **In Situ**
  - *Data*: CubeSats
- **Impact Experiments**
  - *Data*: future light-gas gun tests
  - *Models*: Computational Fluid Dynamics (CFD) for initial conditions, PIC for plasma development and RF emission

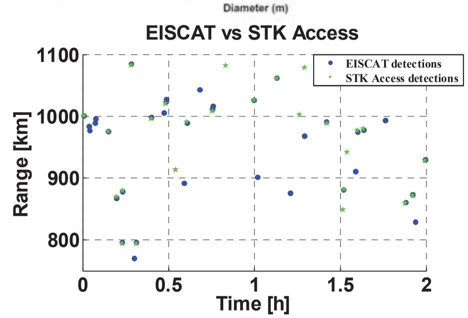




Debris

- **Characterization of debris field during impact**
- **EISCAT Radar**
- **Minimum eccentricity solution gives inclination bands**
- **Cumulative number of debris detected of smaller size than reported by NASA**
- **Correlation with Spacetrack to see untracked debris**
  - 42.4% confirmed detections from ASAT test

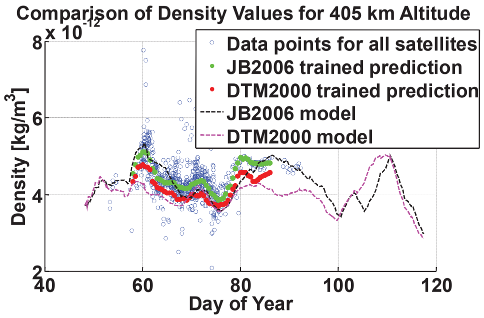


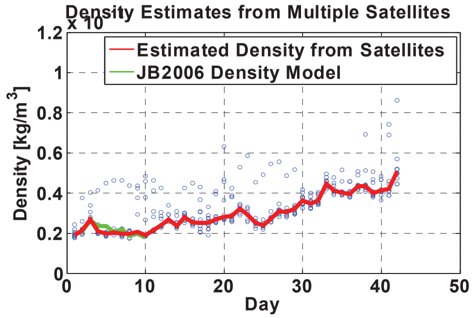


In Situ Data and Models

- **Advent of Cubesats**
  - **Many Cubesats in orbit, now starting in constellations**
  - **Known mass & area**
  - **Low Earth Orbit**
  - **Commercial Space Flight likely to remain in this region**
- **Drag in LEO is the predominant force other than gravity**
- **Models:**
  - **Jacchia-Bowman (JB)**
  - **Drag Temperature Model (DTM)**
  - **High Accuracy Satellite Drag Model (HASDM)**
- **Issues:**
  - **Most models have error of 10%-20% depending on solar conditions**
  - **Specialized drag satellites required**

Neutral Density Estimation





- Known minimum ballistic coefficient
- Likelihood of satellite frontal area given ADACS and decay measurements
- Calculate most likely neutral density observed with confidence intervals

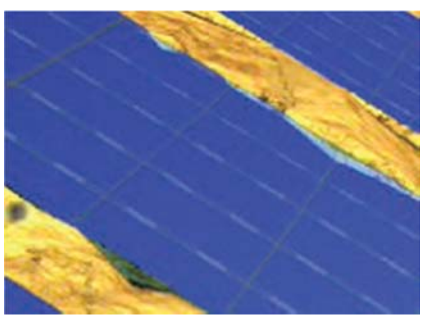
Conclusions and Future Work

- **Meteoroids**
  - Bulk density determination
  - FDTD scattering
  - Effect of charging on electrical failure mechanism
- **Debris**
  - Filtering methods for larger constellation of satellites
  - Propagation of debris using near real time density data

Initial Threat Assessment Model

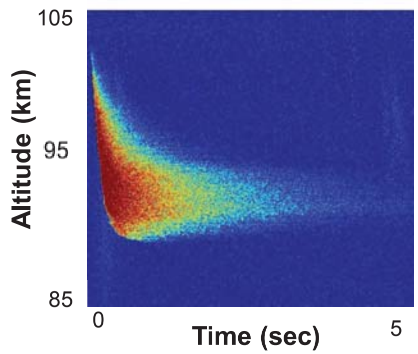
Thank You!

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

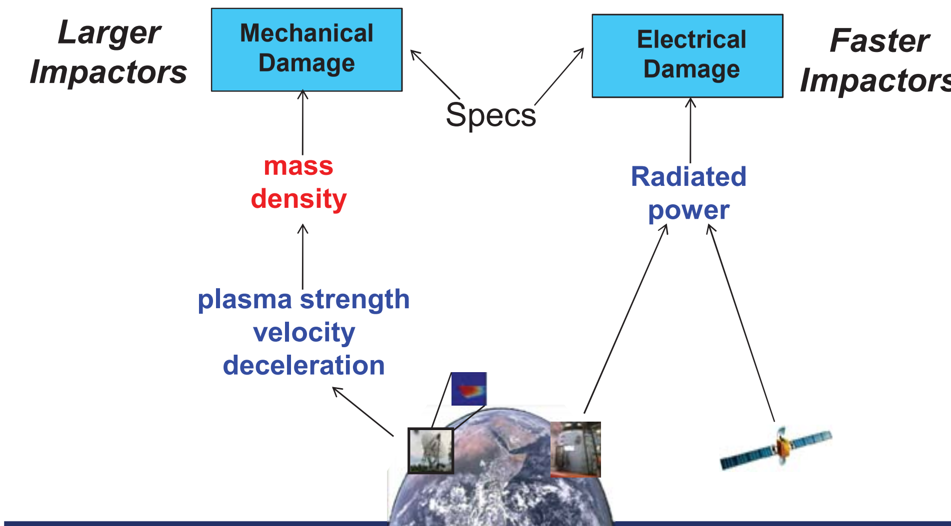


Backup

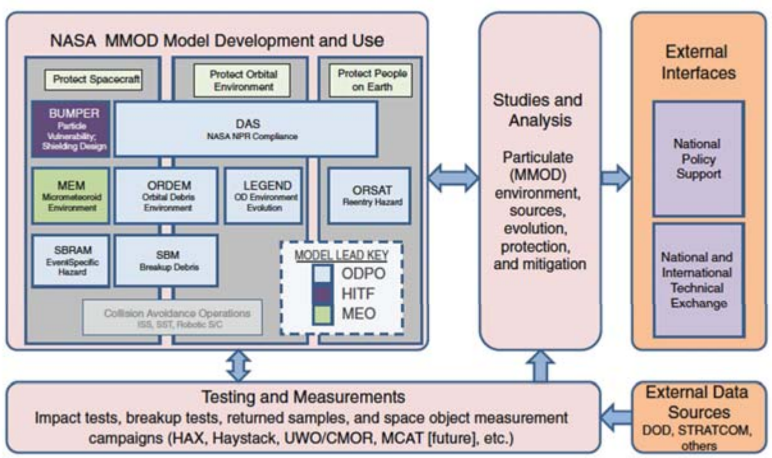
ALTAIR Radar Data



Mechanical and Electrical Damage



NASA Approach



Results or Schedule/Milestones

- 1-2 slides

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

Next Steps

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

Contact Information

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

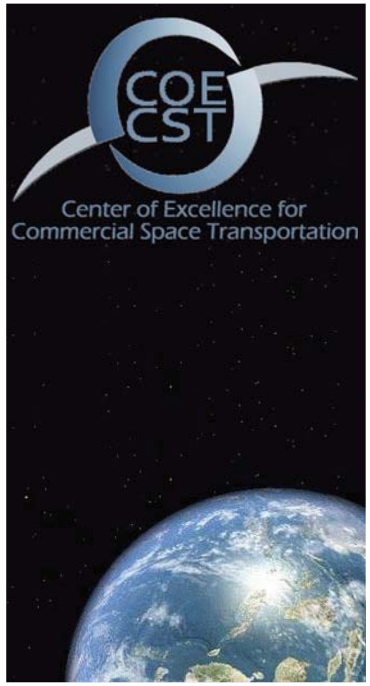
COE CST Fourth Annual Technical Meeting:

Mitigating threats through space environment modeling/prediction

PI: Tim Fuller-Rowell
Student: Catalin Negrea

University of Colorado Boulder

October 29-30, 2014
Washington, DC



Overview

University of Colorado Boulder

- Team Members
- Motivation
- Task Description
- Research Methodology
- Results
- Conclusions and Future Work
- Contact Information

Team Members

University of Colorado Boulder
CIRES

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

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

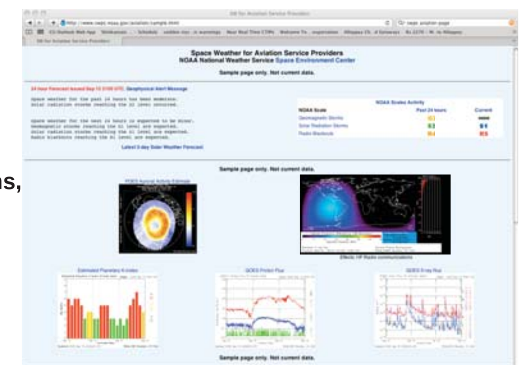
Mihail Codrescu, **Rodney Viereck, Mark Iredell**
NOAA Space Weather Prediction Center, Boulder, CO
and Environmental Modeling Center, Camp Springs, MD

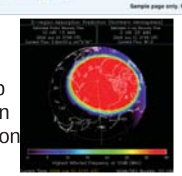
Jeffrey Forbes
Aerospace Engineering Sciences, University of Colorado, Boulder

Current: Aviation Space Weather Support

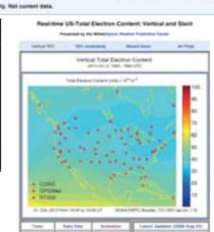
: conditions above ~80 km from NOAA Space Weather Prediction Center impacting communications, navigation, and radiation hazard

- Solar flare prediction: D-region absorption, HF radio blackout
- Solar proton events: polar cap absorption, radiation hazard
- Coronal mass ejections: geomagnetic activity forecast, ionospheric disturbances
- Empirical neutral density model for orbit prediction (Jacchia-Bowman 2008)





Polar cap absorption and radiation hazard



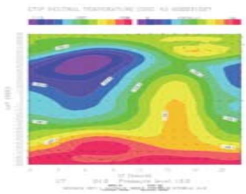
US-TEC for GPS positioning correction

Current:
Aviation Weather Support

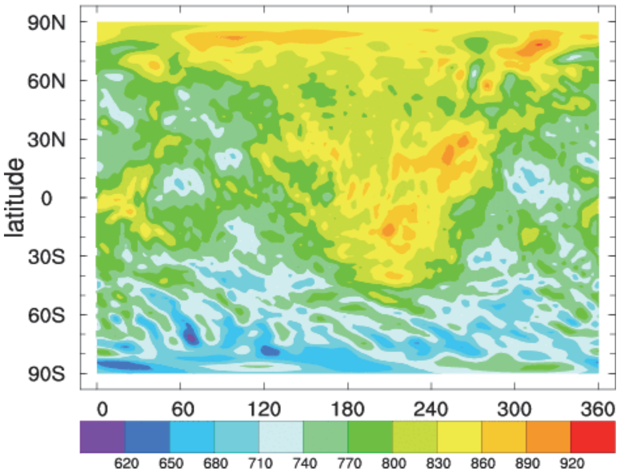
: conditions below 50 km from National Weather Service Global Forecast System (GFS) model and Gridpoint Statistical Interpolation (GSI) data assimilation system

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

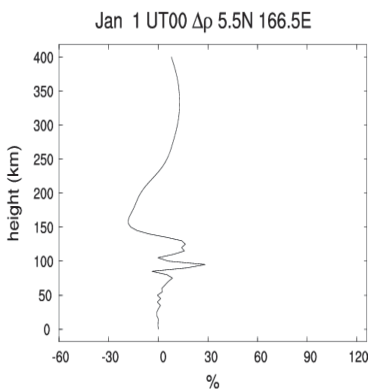
Is this reality in the upper atmosphere?

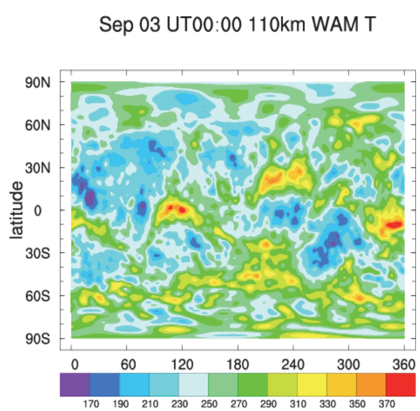


....or is this reality?



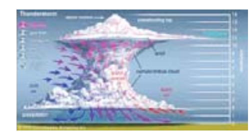
Structure and variability between 80 and 120 km altitude

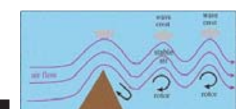




Many Lower Atmosphere Sources of Waves

- Tropical convection
- Hurricanes, tornados, thunderstorms
- Wind shear, frontal systems
- Large-scale ocean swell
- Orographic effects such as airflow over mountains
- Jet stream, polar stratospheric vortex
- Equatorial Kelvin waves
- Ozone and water vapor absorption of solar radiation
- etc., etc., ……………………………





Task Description

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 and space weather conditions (winds, wind shear, temperature, variability and turbulence, storms, lightning, etc.),

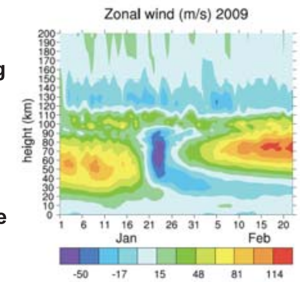
3. Plasma density, D-region absorption, total electron content, ionospheric structure and irregularities, and radiation conditions, for communications, navigation, and safety in flight

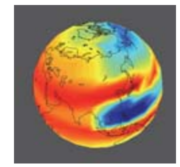
Objectives: *Fill the gap between terrestrial and space weather forecasts and develop a "weather" prediction model extending from Earth's surface to the top of the atmosphere*

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

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



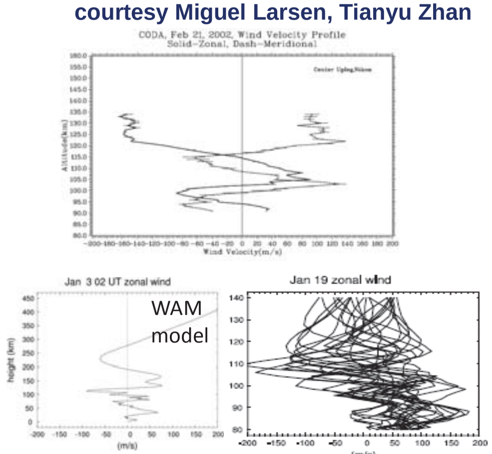


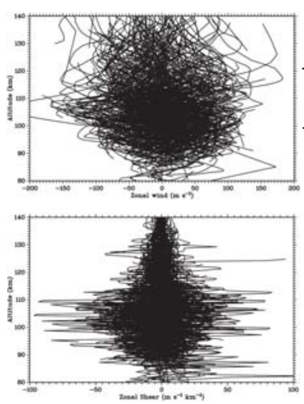
Coupled to a global ionosphere, plasmasphere, electrodynamics module (GIP) for plasma parameters

Chemical trails show steep horizontal wind shear

courtesy Miguel Larsen, Tianyu Zhan

Four decades of wind measurements in lower thermosphere Larsen, 2002



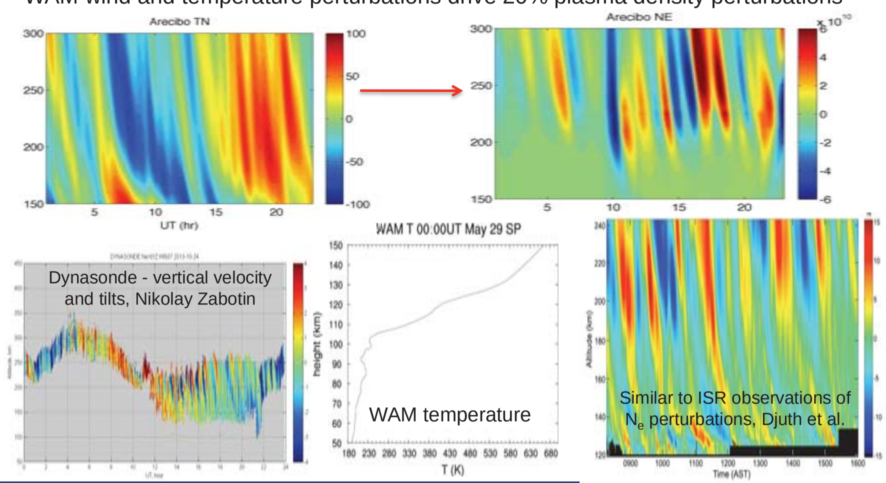


Typical peak zonal wind +/- 100 m/s

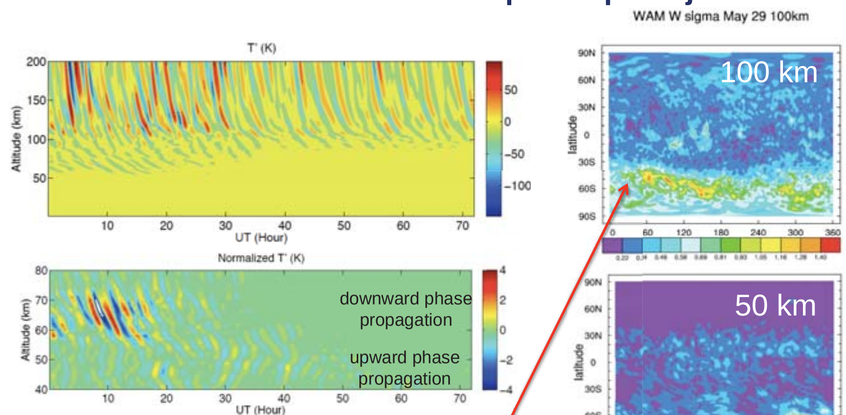
Vertical wind shear +/- 50 m/s per km

Use WAM winds, composition, density to drive plasma density
- agrees well with Arecibo ISR observations by Djuth et al. -

WAM wind and temperature perturbations drive 20% plasma density perturbations



Tracing the origin of one of the many source of waves – unbalance flow of stratospheric polar jets –



Instabilities in strong polar stratospheric jets in winter high latitudes at 50 km growing in amplitude into the lower thermosphere (~100km)

Opportunity

- To define the weather and space weather products tailored to suborbital flights and commercial space transportation needs
- Integrate 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, wind shears, deviations from average, and vehicle drag
- Ionospheric space weather forecast for plasma density and ionospheric structure and irregularity conditions
- Radiation hazard (e.g., NAIRAS potential new start)

Summary, Conclusions, and Next Steps:

- WAM and plasma model 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 ~2016
- WAM predicts strong neutral wind and density shear at sub-orbital apogee and re-entry region 80-120 km
- WAM spectrum of variability agrees with observations of ISR N_e, Fe LIDAR, and winds from rocket trails and Fabry-Perot

Next steps:

- **Continue to validate** WAM and ionospheric model and determine what is it about the environmental conditions that impacts CST
- Establish full **two-way coupling of WAM to the ionosphere** 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, wind shear, and ionosphere structure
- Explore **assimilation of ionospheric data**
- Whole atmosphere/ionosphere data assimilation at high resolution

Contact Information

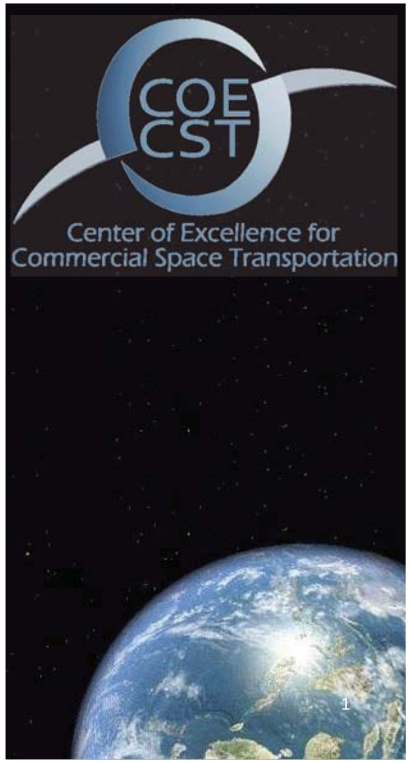
- **Dr. Tim Fuller-Rowell,** Physicist, Cooperative Institute for Research in Environmental Sciences, University of Colorado/Space Weather Prediction Center, Tim.Fuller-Rowell@noaa.gov
- **Dr. Tomoko Matsuo**, Physicist, Cooperative Institute for Research in Environmental Sciences, University of Colorado/Space 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 Fourth Annual Technical Meeting

Task 187: Space Situational Awareness

Scheeres / Park
University of Colorado

October 29-30, 2014
Washington, DC



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Agenda

- Team Members
- Task Description
- Research Methodology
- Research Results
- Next Steps
- Conclusions and Future Work

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 (current support)
Related Research from Fellowship Students
•Aaron Rosengren, CU Graduate Student, NSF Fellow (graduated March 2014)
•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
•Orbital Sciences Corporation

Task Description

- ***Space Situational Awareness***

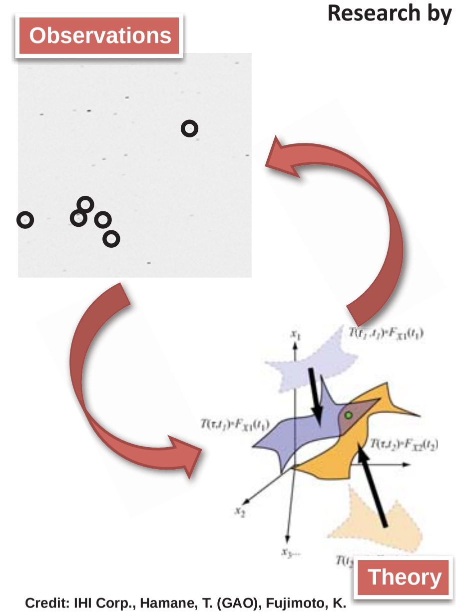
  SSA = Cognizance of Resident Space Objects (RSO) and activities in orbital regions of interest, both now and in the short and long-range future.
- **Objectives**: Improve SSA abilities in regions of interest to the FAA for space-based activities.
- **Current regions of focus**: LEO-*down* and GEO-*up*
- **Goals are to improve**: uncertainty modeling and propagation, precision long-term debris orbit and attitude propagation, non-gravitational model prediction and estimation, orbit estimation techniques.

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 26 papers at 14 international conferences
  - Published 7 papers in peer-reviewed journals
  - Submitted additional 4 papers to journals

Association of Optical Observations

Research by Kohei Fujimoto

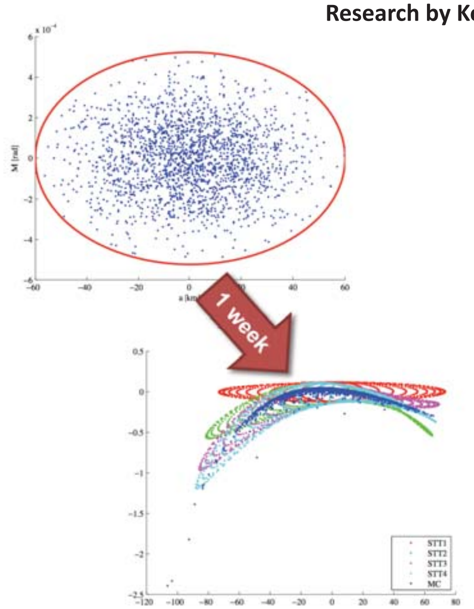


Credit: IHI Corp., Hamane, T. (GAO), Fujimoto, K.

- 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 published in Journal ASR

Analytic Propagation of Uncertainty

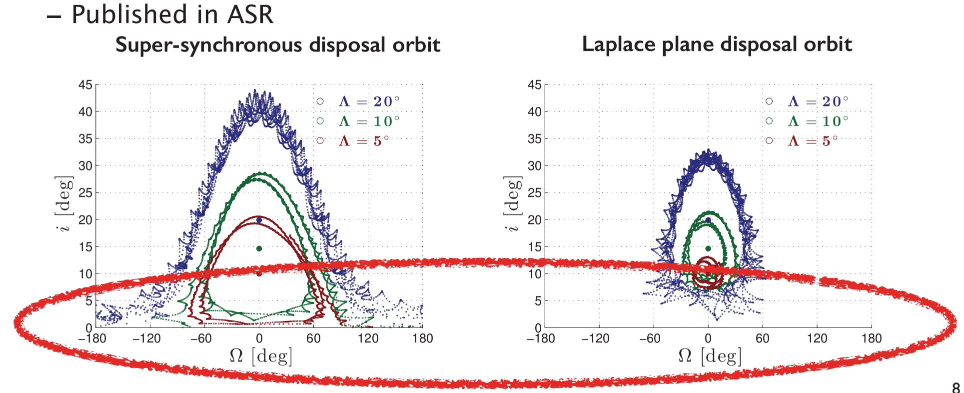
Research by Kohei Fujimoto



- Rapid non-linear uncertainty propagation
  - Special soln. to the Fokker-Planck eqn. for deterministic systems
  - State transition tensor description of the solution flow
- Added effects due to atm. drag
  - Classical results (King-Hele) applied to a modern problem
- Developed new approach to conjunction analysis
  - Mixes the use of analytical theories and GMMs
  - Currently submitted to JGCD for publication

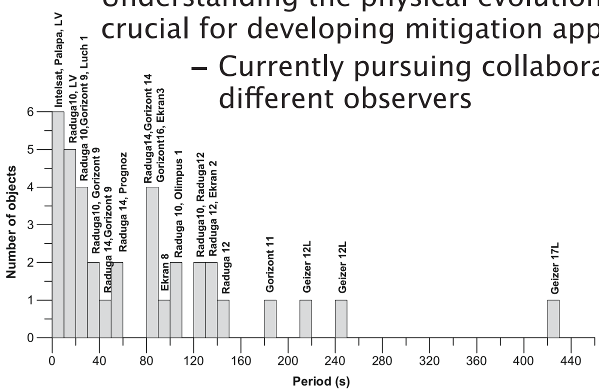
Long-Term GEO Disposal Orbits

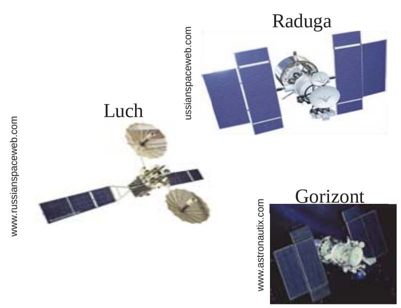
- Research by Aaron Rosengren:
  - Current GEO "disposal" orbits are boosted to higher altitudes, but stay in the same plane. Debris shed from these defunct satellites can – and will – cross into the GEO belt
  - Transferring satellites into the Laplace Plane for disposal will minimize future risk of orbit debris at GEO, maintaining this natural resource for future generations
  - Published in ASR



Evolution of Defunct Satellites

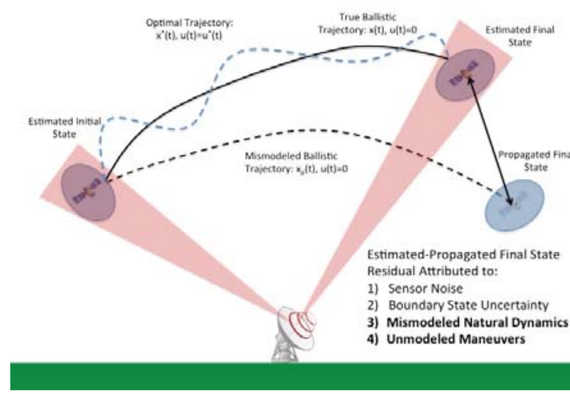
- Research by Antonella Albuja:
  - Observations of defunct GEO satellites shows that their rotation periods change over time, and that many of them rotate rapidly
  - Such evolutionary changes can occur due to environmental perturbations — especially due to solar radiation pressure torques
  - Understanding the physical evolution of defunct satellites is crucial for developing mitigation approaches
    - Currently pursuing collaborations with several different observers

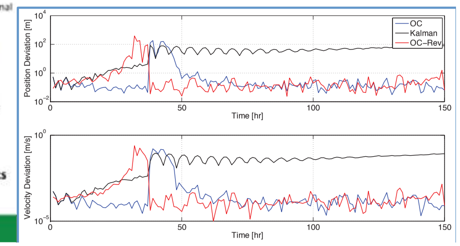




Orbit Debris Model Estimation

- Research by Daniel Lubey:
  - Space debris orbit estimation is limited by non-gravitational effects
  - These are unique for each body, and must be modeled and estimated accurately for generating precise long-term predictions
  - Current research is leveraging previous AFOSR-sponsored research on optimal control to develop automatic methods for estimating non-gravitational models based on tracking data



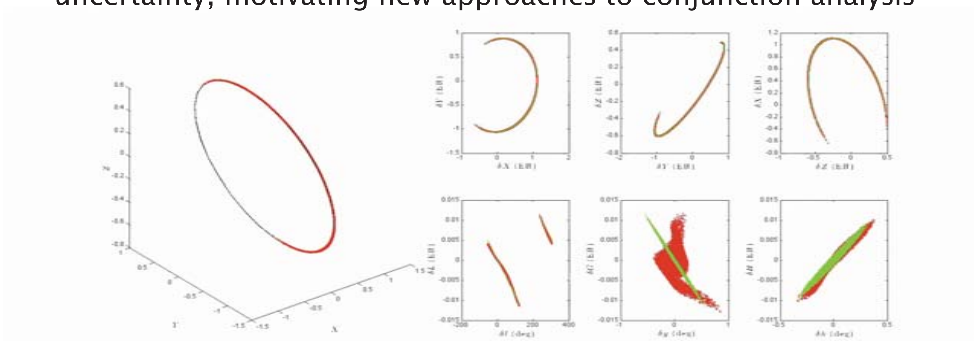


Necessary Accuracy for Uncertainty

- Research by In-Kwan Park: Focus on a fundamental question –

"How much precision is needed in describing the dynamical motion of a spacecraft to ensure an accurate determination of propagated orbit uncertainty?"

- Answer: Secular dynamics approximations can fully capture the first few moments of a statistical PDF distribution
- Implications: Computationally fast theories can capture debris uncertainty, motivating new approaches to conjunction analysis



Next Steps

- Combe recent research by Fujimoto and Park to explore methods for rapidly and accurately propagating orbit uncertainty distributions and performing conjunction analyses
  - Will use secular equations to propagate orbit uncertainty distributions
  - Will use State Transition Tensors and GMMs to analytically compute conjunction probabilities
  - Can achieve orders of magnitude increase in computational efficiency

Conclusions and Future Work

- Spent allocated funds through May 2014
  - New funds for research support through May 2015 just allocated
- 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

TASK 187. Space Situational Awareness

- **PROJECT AT-A-GLANCE**
- UNIVERSITY: University of Colorado at Boulder
- PRINCIPAL INVESTIGATOR: Dr. Dan Scheeres
- STUDENT RESEARCHER: Mr. In-Kwan Park (PhD)

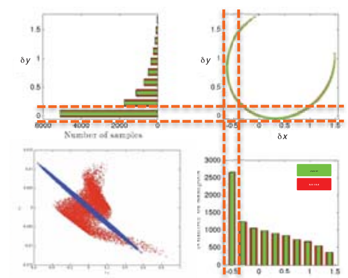
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- 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.

Analytical vs Numerical Uncertinaty Propagation



STATUS

- Graduated one funded PhD student: Kohei Fujimoto, May 2013
- Combined student team focused on relevant SSA research topics of direct interest to the COE
- Presented over 26 distinct papers at 14 conferences
- 7 papers published, 4 more in peer review at journal

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 2014

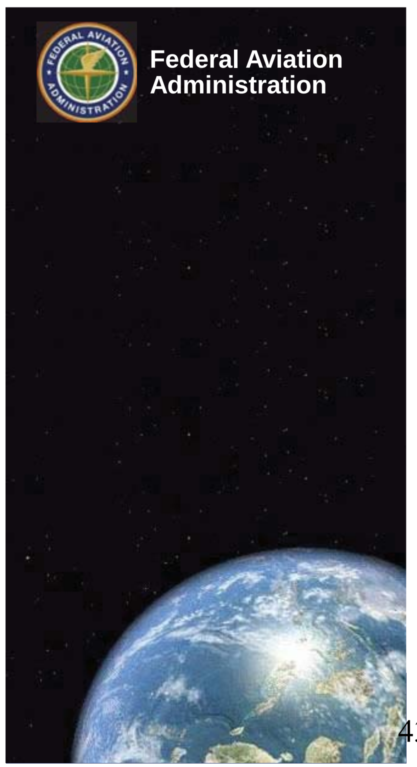
ANNUAL TECHNICAL MEETING #4:

Task 220: Update

PI: Patricia C. Hynes, Ph.D.

New Mexico State University

October 30, 2014



QUIZ

- OPERATIONS AND MAINTENANCE (O&M) FOR COMMERCIAL SPACEPORTS IS SIMILAR.
- QUESTION 2
- TRUE OR FALSE?

ANSWER – FALSE

- ONE OF THE BIGGEST OPERATING COSTS IS FIREFIGHTING AND EMT SERVICES.

- Some spaceports are within range of local firefighting facilities - like Mojave Air and Space Port
- Spaceport America established their own fire department, hired firefighters, EMTs and purchased equipment no local facilities available

COMMERCIAL SPACEPORTS CAN BE SITED IN SIMILAR LOCATIONS AS COMMERCIAL AIRPORTS.

- True or False

False

- Population densities would preclude the majority of airport site locations… to be continued

Overview

- Quiz
- Team Members
- Task History
- Current statues
- Next Steps
- Next Step Task 4 – Disseminate and test results

Team Members

- **Pat Hynes,** Principal Investigator, New Mexico State University
- **Paul Arthur,** Deceased in June, 2014. Rear Admiral (Retired), Former Technical Director/Deputy Commander, White Sands Missile Range
- **Herb Bachner,** HBachner & Associates
- **Jim Hayhoe,** Spaceport America Consultants
- **Lou Gomez,** Program Manager, Spaceport America
- **Norice Lee,** Associate Dean, Library, NMSU
- **Ingrid Schneider,** Metadata & Authority Control Librarian, Library, NMSU
- **Marianne Bowers,** Graduate Intern, Dept. of Government, NMSU

Task 1

- Develop a Framework to capture the Body of Knowledge for Spaceport Operation Best Practices

Task 2

- Integrate into the framework Applicable Documents Relevant Materials;
- Enable Documents to Be Found by Title, Subject, Or Keyword;
- Assure Copyright Protections.

Task 3

- Implement a Document Management System (DMS)
- Add documents to the Body of Knowledge DMS Database
- Create an online searchable database.
- House the database at the NMSU Library to provide 24/7/365 access
- Assure annual updates and maintenance of site and its contents

Results

Current Status:

Online searchable data base of 124 categories related to spaceport operations.

http://contentdm.nmsu.edu/

Next Steps

- Disseminate results through conference papers and presentation at industry meetings.
- Survey online users
- Implement analytics onto Digital Collections site

Next Steps

- Present at ATM-5
- Publish paper in journal
- Submit two papers for publication
- Present at three conferences, create three conference papers

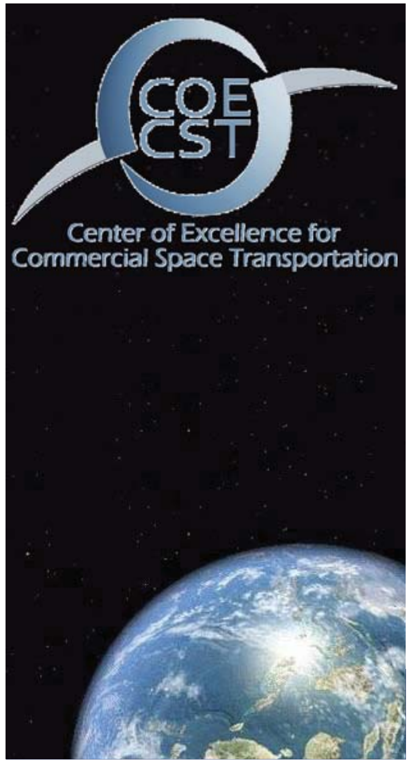
Conclusion

- Encourage, Facilitate Promote
- Enable & Facilitate education of a new workforce through this Digital Collection
- Promote Best Practices by Encouraging industry to share what they can to keep this collection relevant

COE CST Fourth Annual Technical Meeting:

Task 257: Commercial Spaceflight Operations Curriculum Development

PI: George Born
Bradley Cheetham



October 30th 2014

Overview

- Team Members
- Purpose of Task
- Research Methodology
- 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
- **Ken Davidian –** Program Manager, FAA AST

Industry Partners

Recent/Notable Industry Partners

SSL — Lab project mentorship/direction

LOCKHEED MARTIN — Commercial satellite lecture

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

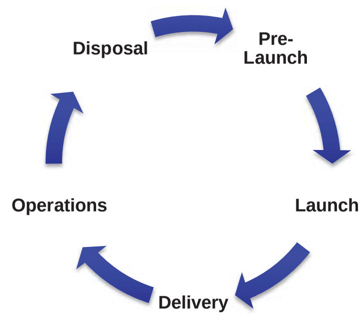
Approach

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

Operations Lab



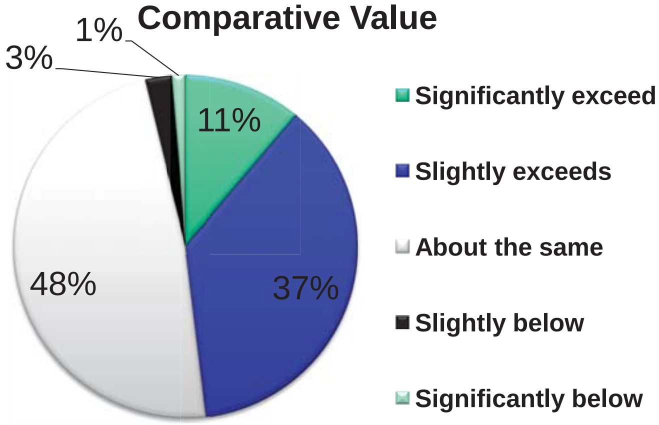

Schedule/Milestones

- Lecture offered: fall 2011, 2012, 2013, 2014
- Lab offered: spring 2013, 2014, 2015
- Total students: 102

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

Results

Value proposition to students:



Next Steps

- Spring 2015 – Lab offered with industry partner
- Certificate Development (in progress)
- Broaden impact via distance learning and collaboration

Publications

Cheetham, B.W., J. Feldhacker, J. Herman, and G.H. Born, "Bringing Together Industry and Academia via Graduate Commercial Spaceflight Operations Curriculum," 2014 Spaceflight Operations Conference.

Cheetham, B.W., J. Feldhacker, J. Herman, E. Heeren, G. Born, "Commercial Spaceflight Operations: Graduate Level Curriculum Development" IAC-12-E1.4.5, 63rd International Astronautical Congress, Naples, Italy.

Contact Information

- George Born

George.Born@Colorado.edu

- Bradley Cheetham

Bradley.Cheetham@Colorado.edu

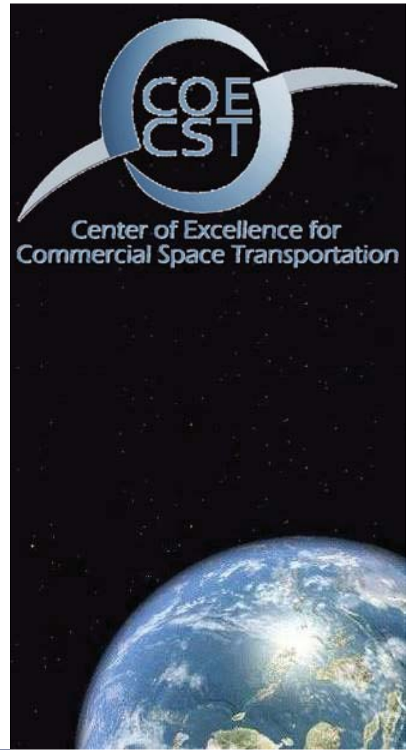
ccar.colorado.edu/CSO

COE CST Fourth Annual Technical Meeting

Task 184: Human-Rating of Commercial Spacecraft

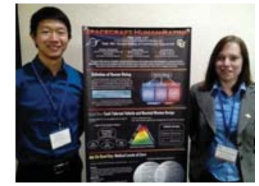
Prof. David Klaus, Christine Chamberlain, And Roger Huang

October 29-30, 2014
Washington, DC



Team Members

- FAA AST TM: **Henry Lampazzi** *(no photo)*
- Principal Investigator: **David Klaus**
- Students
  - *current*: **Christine Chamberlain**
    Roger Huang
  - *former*: **Christine Fanchiang**
  - *SNC:* **Robert Ocampo**
  - *unfunded*: **Stefan Neis** *(no photo)*

University of Colorado Boulder

Task Description

Comprehensive

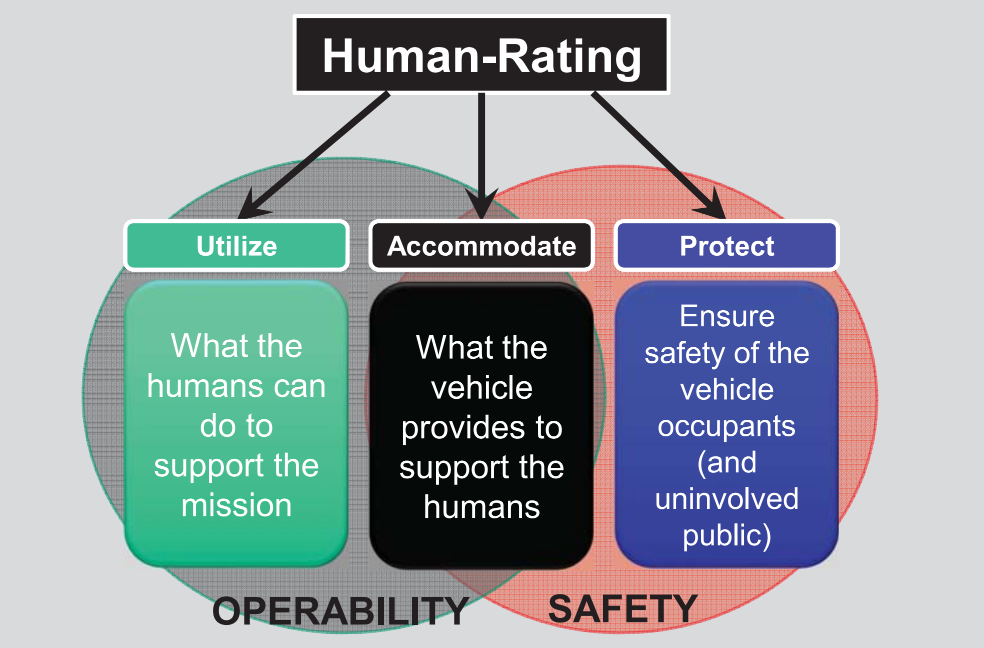
- Define and assess criteria and protocols typically employed for ensuring human-rating objectives (primarily safety) are met, including extension beyond crew and space flight participants toward an era of passenger carrying spacecraft, and while also minimizing risk to the uninvolved public

Current Efforts

- Medical Levels of Care for CST
- Emergency Crew Survival Methods
- Risk Perception / Communication

What does 'human-rated' mean?

- "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 (2012)*
- **How is it assessed?**
  - Requirements-driven or Outcome-determined?
  - NASA Requirements and FAA Airworthiness Certificate?
- **How is it confirmed?**
  - License, Certificate, Permit, Waiver, Other?



What does 'human-rated' mean?

- For CST, this translates to protect the crew and passengers (*occupants*) from harm, to accommodate their physiological needs, and to utilize the crew's capabilities to safely and effectively achieve the goals of the mission, *while also minimizing risk the uninvolved public*.
- The protection element of this research, which has been the focus to date, is directed at supporting an informed decision making process that will allow the FAA to ultimately develop appropriate safety regulations and verification strategies

How is it confirmed?

- **License** (i.e., Driver's)
  - to give permission
  - document recording that permission
- **Certification** (i.e., Pilot's)
  - refers to certain characteristics of an object, person, or organization
  - some are valid for a lifetime, once the exam is passed, others have to be recertified again after a certain period of time
  - certification does not refer to the state of legally being able to practice or work in a profession (that is licensure)
  - usually, licensure is administered by a governmental entity for public protection purposes and a professional association administers certification
  - licensure and certification are similar in that they both require the demonstration of a certain level of knowledge or ability

How is it confirmed?

- **Permit**
  - authorization or consent to someone to do something
  - a written warrant or license granted by one having authority
  - various legal licenses
- **Waiver**
  - regulatory agencies or governments may issue waivers to exempt companies from certain regulations
- **Other means of assuring safe operations?**
  - Safety is addressed through use of published guidelines and recommendations, industry protocols and best practices, and established standards. Licensing, certification and requirements can also be used to systematically assess safety compliance. Ultimately, safety is a product of proper design, quality workmanship and proficient operations.

  (Ocampo and Klaus, 2013)

Historical Perspective

"In the early days of airmail flying, the mail pilots came to believe that their crash rate was unacceptable, even for people accustomed to danger. Finally a group of them convinced the US. Air Mail Service that postal supervisors at the airports were ordering them aloft in bad storms and poor visibility. The solution? Not a new regulation spelling out what weather was safe and unsafe, but rather this simple order: if an outgoing pilot desired, his supervisor had to join him in the cockpit to fly a circuit around the airport before the pilot went off on his mail run. Quickly the supervisors' tolerance for bad weather dropped."

"Inviting Disaster: Lessons from the Edge of Technology" by James Chiles, 2002

Historical Perspective

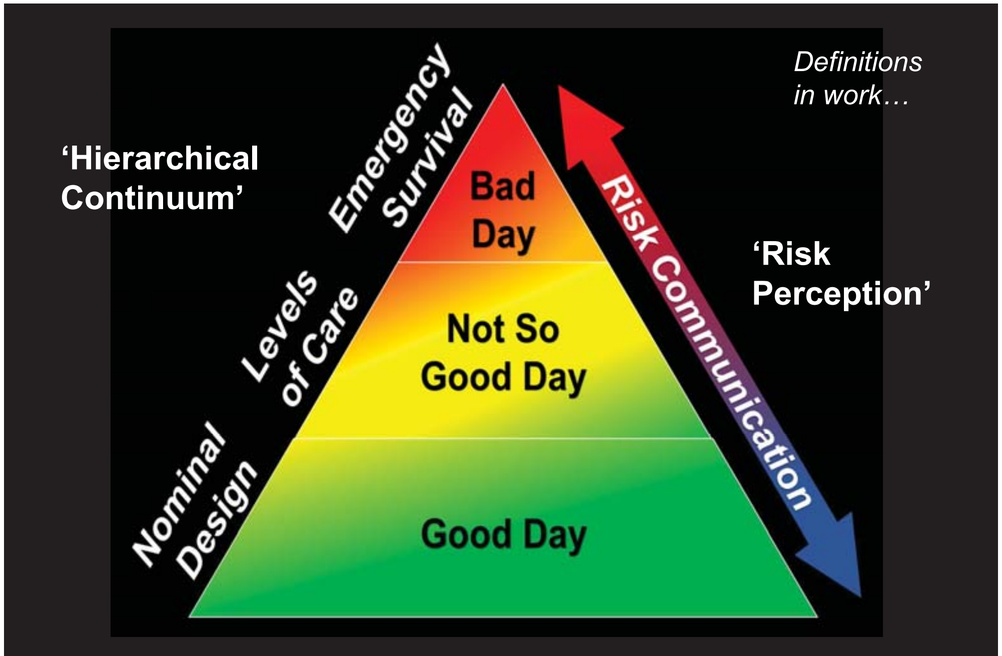
- The human-rating process for the Mercury, Gemini, and Apollo Programs was centered on **safety**
- As Mercury and Gemini evolved into Apollo and Skylab, human-rating began to focus on improvements to **operability** in addition to the focus on safety
- Skylab and Shuttle Programs added an emphasis on human **performance** and **health** management
- CST focus is on **safety**

Schedule (comprehensive *June 2011 through December 2014*)

- **2011/12**
  - Historical Perspectives on Human-Rating
  - Human-Rating Terms and Definitions
- **2012/13**
  - FAA Human-Rating Ground Rules and Assumptions
  - FAA Established Practices for Human Spaceflight Occupant Safety
- **2013/14**
  - FAA Recommended Practices for Human Space Flight Occupant Safety
  - **Medical 'Levels of Care' for Commercial Spaceflight**
  - **Crew Survival Methods**
  - **Risk Perception / Communication**

Goals: Risk perception/communication plan

- **Human-Rating Guidelines** – defined to help ensure a 'good day' occurs through risk mitigation and fault tolerant vehicle design
- **Medical 'Levels of Care'** – intended to address minor (non-life threatening) injury or illness leading to a 'not so good day'
- **Emergency Survival** – allow potential to deal with life-threatening illness/injury or recover from catastrophic vehicle failure to keep a 'bad day' from getting worse…



Medical 'Levels of Care' for CST

- **Primary** care covers generalized treatment for minor, acute injuries or illnesses.
- **Secondary** care follows with more specialized services on specific body systems or for specific diseases or chronic health conditions.
- **Ambulatory** care typically refers to outpatient treatment.
- **Tertiary** care involves highly specialized equipment and expertise for complex treatments such as surgeries or other procedures associated with hospitalization.
- **Quaternary** care is an extension into even more specialized and highly unusual treatment options, up to and including experimental medicine

Medical 'Levels of Care' for CST

- **Determining appropriate 'Level of Care' for commercial space flights should consider**
  - unique risks posed by each phase of suborbital and orbital flight
  - means of effectively accommodating safety and medical concerns as they relate to the vehicle design and operations and the onboard crew's degree of training
- **Implementing an appropriate 'Level of Care'**
  - function of vehicle design and operations, including personnel training

Results: COE Reports to FAA

1. Safe Return to Earth, 2012
2. Human Spaceflight Terminology and Definitions, 2013
3. Human Spaceflight Safety Terms and Definitions, 2013
4. Human Spaceflight Safety Perspectives, 2013
5. Thoughts and Considerations on Necessary Levels of Care for Commercial Spaceflight Transportation, 2014

Results: Contributions to FAA Documents

1. FAA Human-Rating Ground Rules and Assumptions Document (pre-decisional, 2013)
2. FAA Established Practices for Human Spaceflight Occupant Safety draft (7/31/13), with rationale (9/23/13)
3. FAA Recommended Practices for Human Space Flight Occupant Safety Version 1.0, (8/27/2014)

Results: Publications to date

1. Fanchiang, C. **Characterization and Evaluation of Manned Spacecraft Operability Factors**. 63rd IAC, Naples, Italy, Oct 2012 (presentation and proceedings)
2. Fanchiang, C., Johnson, M., and Ocampo, R. (2012) **Evaluation of Commercial Human Spaceflight Laws and Regulations in the United States**, IAC-12-D6.1.7 63rd IAC, Naples, Italy, Oct 2012
3. Klaus, D.M., Fanchiang, C. and Ocampo, R.P. (2012) **Perspectives on Spacecraft Human-Rating**. AIAA 2012-3419
4. Ocampo, R.P. and Klaus, D.M. (2013) **A Review of Spacecraft Safety: from Vostok to the International Space Station**. New Space 1(2): 73-80
5. Klaus, D.M., Ocampo, R.P. and Fanchiang, C. (2014) **Spacecraft Human-Rating: Historical Overview and Implementation Considerations**. IEEE Aerospace Proceedings (978-1-4799-1622-1/14, no. 2272)
6. Neis, S.M. and Klaus, D.M. (2014) **Considerations toward Defining Medical 'Levels of Care' for Commercial Spaceflight**. New Space [accepted]

Conclusions and Future Work

- **Next Steps**
  - Explore Emergency Crew Survival Methods
    - All occupants should have a 'reasonable chance of survival' in the event of an emergency. (FAA, 2014)
  - Assess Risk Perception / Communication
    - Contrasting with familiar Earth-based activities can be used to improve public perception of spaceflight risk
    - *e.g., In recent years, the odds of dying on Mount Everest were virtually equivalent to those of dying in a space shuttle accident*
  - Compile Final Report for Task 184
    - Guidelines and Considerations for Spacecraft Human-Rating
- **Final Remarks**
  - *Current funding runs out 12/31/14*

COE CST Fourth Annual Technical Meeting

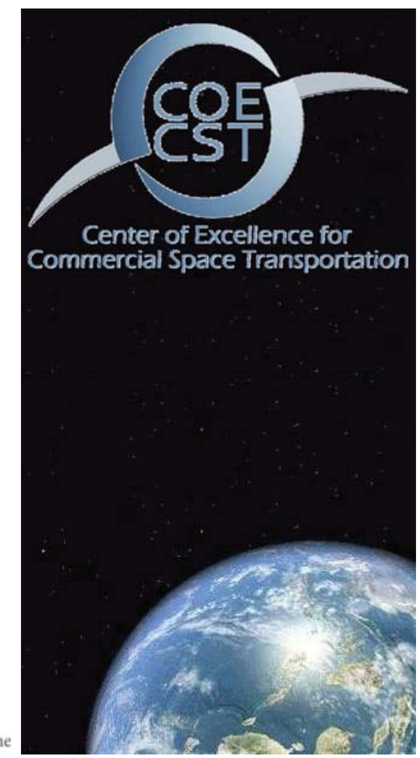
Task 256: Tolerance of Centrifuge-induced G-force by Disease State

PI: James Vanderploeg, MD
Co-I's: Rebecca Blue, MD; Tarah Castleberry, DO; Charles Mathers, MD

Students: James Pattarini, MD; David Reyes, MD; Robert Mulcahy, MD; Natacha Chough, MD; Eric Blacher, MD

October 29-30, 2014
Washington, DC

utmb Health Aerospace Medicine



Agenda

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

Team Members

- People
  - PI: James Vanderploeg, MD
  - Co-Investigators: Rebecca Blue, MD; Tarah Castleberry, DO; Charles Mathers, MD
  - Students: James Pattarini, MD; David Reyes, MD; Robert Mulcahy, MD; Natacha Chough, MD; Eric Blacher, MD
- Organizations:

Task Description

- Purpose:
  - To evaluate research subjects with defined disease states under the G-loads expected during commercial spaceflight using centrifuge-induced acceleration
  - Disease cohorts:
    - Cardiovascular disease
    - Hypertension
    - Diabetes
    - Pulmonary Disease
    - Spinal Disease or Injury

Schedule

- Funding and IRB approval obtained during 2012
- Test subject recruiting and testing from December 2012 through November 2013
- Data analysis completed in April 2014
- Publication of results in July 2014

Aviation, Space, and Environmental Medicine Vol. 85, No. 7 July 2014

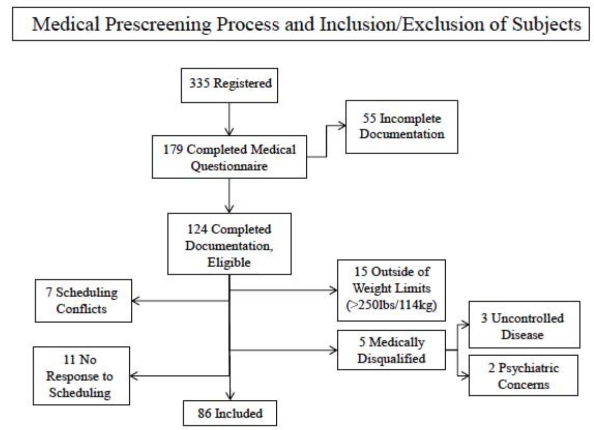
Tolerance of Centrifuge-Simulated Suborbital Spaceflight by Medical Condition

Rebecca S. Blue, James M. Pattarini, David P. Reyes, Robert A. Mulcahy, Alejandro Garbino, Charles H. Mathers, Johnené L. Vardiman, Tarah L. Castleberry, and James M. Vanderploeg

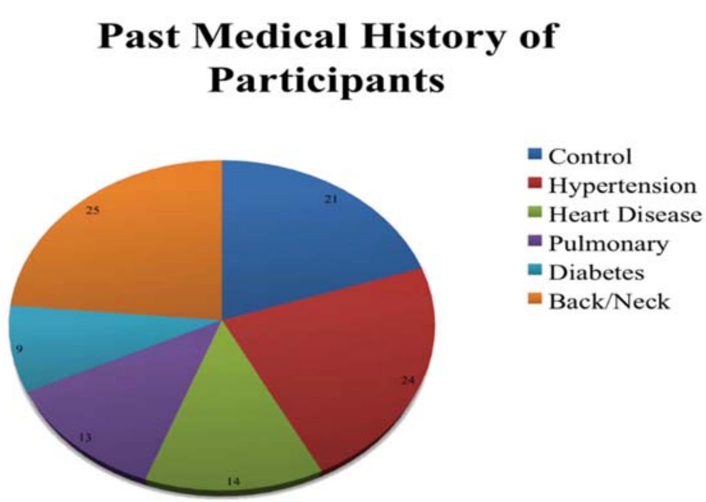
Goals

- Goals of Task 256
  - How do "non-career astronauts" tolerate increased G-force acceleration profiles?
  - What are the diseases of greatest concern for commercial human spaceflight?
- Relevance to Commercial Space Industry
  - How do individuals with controlled, chronic medical conditions tolerate spaceflight acceleration profiles?
  - Can these people safely take a space flight?

Results



Results



Results

- Five subjects voluntarily withdrew
  - Anxiety: 3 subjects
  - Back pain: 1 subject
  - Time constraints: 1 subject
- Despite significant medical history, NO subject experienced significant adverse or abnormal physiological responses to centrifuge profiles

Results

- Technical Reports and Journal Articles
  - Two panel presentations at 2014 AsMA meeting
  - Three publications completed
    - Blue RS, Pattarini JM, Reyes DP, Mulcahy RA, Garbino A, Mathers CH, Vardiman JL, Castleberry TL, Vanderploeg JM. Tolerance of centrifuge-simulated suborbital spaceflight by medical condition. Aviat Space Environ Med 2014; 85(7): 721-9.
    - Mulcahy RA, Blue RS, Vardiman JL, Mathers CH, Castleberry TL, Vanderploeg JM. Subject Anxiety and Psychological Considerations for Centrifuge-Simulated Suborbital Spaceflight. Aviat Space Environ Med 2014; 85(8): 847-851.
    - Pattarini JM, Blue RS, Castleberry TL, Vanderploeg JM. Preflight screening techniques for centrifuge-simulated suborbital spaceflight. Aviat Space Environ Med 2014; 85(12).
  - Three additional manuscripts in preparation
    - Case study of subjects with a cardiac pacemaker
    - Case study of subjects with an implanted insulin pump
    - Case study of subject with congenital heart defects and valve replacement

Conclusions and Future Work

Most individuals with well-controlled medical conditions should be able to tolerate a commercial spaceflight experience.

Next Steps:

- Assessment of Screening and Training Requirements for SFPs regarding Anxiety during Repeated Exposures to Sustained High Acceleration
- Assessment of Screening and Training Requirements for Pilots with Repeated Exposures to Sustained High Acceleration
- Assessment of methods, procedures, and technologies available for protection of passenger-occupied space in commercial spaceflight vehicles

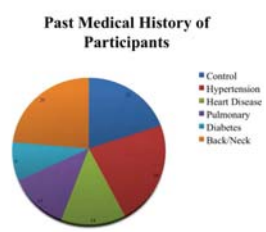
Task 256: Tolerance of Centrifuge-induced G-force by Disease State

utmb Health Aerospace Medicine

Project At-A-Glance
- University: The University of Texas Medical Branch
- Principal Investigator: James Vanderploeg, MD
- Co-Investigators: Rebecca Blue, MD; Tarah Castleberry, DO; Charles Mathers, MD
- Residents: James Pattarini, MD; David Reyes, MD; Robert Mulcahy, MD; Natacha Chough, MD; Eric Blacher, MD

Relevance to Commercial Spaceflight Industry
- There is little to no data on how individuals with chronic diseases will perform in a high-performance environment such as commercial spaceflight. This study provides data on how individuals with chronic diseases responded 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
- Completed testing and evaluation using the NASTAR centrifuge
- Performed data analysis
- Published results

Future Work
- Develop optimal acceleration training protocols for passengers
- Further evaluate role of training in reducing anxiety

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

utmb Health Aerospace Medicine

Project At-A-Glance
- University: The University of Texas Medical Branch
- Principal Investigator: James Vanderploeg, MD
- Co-Investigators: Rebecca Blue, MD; Tarah Castleberry, DO; Charles Mathers, MD
- Residents: **Robert Mulcahy, MD**; Eric Blacher, MD; Ben Johansen, DO; James Pattarini, MD; Natacha Chough, MD

Relevance to Commercial Spaceflight Industry
- Psychological stressors can be significant challenges in the operational environment. This study will provide data on how individuals with high anxiety levels can best be prepared for suborbital spaceflight through training and anxiety mitigation techniques.

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

Status
- Research protocol submitted to IRB
- Psychological testing methods defined

Future Work
- Complete IRB approval process
- Recruit test subjects
- Conduct training and testing at NASTAR centrifuge throughout 2015

Task 309: Assessment of Screening and Training Requirements for Pilots with Repeated Exposures to Sustained High Acceleration

utmb Health Aerospace Medicine

Project At-A-Glance
- University: The University of Texas Medical Branch
- Principal Investigator: James Vanderploeg, MD
- Co-Investigators: Rebecca Blue, MD; Tarah Castleberry, DO; Charles Mathers, MD
- Residents: **Eric Blacher, MD**; Benjamin Johansen, DO; Robert Mulcahy, MD; James Pattarini, MD; Natacha Chough, MD

Relevance to Commercial Spaceflight Industry
- Repeated exposure of the crew to sustained high +Gx and +Gz acceleration in highly demanding spaceflight profiles is a new and untested paradigm. Identifying the unique physiological challenges and medical clearance requirements will enable spaceflight operators to ensure safe operations.

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

Status
- Preliminary monitoring techniques for use in the Extra acrobatic plane are being conducted.
- IRB research protocol being prepared

Future Work
- Complete IRB approval process
- Recruit pilots for research study
- Conduct aerobatic flights and NASTAR testing throughout 2015
- Conduct physiological monitoring during spaceflights in 2015 and 2016

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

utmb Health Aerospace Medicine

Project At-A-Glance
- University: The University of Texas Medical Branch
- Principal Investigator: James Vanderploeg, MD
- Co-Investigators: Charles Mathers, MD; Rebecca Blue, MD; Tarah Castleberry, DO
- Residents: Benjamin Johansen, DO; Eric Blacher, MD; Robert Mulcahy, MD; James Pattarini, MD; Natacha Chough, MD

Relevance to Commercial Spaceflight Industry
- Optimization of crew and passenger compartments to promote the survival of occupants during human spaceflight operations is a necessary component of vehicle interior fit out. Dedicated efforts towards the de-lethalization and advanced crashworthiness of spaceflight vehicles will improve the safety of commercial space endeavors.

Statement of Work
- This project will evaluate methods for the de-lethalization of the cabin environment, space vehicle crashworthiness, individual restraint systems, emergency evacuation systems, and survival equipment.

Status
- Literature search underway
- Students being trained in conducting and evaluating relevant literature review

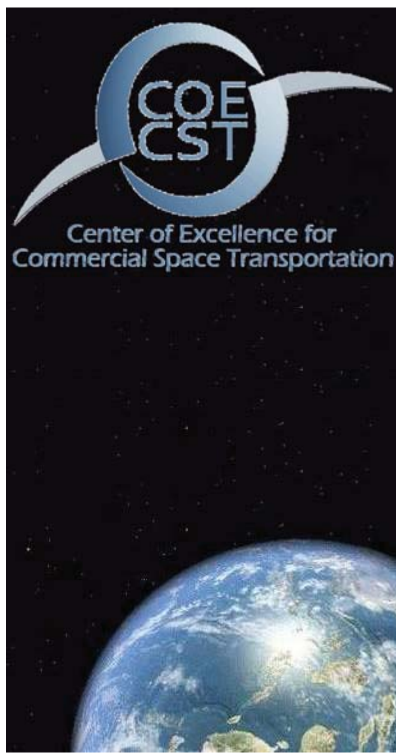
Future Work
- Complete literature review and analysis.
- Compare current spaceflight operators' interior cabin designs with historical precedents for cabin safety.

COE CST Third Annual Technical Meeting:

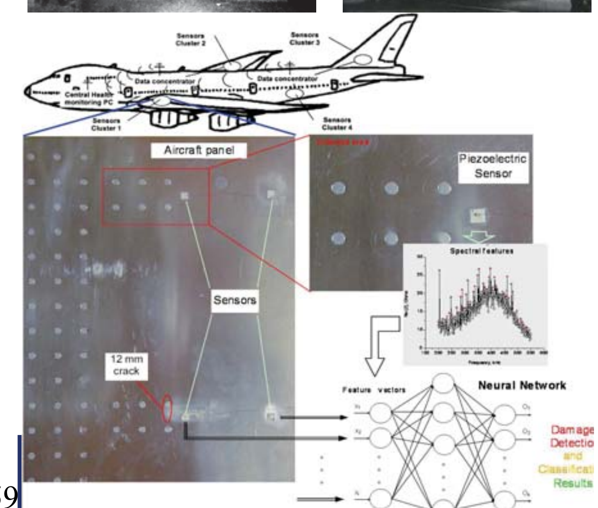
Task 228: Magneto-Elastic Sensing for Structural Health Monitoring

Andrei Zagrai and Warren Ostergren

29 October 2013



Aircraft Structural Condition Assessment

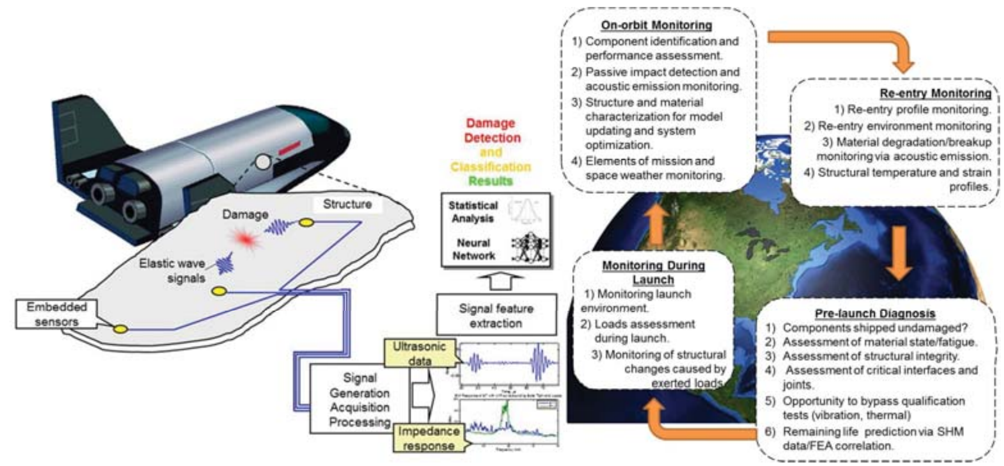


- PAST/CURRENT
  - Pre-flight critical components assessment
  - In-flight data (control, voice, communication, altitude, etc.) recording in "black box"
  - Mandatory periodic inspections (often manual) of structural elements (downtime!)
- +CURRENT/FUTURE
  - In-flight video
  - Improved inspections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

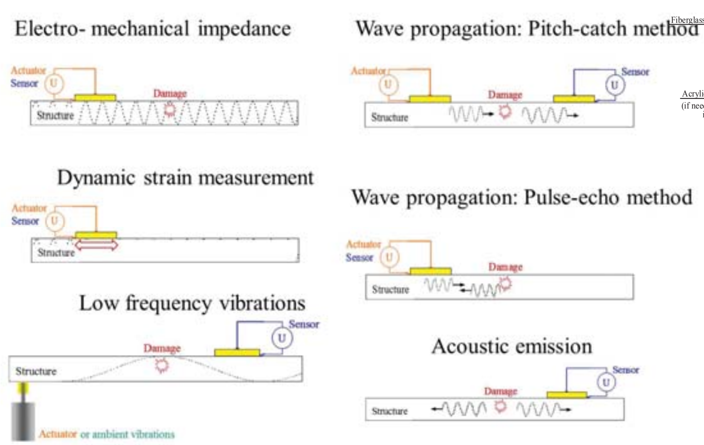
Spacecraft Structural Condition Assessment

- 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?

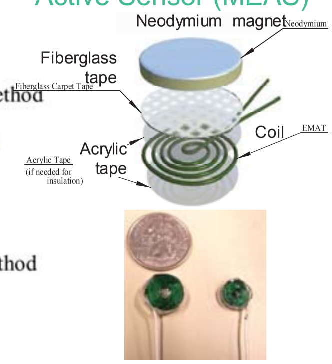
Flight Safety: Certification/anomaly detection



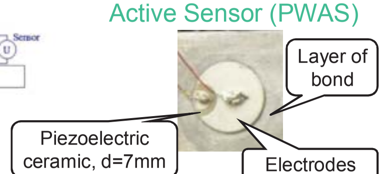
SHM Strategies for Commercial Space Vehicles



Magneto-elastic Active Sensor (MEAS)



Piezoelectric Wafer Active Sensor (PWAS)



Focus on appropriate sensors + off-the-shelf hardware

Purpose of Task

- Demonstrate utility of various SHM strategies during suborbital space 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 portable hardware for electro-mechanical impedance SHM

Team Members

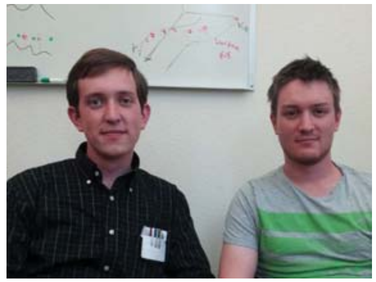
Task 228 NMT Team

- Blaine Trujillo (GR ME)
- Joel Runnels & William Masker (UG ME/EE) (Graduated)

- Andrei Zagrai & Warren Ostergren

Collaborators

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



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

038 BS NASA FOP Flight Team

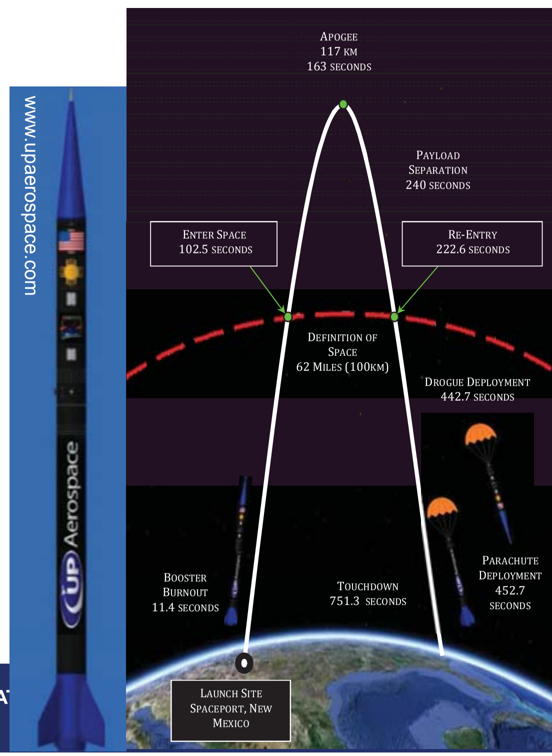
Andrei Zagrai (NMT), Nickolas Demidovich (FAA), Ben Cooper (NMT), Jon Schlavin (NMT), Chris White (NMT), Seth Kessler (Metis Design Corporation), Joe MacGillivray, Sam Chesebrough, Levi Magnusion, Lloyd Puckett, Karen Tena, Jaclene Gutierrez, Blaine Trujillo, Tiffany Gonzales. (NMT-undergrads)

COE CST Fourth Annual Technical Meeting (ATM4)
October 29-30, 2014
COE CST Center of Excellence for Commercial Space Transportation

SL8 – Suborbital Mission

New Mexico Spaceport commercial launch of SpaceLoft rocket on November 12, 2013.

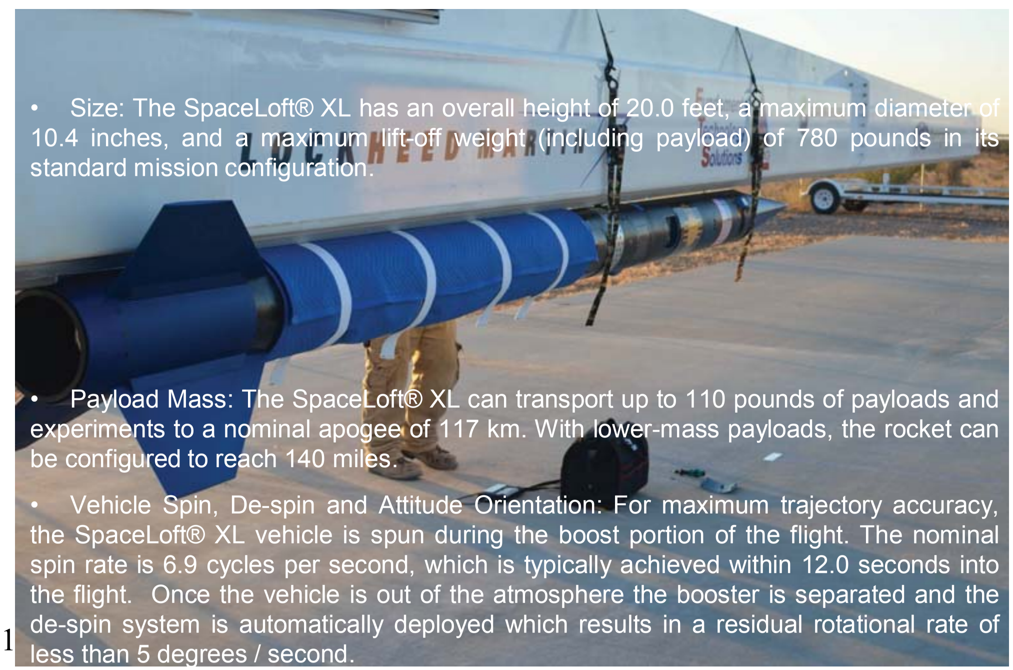
- Goal: Test innovative sensing technologies for real-time assessment of spacecraft structural integrity.
- Results: Experimental data on influence of space environment on structural dynamic signatures associated with spacecraft's integrity.



COE CST Fourth Annual Technical Meeting (A
October 29-30, 2014

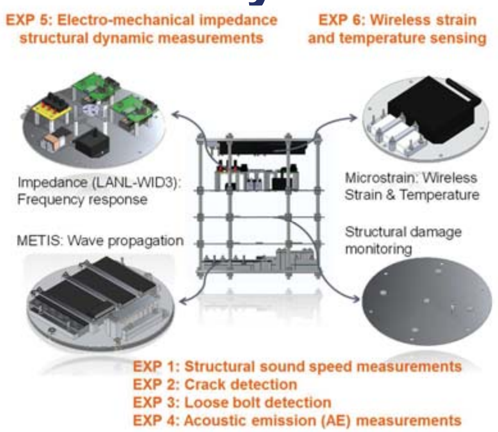
61

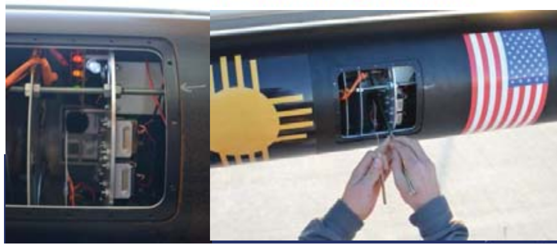
SL8 Rocket



- Size: The SpaceLoft® XL has an overall height of 20.0 feet, a maximum diameter of 10.4 inches, and a maximum lift-off weight (including payload) of 780 pounds in its standard mission configuration.
- Payload Mass: The SpaceLoft® XL can transport up to 110 pounds of payloads and experiments to a nominal apogee of 117 km. With lower-mass payloads, the rocket can be configured to reach 140 miles.
- Vehicle Spin, De-spin and Attitude Orientation: For maximum trajectory accuracy, the SpaceLoft® XL vehicle is spun during the boost portion of the flight. The nominal spin rate is 6.9 cycles per second, which is typically achieved within 12.0 seconds into the flight. Once the vehicle is out of the atmosphere the booster is separated and the de-spin system is automatically deployed which results in a residual rotational rate of less than 5 degrees / second.

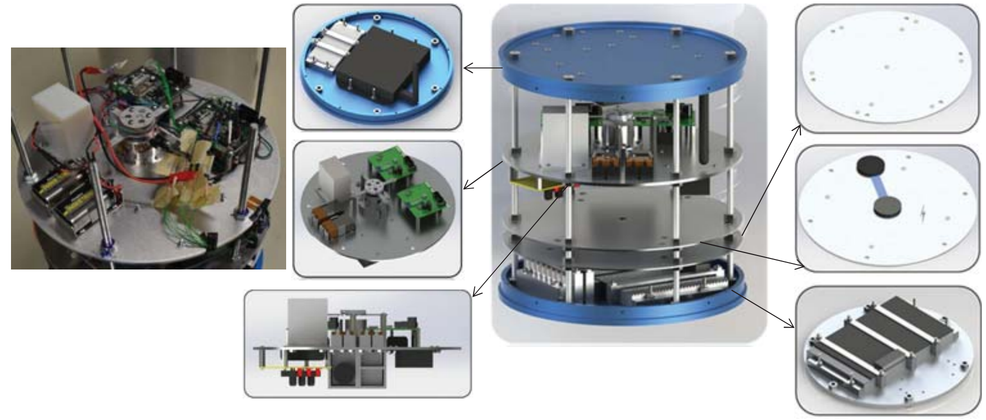
SL8 – Payload

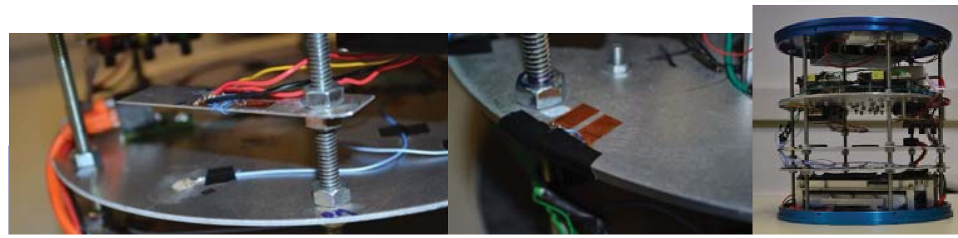




Center of Excellence for Commercial Space Transportation

SL8 – Payload



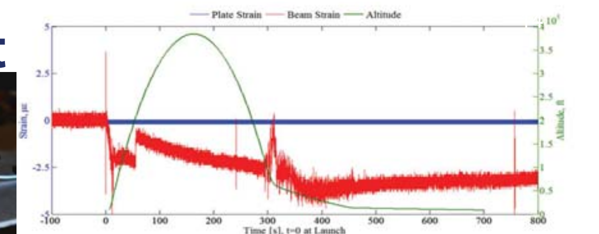


Sl8 Launch, November 12, 2013

COE CST Fourth Annual Technical Meeting (ATM4)
October 29-30, 2014

Center of Excellence for Commercial Space Transportation

Wireless Test



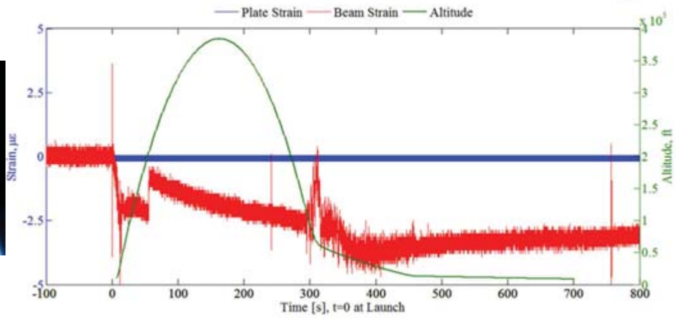
UP Aerospace Inc.
SpaceLoft-8
Launched November 12, 2013
NASA Flight Oportunities Program

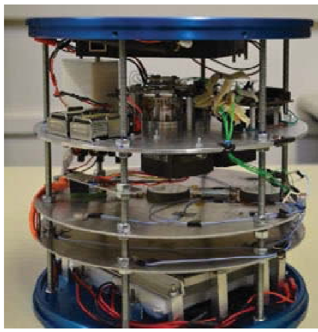
Two SG-Link -LXRS 3 Channel Wireless Analog Sensor Node (about 50 grams each)

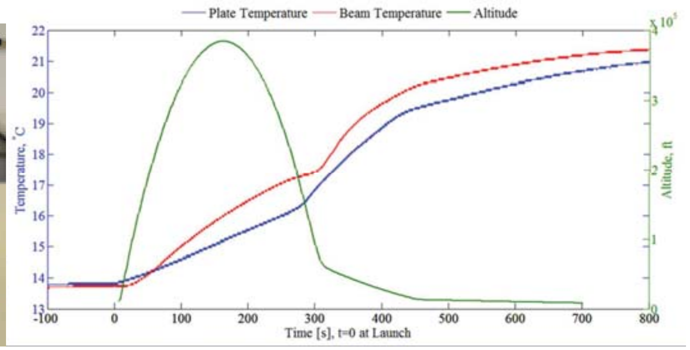
120Ω foil strain gauges connected in Full Wheatstone bridge configurations

256 Hz synchronous sampling

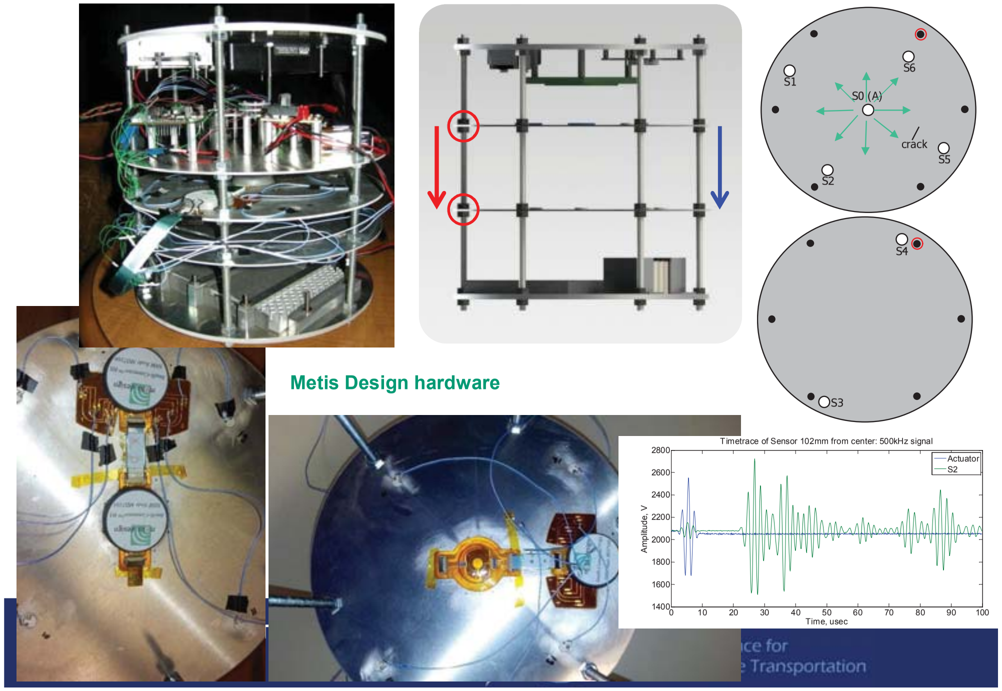
Wireless Strain and Temp. Sensing



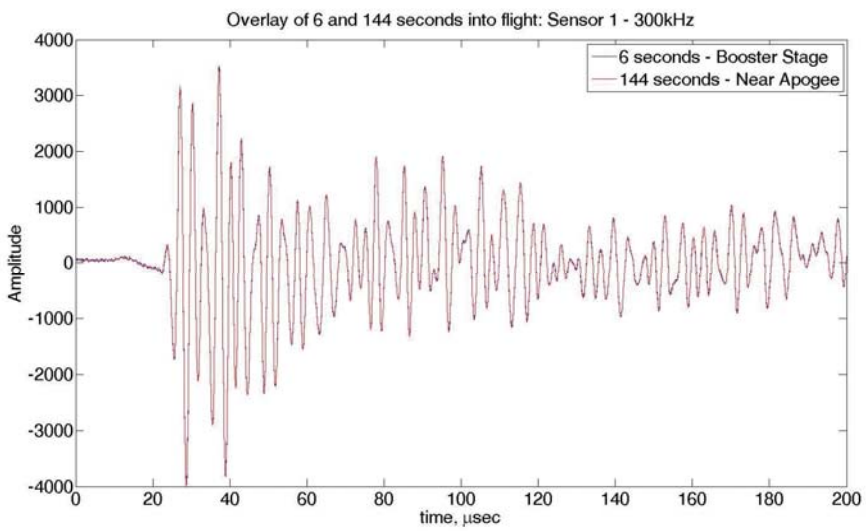




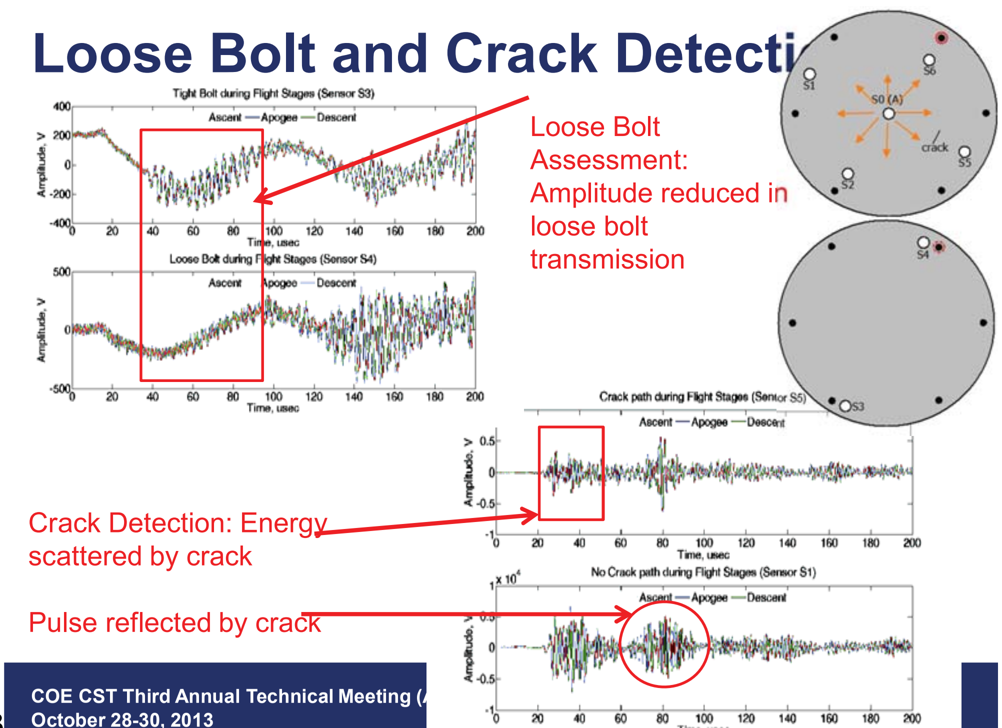
Wave Propagation (SHM & Sound Speed)



SL8 Flight Noise Effects



Loose Bolt and Crack Detecti

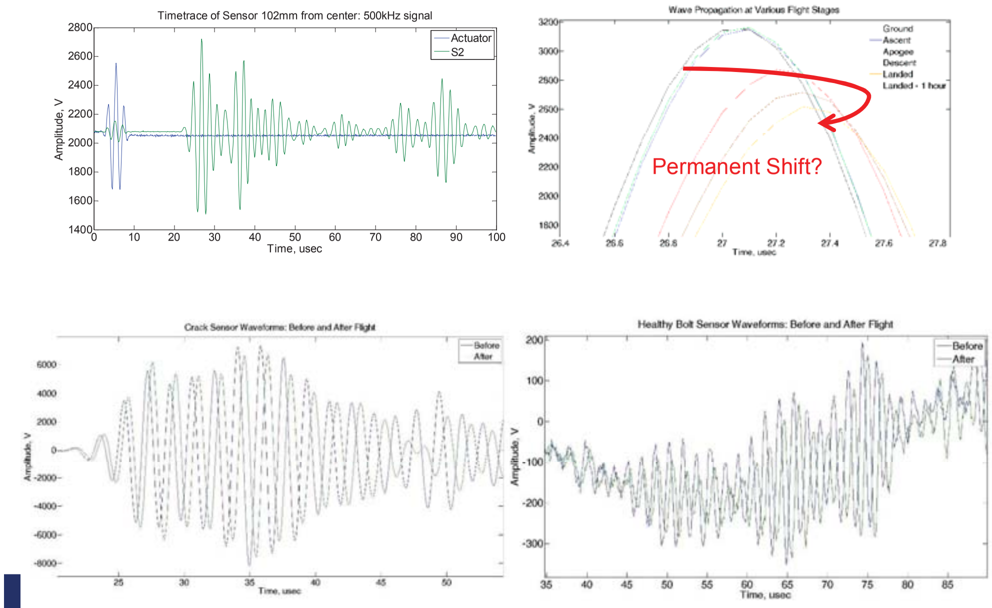


Loose Bolt Assessment: Amplitude reduced in loose bolt transmission

Crack Detection: Energy scattered by crack

Pulse reflected by crack

SL8 – Suborbital Flight Temperature Effects



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October 29-30, 2014
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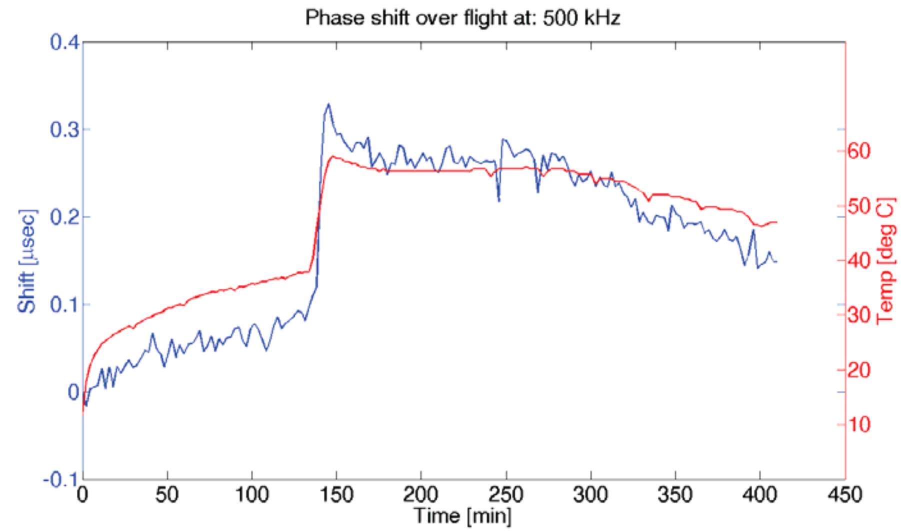
Phase Shift vs. Temperature



COE CST Fourth Annual Technical Meeting (ATM4)
October 29-30, 2014
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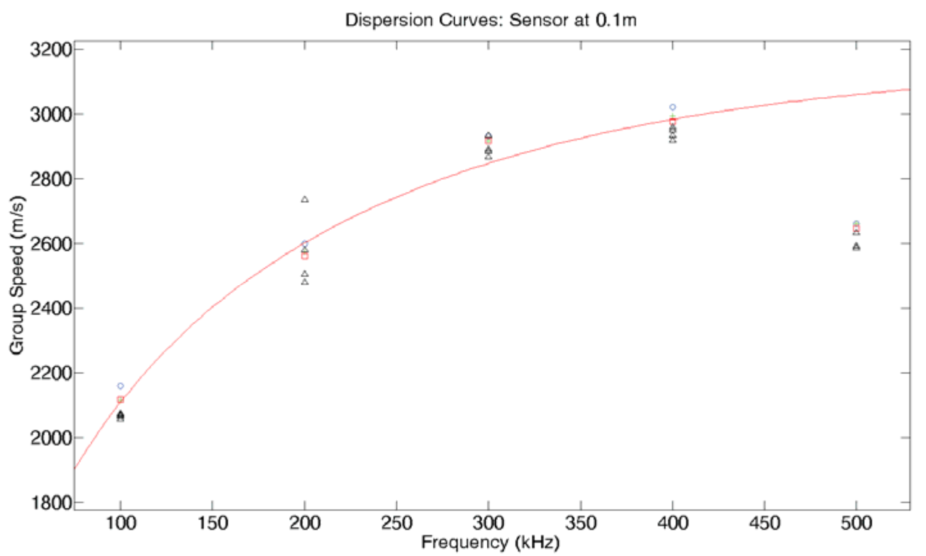
Phase Shift vs. Temperature



COE CST Fourth Annual Technical Meeting (ATM4)
October 29-30, 2014
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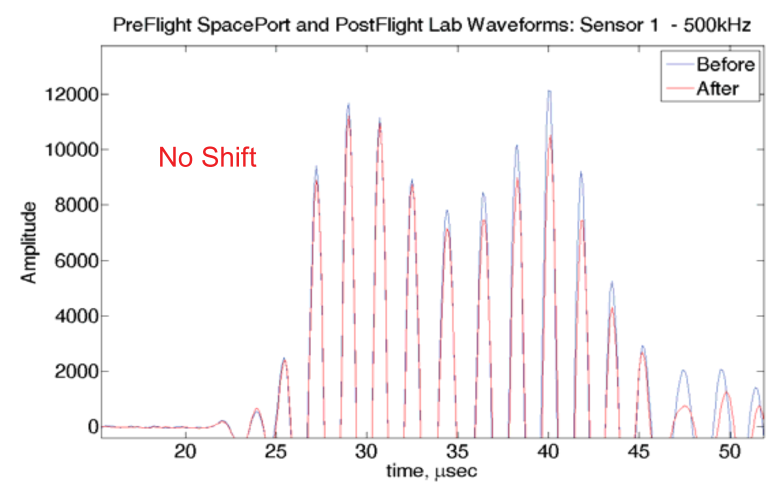
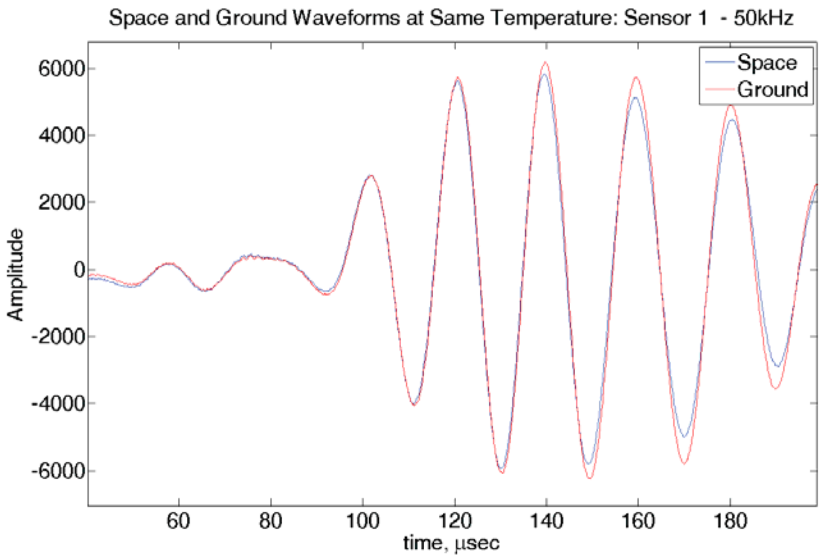
PreFlight and PostFlight at Same Temp

- Two records at 36.6°C, week before and week after space flight.
- Little, if any, permanent shift due to space environment is observed when temperature is accounted for.

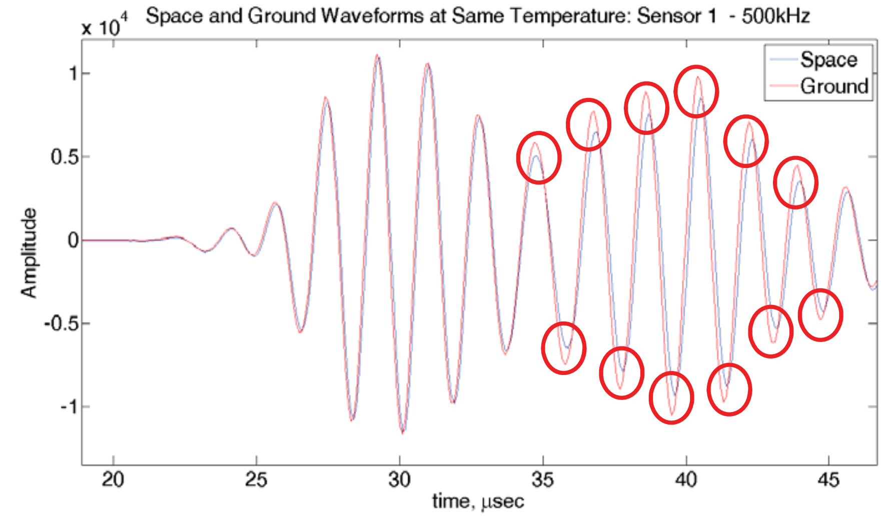


COE
Octo

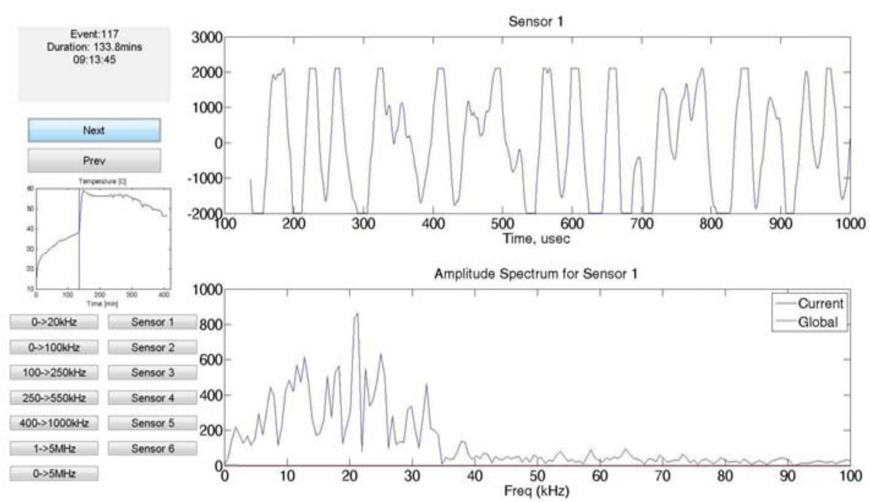
Same Temp 50.79⁰ C : 500 kHz waveform



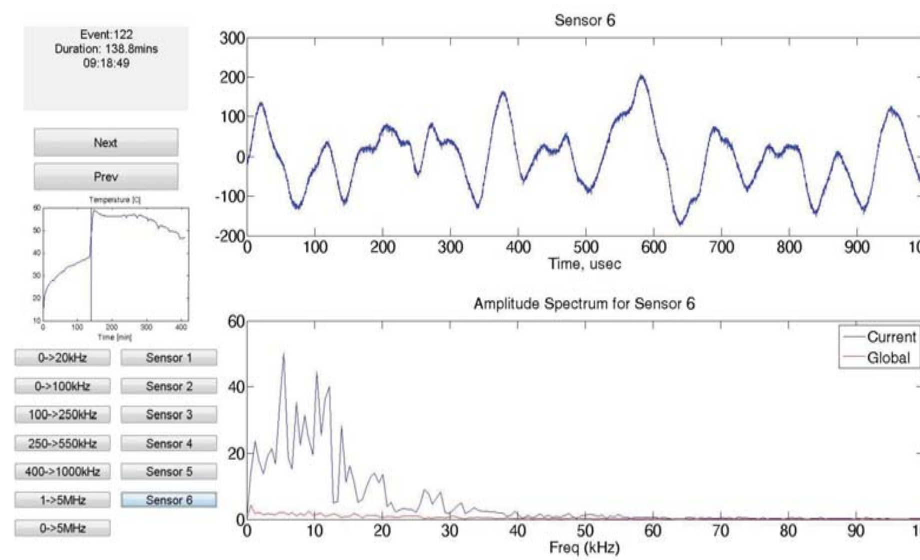
Same Temp 50.79⁰ C : 500 kHz waveform



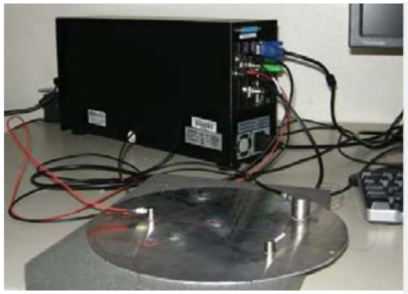
Passive Observations – Booster/Ascent

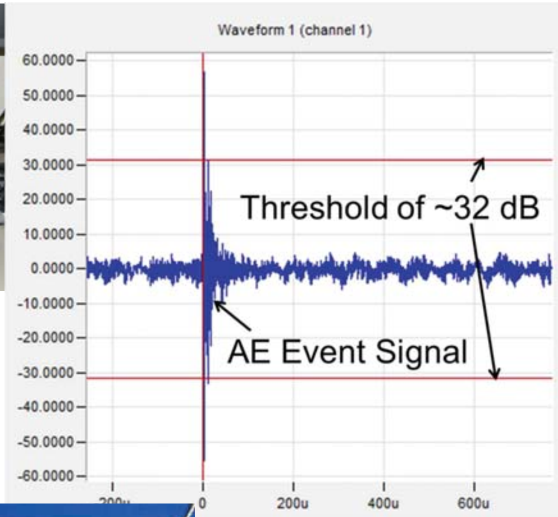


Passive – Drogue/Chute Deployment



Acoustic Emission Investigations

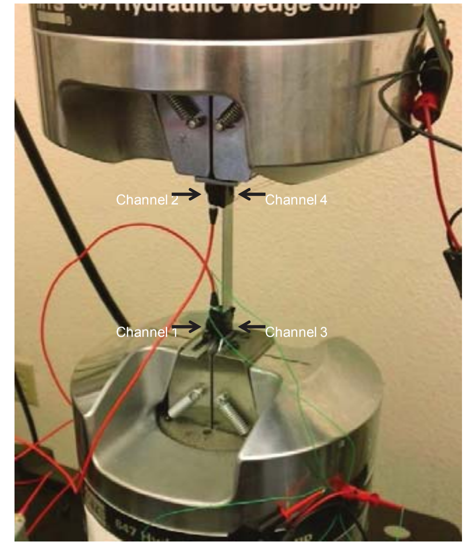




- PWAS and conventional AE sensors were were compared
- PWAS demonstrated utility in recording AE activity, but is more noisy
- New sensor design with shielding options is recommended.

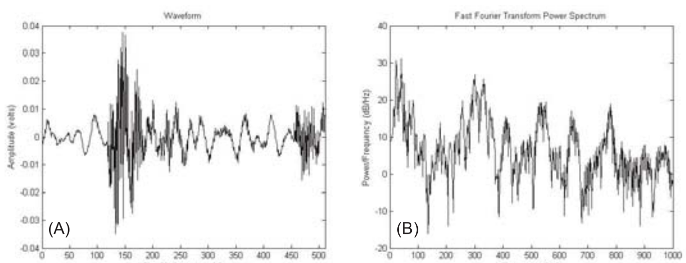
Fatigue Test Parameters

- ASTM Standard 557M-06 aluminum 6061 dog-bone specimens we used
- MTS 810 machine applied 10 Hz harmonic fatigue load
- 2 Micro-80 sensors (CH 1,2) and 2 PWAS (CH 3,4) were tested



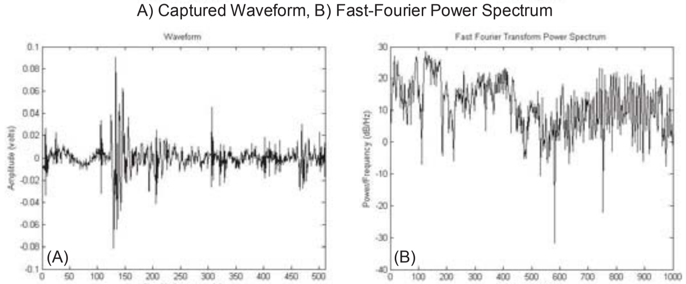
Fatigue Test Waveform Data

Micro-80 Sensor, Ch. 1,2



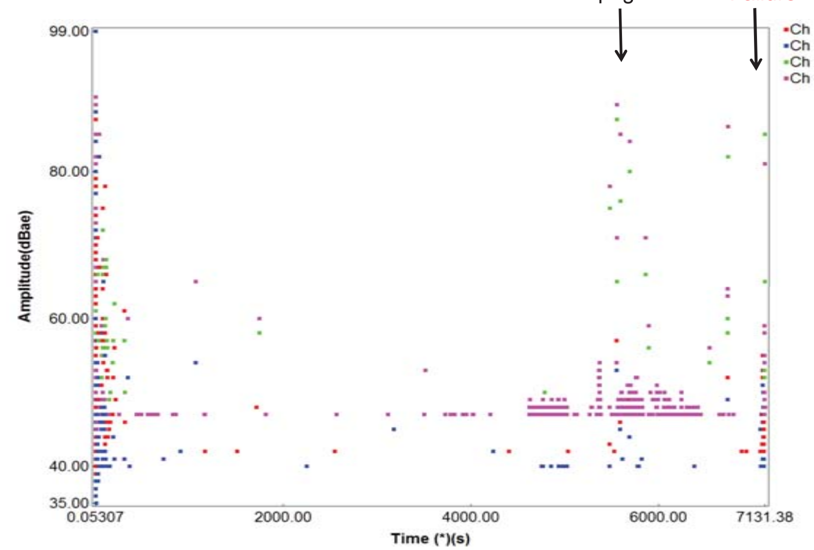
A) Captured Waveform, B) Fast-Fourier Power Spectrum

Piezoelectric Wafer Active Sensor, Ch 3,4



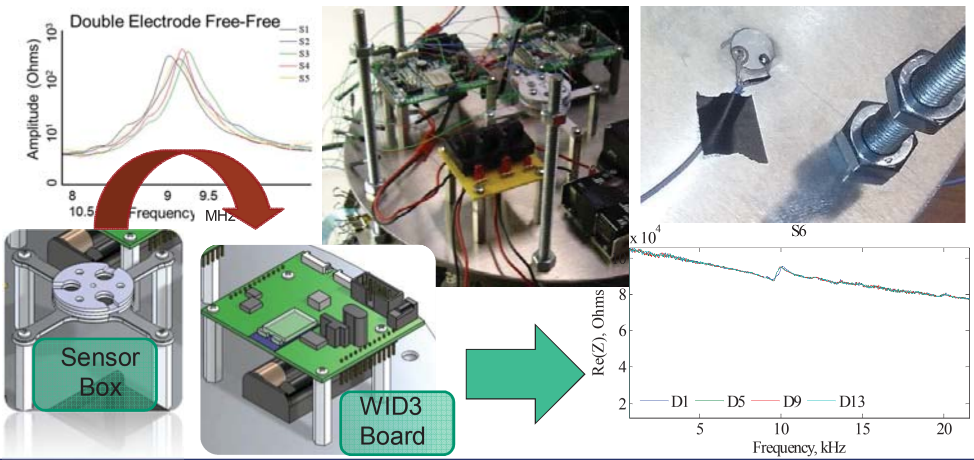
A) Captured Waveform, B) Fast-Fourier Power Spectrum

Fatigue Test Results



Impedance Measurements

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

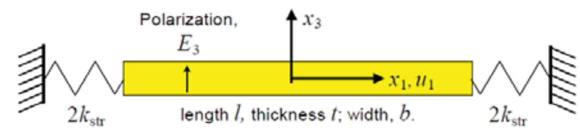


Principles of EMI Method

Giurgiutiu, 2000

$$Y(\omega)=\frac{I(\omega)}{V(\omega)}=i\omega\cdot C\left(1-\kappa_{31}^{2}\left(1-\frac{1}{\varphi\cot\varphi+r(\omega)}\right)\right) \qquad r(\omega)=\frac{k_{str}(\omega)}{k_{PWAS}^{b}}$$

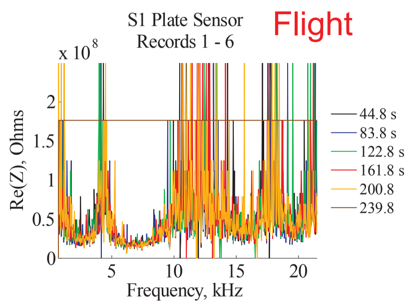
Admittance; Sensor dynamics; Structural dynamics; Structural dynamics stiffness

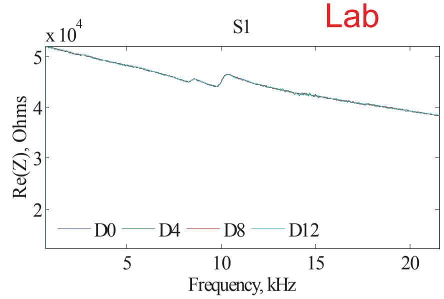


- Structural dynamic characteristics can be obtained through electro-mechanical impedance measurements
- Damage effects are reflected in the structural dynamic stiffness ratio
- Fatigue and other types of damage modify structural stiffness and thus impedance.

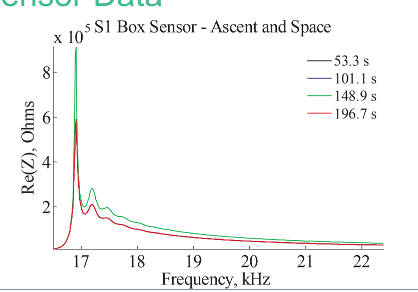
SL-8 Impedance Measurements

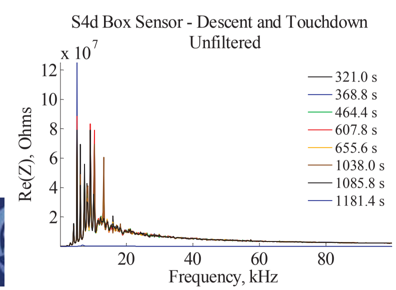
Structural Data





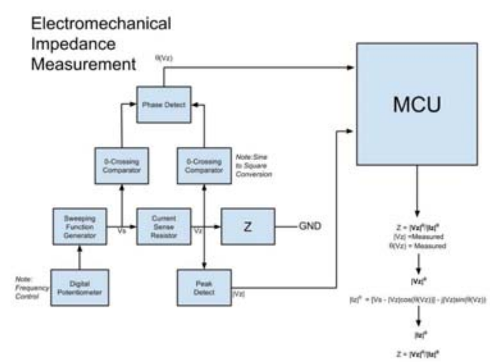
Sensor Data

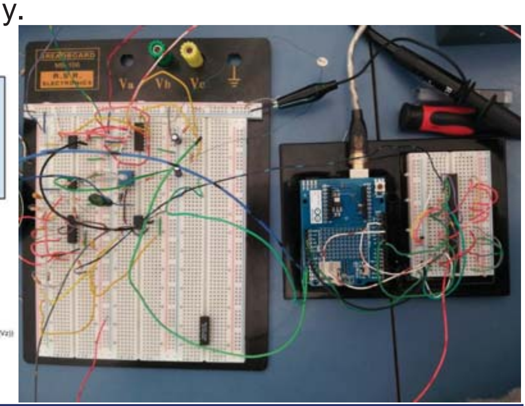




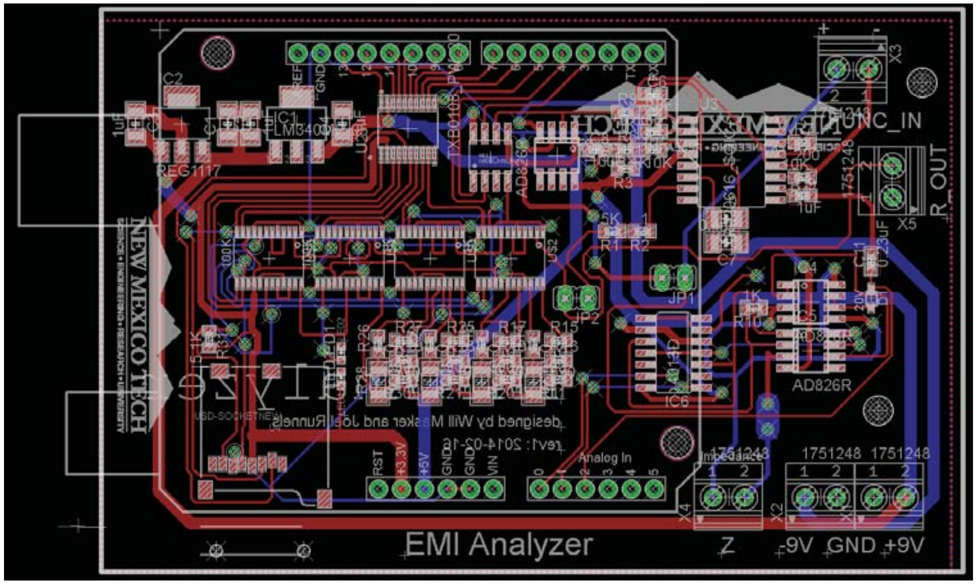
NMT Electro-mechanical Impedance Board

- Reliable impedance (amplitude and phase) measurements in high-altitude and space environments.
- Frequency band up to 0.5 MHz, at least 10 Hz sweep resolution.
- On-board impedance processing, frequency tracking
- Compact, light, and user friendly.



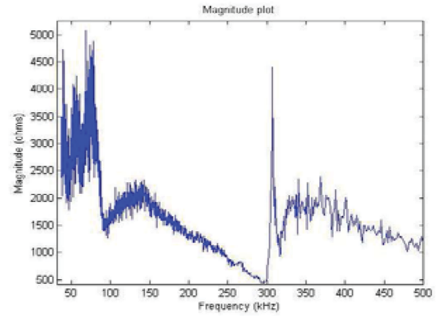


First Circuit Prototype

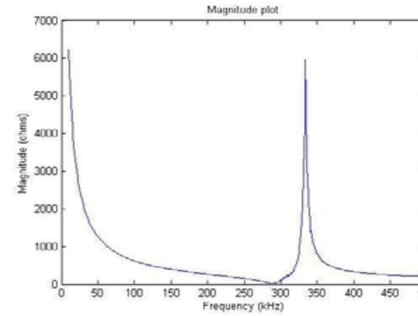


Piezoelectric Sensor Impedance Measurements

NMT EMI Board



HP 4192A



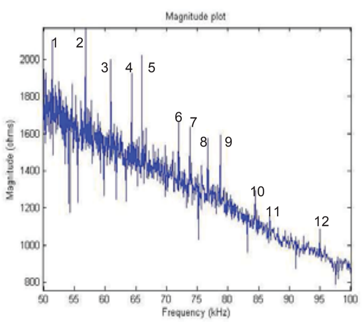
- Resonant Peak at 308 kHz

Potential response corrections:
- Measure Frequency (vs Calculate)
- Linearize Resolution

- Resonant Peak at 334 kHz
- Industry Standard Impedance Analyzer (HP 4192A)

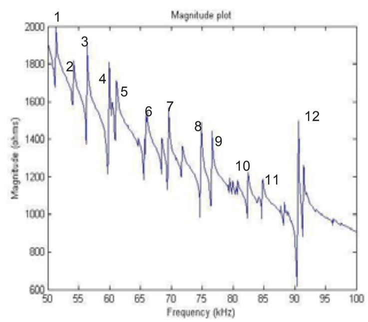
Structural Impedance Measurements

NMT EMI Board



- Points 1-12 show peaks
- Decreasing with freq. noise level
- Lower resolution at end of sweep

HP 4192A



+ and – of the NMT EMI Board

- Advantages
  - Low cost
  - Flexible bandwidth
  - Customizable programming
  - Expandable to provide wireless capabilities
- Disadvantages
  - Bandwidth limited to 500KHz
  - Currently no method to verify excitation frequency
  - Only one impedance measurement port (expandable in future)

Publications/Presentations

- Zagrai, A., (2013) "Structural Health Monitoring in Space and Near-Space Environments", presentation at EI, EI-K Los Alamos National Laboratory Workshop,5 December 2013, Los Alamos, NM, USA
- Zagrai, A., (2013) "Embedded Ultrasonics – Path From Aircraft to Spacecraft Applications", keynote presentation on First International Symposium on Aviation Maintenance and Management (ISAMM 2013) & Maintenance Equipment Exhibition, 25-28 November 2013, Xi'an, China.
- Zagrai, A., (2014) "High-frequency Sensor Technology", presentation at AFOSR Workshop on Microsecond State Monitoring of Multicomponent Structures, 8 April 2014, Niceville, Florida 32578-1295
- Masker, W., Runnels, J., and Zagrai, A., (2014) "Small-factor Electromechanical Impedance Measurement Board for Space Applications", presentation at SPIE's 21th Annual International Symposium on Smart Structures and Materials + NDE for Health Monitoring and Diagnostics, 9 - 13 March 2014, CA
- Trujillo, B. and Zagrai, A., (2014) "Monitoring of Acoustic Emission Activity using Thin Wafer Piezoelectric Sensors", paper at SPIE's 21th Annual International Symposium on Smart Structures and Materials + NDE for Health Monitoring and Diagnostics, 9 -13 March 2014, CA
- Zagrai, A, Cooper, B., Schlavin, J., Clemens, R., White, C., Kessler, S., (2014) "Assessing structural condition during suborbital space flight," Technical presentation at ASME Conference on Smart Materials, Adaptive Structures and Intelligent Systems, September 9, 2014, Newport, RI, presentation: SMASIS2014-7726.

Conclusions

- Commercial hardware (wave propagation, wireless) ran entire suborbital flight. Impedance hardware malfunctioned. Camera batteries discharged.
- Passive acoustic emission correlated with mechanical events during flight.
- Damage (crack and loose bolt) was detectable at all stages of flight
- Temperature has major influence on wavespeed
- The **first anti-symmetric mode (A0) appears to be modified** between space and ground, even with matched temperature. Symmetric mode (S0) appears unchanged in both
- Fatigue studies demonstrated feasibility of using embeddable piezoelectric sensors for Acoustic Emission monitoring.
- Compact EMI measurement board is under development

Acknowledgements

- FAA, NASA, AFOSR for support
- New Mexico Space Grant Consortium and Patricia C. Hynes
- The flight opportunity was provided by the NASA Flight Opportunities Program http://flightopportunities.nasa.gov , flight 38 BS
- Federal Aviation Administration (FAA) through Center of Excellence for Commercial Space Transportation, AFRL Space Vehicles Directorate, and NMT Department of Mechanical Engineering for assistance and 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.
- UPAerospace and Near Space Corporation for payload integration, launch and recovery.

Contact Information

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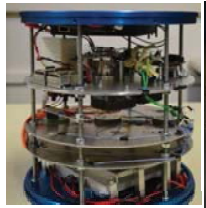
- E-mail: azagrai@nmt.edu

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 suborbital space 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 portable hardware for electro-mechanical impedance measurements in space environment.

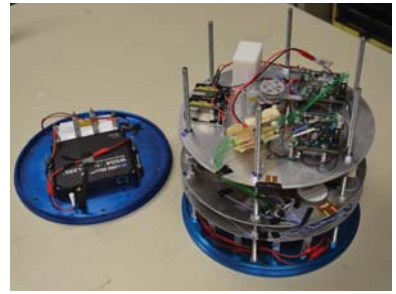
STATUS

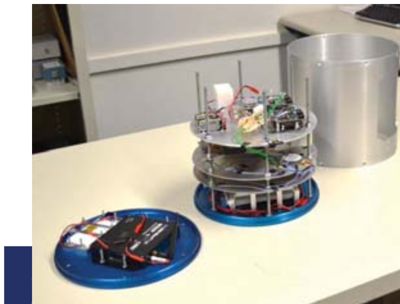
- 038S NASA FOP Flight completed & analyzed
- Acoustic emission measurements of fatigue damage is explored. PWAS AE validated.
- Development of portable EMI board started

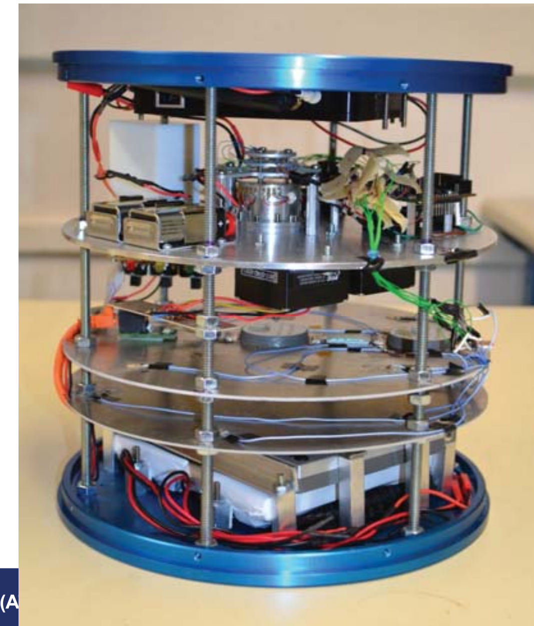
FUTURE WORK

- Electro-mechanical impedance manifestation of dynamic behavior of bolted joints
- Modeling of temperature effects on electro-mechanical impedance

S38 Payload





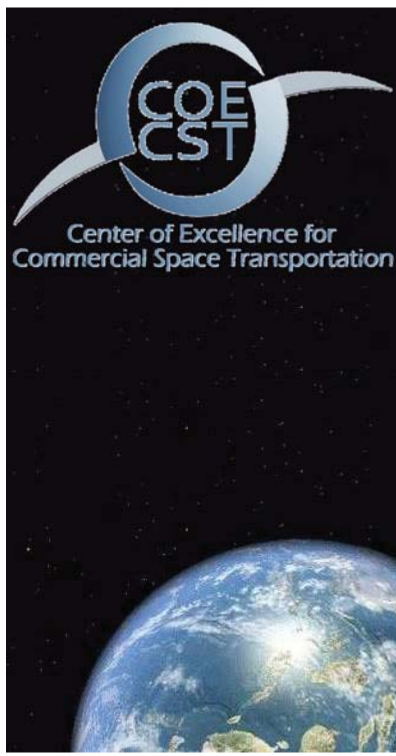


COE CST Fourth Annual Technical Meeting

High-Temperature Pressure Sensors for Hypersonic Vehicles

David Mills
Mark Sheplak

October 29-30, 2014
Washington, DC



Agenda

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

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

Task Description

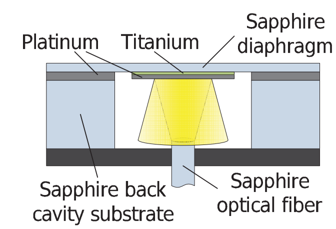
- Conventional instrumentation is unsuitable for continuous measurement in high-temperature environments such as:
  - High-speed reentry vehicles
  - Hypersonic transports
  - Gas Turbines
  - Scramjets
- Temperature mitigation techniques:
  - Stand-off tubes - cause signal attenuation and degradation
  - Water cooling - impart unknown aerothermal effects on the surrounding flow
- Pressure sensors capable of high-temperature operation (>1000°C) **without use of these techniques** will improve understanding of shock-wave/boundary layer interactions which directly influence critical vehicle characteristics such as lift, drag, and propulsion efficiency

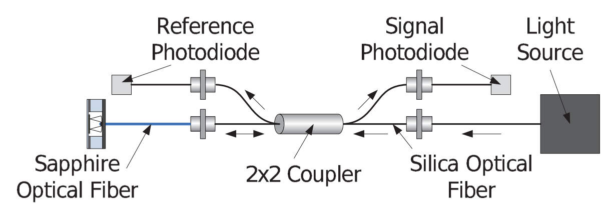
Goals

- 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

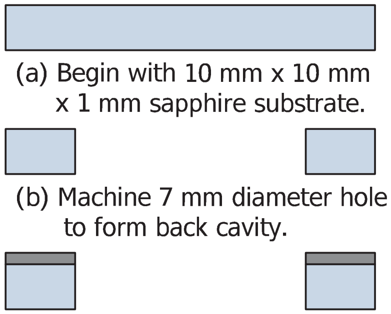
Sensor Overview

- Fiber-optic lever
  - Intensity modulation via diaphragm deflection
  - Single send/receive fiber
- Optical configuration
  - 850 nm LED source with multimode fibers
  - Silica optical fiber components reduce packaging costs
  - Reference photodiode monitors drift in LED source





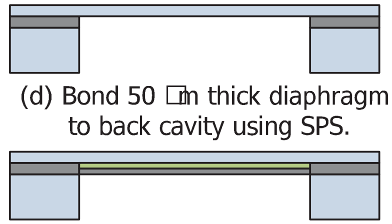
Fabrication



(a) Begin with 10 mm x 10 mm x 1 mm sapphire substrate.

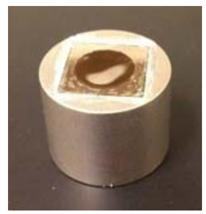
(b) Machine 7 mm diameter hole to form back cavity.

(c) Sputter deposit 500 nm of platinum for bonding layer.



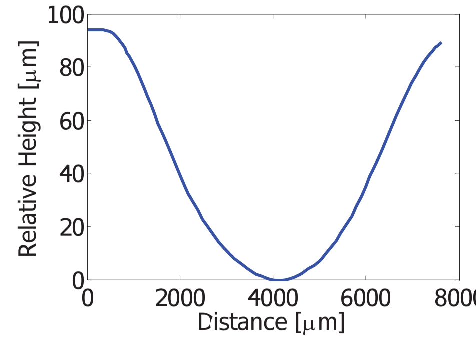
(d) Bond 50 □m thick diaphragm to back cavity using SPS.

(e) Sputter deposit 20 nm of Ti and 200 nm of Pt under continuous vacuum.



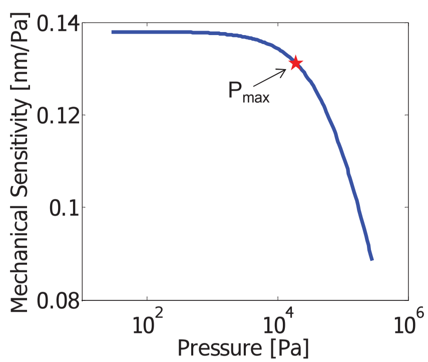
Post-bond Buckling Analysis

- Static deflection of the diaphragm measured using a scanning white-light interferometer
- Axisymmetric buckling profile – 94.1 μm center deflection



Post-bond Buckling Analysis

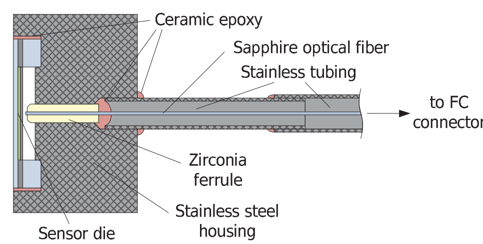
- Nonlinear plate model developed by Williams et al[1]
  - Compression factor, $k^2 = 42.8$
  - Residual compressive stress = 296 MPa
  - Mechanical sensitivity = 0.138 nm/Pa
    - 4x reduction in sensitivity compared to unstressed diaphragm
  - Max pressure (5% reduction in sensitivity) = 19.3 kPa

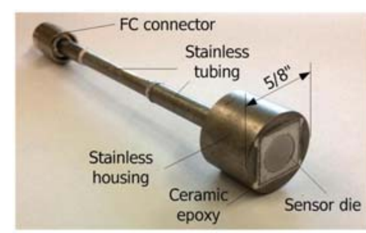


[1] Williams, M., Griffin, B., Homeijer, B., Sankar, B., and Sheplak, M., "The nonlinear behavior of a post-buckled circular plate," Sensors 2007 IEEE, 349–352 (2007).

Packaging

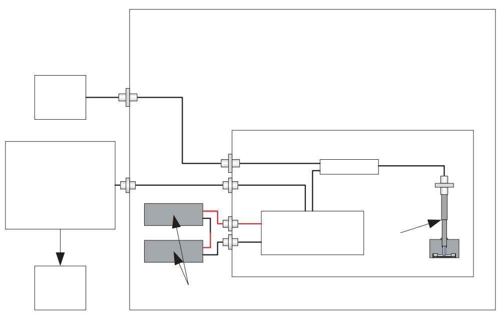
- High-temperature alumina ceramic epoxy used to package sensor in stainless steel housing
- Stainless steel tubing protects sapphire optical fiber and attaches to standard FC optical connector
- Package enables operation up to 900°C

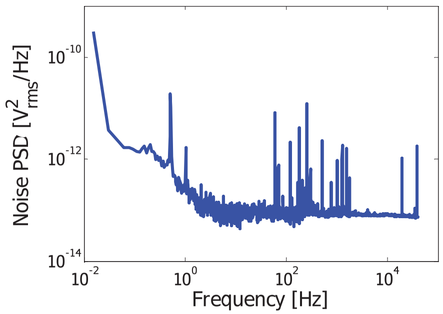




Noise Floor Measurement

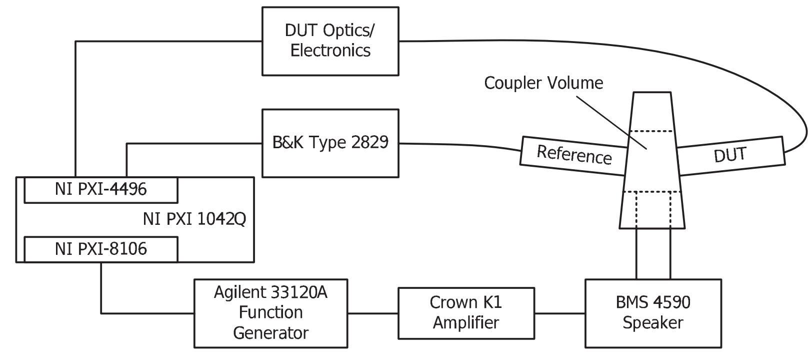
- Noise spectrum dominated by photodiode shot noise
- 1/f corner frequency: 8 Hz
- Noise floor: 1.2 μV @ 1 kHz w/ 1 Hz bin





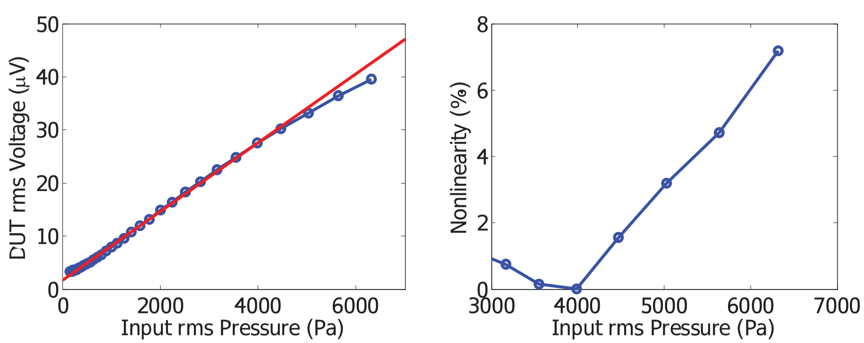
Acoustic Characterization – Setup

- Wedge-shaped acoustic coupler
  - Reduces number of supported modes within the cavity
  - Cavity volume: 0.5 cm^3



Acoustic Linearity

- Testing frequency: 1.9 kHz
- Input pressure level: 138-170 dB (ref 20 μPa)
- Sensitivity: -164 dB (ref 1 V/Pa)
- 5% acoustic nonlinearity: 5.7 kPa



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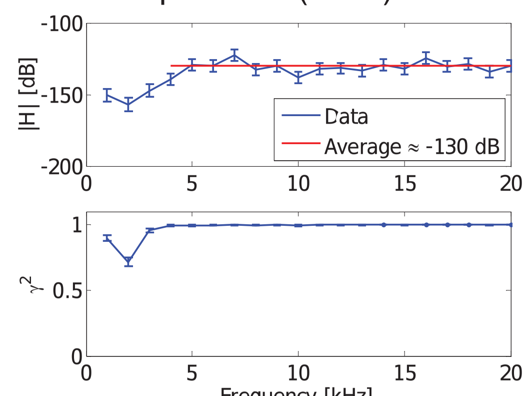
Frequency Response

- Single-tone measurements from 1-20 kHz at 145 dB in 1 kHz steps
- Flat-band sensitivity: -130 dB re 1 V/Pa (0.32 μV/Pa)
- Minimum detectable pressure (MDP): 3.8 Pa



Conclusions and Future Work

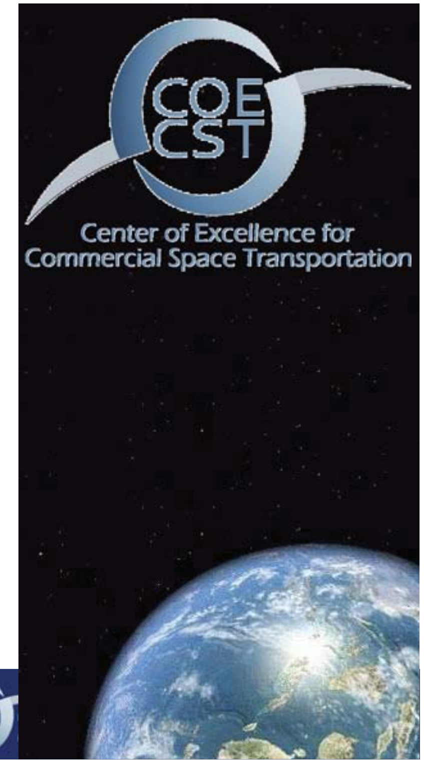
- Summary
  - Demonstrated novel SPS bonding process for joining sapphire substrates
  - Developed high-temperature package for operation up to 900°C
  - Determined noise floor, linearity, and frequency response of the packaged sensor at room temperature
- Next Steps
  - Further modification of SPS bonding process to reduce residual stress and eliminate buckling in diaphragm
  - Fabricate thinner sapphire diaphragms to improve sensitivity
  - Packaging improvements to extend high-temperature capability and enable dc pressure measurement
  - High-temperature calibration
- Conference Publications
  - D. Mills, D. Blood, J. Collins, W. Oates, T. Schmitz, and M. Sheplak, “Development of processing technology for high-temperature optical pressure sensors,” Technical Digest of the 2012 Solid-State Sensor and Actuator Workshop, Hilton Head Isl., SC, 6/4-7/2012, pp. OP6.
  - D. Mills, D. Alexander, G. Subhash, and M. Sheplak, “Development of a sapphire optical pressure sensor for high-temperature applications,” Proc. SPIE 9113, Sensors for Extreme Harsh Environments, Baltimore, MD, 6/5/2014.

COE CST Fourth Annual Technical Meeting

Task 244: Autonomous Rendezvous & Docking for Space Debris Mitigation

Norman Fitz-Coy

October 29-30, 2014
Washington, DC



Agenda

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

Team Members

- Principal Investigator
  - Norman Fitz-Coy
- Students
  - Tristan Newman (MS student)
  - Kathryn Cason (accepted job with MIE)
  - Takashi Hiramatsu (PhD in 2012 – NESTRA)
- Organizations
  - Collaborator: NASA ODPO (J.-C. Liou)
  - Matching provided by: Space Florida

Task Description (Original)

- Active debris removal is required
  - Interests in small satellites (e.g., CubeSats) especially by new space entrant leads to:
  - More spacecraft → 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

Task Description (Revised)

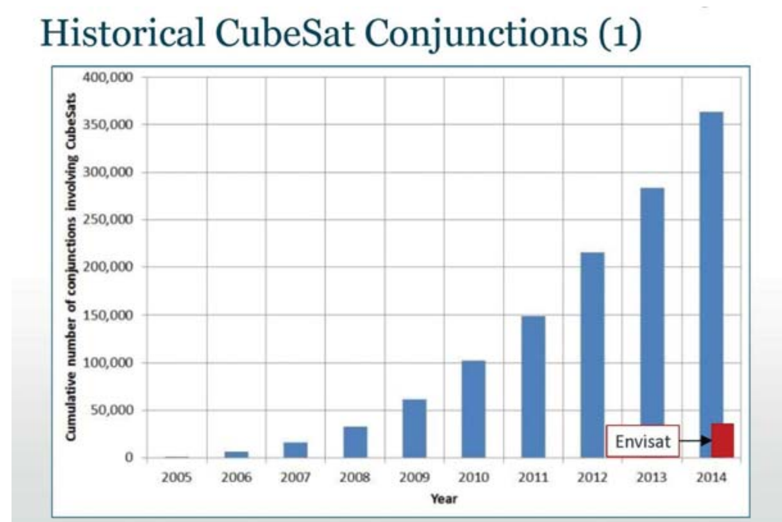
- Objectives
  - Identify/quantify the global growth trends of CubeSat-class satellite; assess the interests of US and international communities for CubeSat applications and investigate emerging CubeSat products (e.g., Planet Labs constellation of CubeSats).
  - Survey the assembly integration and testing practices of these CubeSat developers and utilize that information to investigate the mortality rates of CubeSats
  - Assess the space debris mitigation strategies utilized / implemented by these developers

Replace CubeSats with “Containerized” Satellites

Goals

- Outcomes
  - Utilize the growth trends, mortality information, and mitigation strategies to access the impact of “containerized” satellites to LEO debris
- Relevance to FAA
  - Debris in LEO will re-enter the airspace and could interact with sub-orbital flights and/or air traffic
  - Collisions with 5 mm sized debris could be consequential

Task Motivation (1/2)



Excerpted from H.G. Lewis, B.S. Schwarz, S.G. George and H. Stokes, “An Assessment of CubeSat Collision Risk,” Paper IAC-14-A6.4.1, presented at 65th International Astronautical Congress, Toronto, Canada, 2014

Task Motivation (2/2)

Conclusions

- More than 360,000 conjunctions < 5 km involving CubeSats since November 2005
- Millions of conjunctions predicted to occur in the next 30 years even for relatively low CubeSat launch rates
  - Many orbital regimes in LEO are affected
  - Most likely collision scenario is CubeSat and large object in Sun-synchronous orbit
  - Relatively few collisions (< 2) predicted
- Forecasted CubeSat activity is not sustainable without

Take Away:
The sky is NOT falling – these are opportunities for us to develop innovative solutions!!

Excerpted from … 14-A6.4.1, presented at 65th International Astronautical Congress, Toronto, Canada, 2014

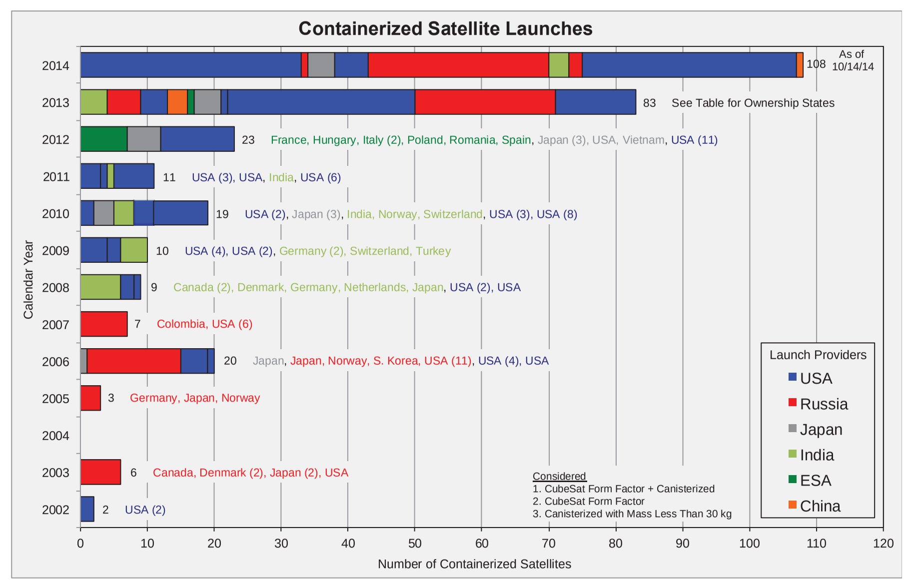
Schedule

- Start date: September 2014
- Develop survey strategy: ongoing
- Pilot test questionnaire: November 2014
- Disseminate questionnaire: January 2015
- Analyze survey results: March 2015
- Finalized results: April 2015

Approach

- Survey research process phases
  1. Identify research objectives
  2. Identify and characterize target audience
  3. Design sampling plan
  4. Design and write questionnaire
  5. Pilot test questionnaire
  6. Disseminate questionnaire
  7. Analyze results and write results

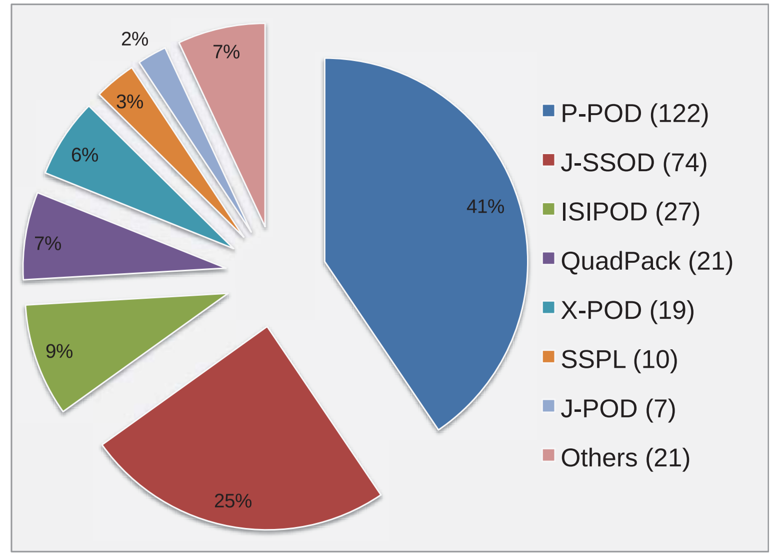
Preliminary Results



Preliminary Results

Year	Launch (Country)	#	Owner States (Country)
2013	PSLV (India)	4	Austria, Canada, Denmark, UK
	Soyuz-2 (Russia)	5	Germany (3), S. Korea, USA
	Antares 110 (USA)	4	USA (4)
	Long March 2D (China)	3	Argentina, Ecuador, Turkey
	Vega (ESA)	1	Estonia
	H-IIB (Japan)	4	USA (3), Vietnam
	Falcon-9 (USA)	1	USA
	Minotaur-1 (USA)	28	USA (28)
	DNEPR-1 (Russia)	21	INT (3), USA (2), Germany (2), Netherlands (2), Spain (2), Argentina, Denmark, Ecuador, Japan Norway, Pakistan, Poland, Peru, Singapore, S. Africa
	Atlas-V (USA)	12	USA (12)
2014	Antares 120 (USA)	33	USA (30), Lithuania (2), Peru
	Soyuz-U (Russia)	1	Peru
	H-IIA (Japan)	4	Japan (4)
	Falcon-9 (USA)	5	USA (5)
	DNEPR-1 (Russia)	27	USA (13), INT (3), Canada (2), Russia (2), Brazil, Denmark, Israel, Singapore, Taiwan, Ukraine, Uruguay
	PSLV (India)	3	Canada (2), Singapore
	Soyuz-2 (Russia)	2	Norway, UK
	Antares 120 (USA)	32	USA (31), Greece
	Long March 4B (China)	1	Poland

Preliminary Results



Others include, T-POD, Dragon, SPL, PEPOD, CSS, FlyMate, CSD, Hand deployment from ISS, Unknowns

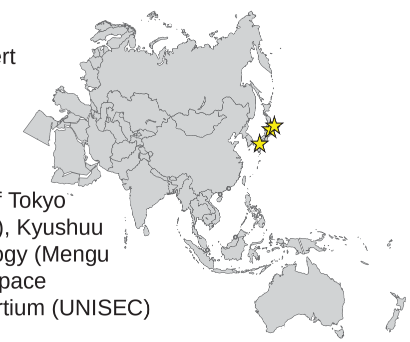
Dissemination Strategy (1/2)

North America
- CubeSat Listserve, CalPoly
- USA: AIAA SmSTC, AMSAT, AFRL, NRO, NSF, NASA, SMDC, SMC, universities
- Canada: University of Toronto, Canada (Freddy Pranajaya)

South America
- Brazil: Brazilian Space Agency (AEB), INPE (Otavio Durao)
- Columbia (Camilo Guzman Gomez)
- Mexico (Carlos Duarte)

Dissemination Strategy (2/2)

Africa
- South Africa: CPUT (Robert van Zyl)
- Ghana: ANU (Quarshie Manfred)



Asia
- Japan: University of Tokyo (Shinichi Nakasuka), Kyushuu Institute of Technology (Mengu Chou), University Space Engineering Consortium (UNISEC)

India
- TBD

Europe
- Denmark (GomSpace Aps)
- Netherlands (Innovative Solutions in Space)
- Spain (University of Vigo)
- United Kingdom (Clyde Space Ltd, Univ. of Leicester)

Draft Survey Questions (1/7)

To be disseminated to containerized satellite developers and operators.

- A containerized satellite is any satellite that is enclosed in a separate structure/volume that interfaces between the satellite and the launch vehicle. Such container may contain one or more satellites and prevents any harm to the primary, launch vehicle, or other secondary satellites

Draft Survey Questions (2/7)

1. Is your team/group a designer, developer, and/or manufacturer of containerized satellites?
   - ✔ Yes
   - o No

1-A. Have any of your team/group's containerized satellites been launched?
- ✔ Yes
- o No

1-A-1. Select the mass range(s) which accurately describe your satellites. For each range, please note the number of satellites.

Mass	Count
Less than 1 kg	0
1 kg to 10 kg	1 to 5
10 kg to 100 kg	0
100 kg to 500 kg	0
Greater than 500 kg	0

Options: 0 / 1 to 5 / More than 5

Draft Survey Questions (7/7)

3. Please select activities that your team/group has conducted for quality assurance of your satellite(s). Select all that apply.
   - o Simulations and analysis
     - o Structural and Thermal
     - o Orbital
     - o Functionality
   - o Functionality testing of hardware and software
   - o Reliability analysis
   - o Requirements verification matrix (i.e., traceability)
   - o Internal(peer) and external(subject matter experts) reviews
   - o Configuration management
   - o Systems engineering process
   - o Others (Please briefly describe):

Optional questions

Name of satellite(s), Name of container(s), Size of team/group, Team/Group's association (academia, industry, government), Mission description, etc

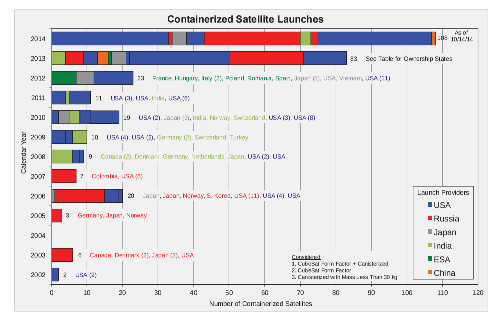
TASK #244. Autonomous Rendezvous & Docking for Space Debris Mitigation

UF UNIVERSITY of FLORIDA

- **PROJECT AT-A-GLANCE**
- AST RDAB POC: Stephen Earle, Ken Davidian
- UNIVERSITY: University of Florida
- PRINCIPAL INVESTIGATOR: Dr. Norman Fitz-Coy
- STUDENT(s): Tristan Newman (MS)

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- The proliferation of small satellites will eventually contribute to space debris and thus methodologies for the mitigation and remediation of space debris are required. The 2010 US Space Policy strongly encourages the development of commercial capabilities to enhance safe space operations.

STATEMENT OF WORK
- The objective of this research effort is the development of computationally efficient and robust methodologies for active space debris remediation. As this research proceeds, it is expected to make the following contributions:
- Development of artificial potential function-based guidance (APFG) algorithms for proximity operations and autonomous rendezvous/docking.
- Development of strategies to minimize the interactions between a rescue spacecraft and a non-cooperative (disabled) spacecraft. These strategies will be based on game theoretic strategies.
- Modification (Sept. 2014): Assess the impact of launch rate and satellite densities (i.e., number of satellites launched simultaneously) on LEO debris growth and identify strategies to mitigate debris growth caused by containerized satellites



STATUS
- Identified some potential impact factors (e.g., launch rate, satellites per launch, orbit, etc)
- Drafting survey questions
- Identified POC for dissemination of survey

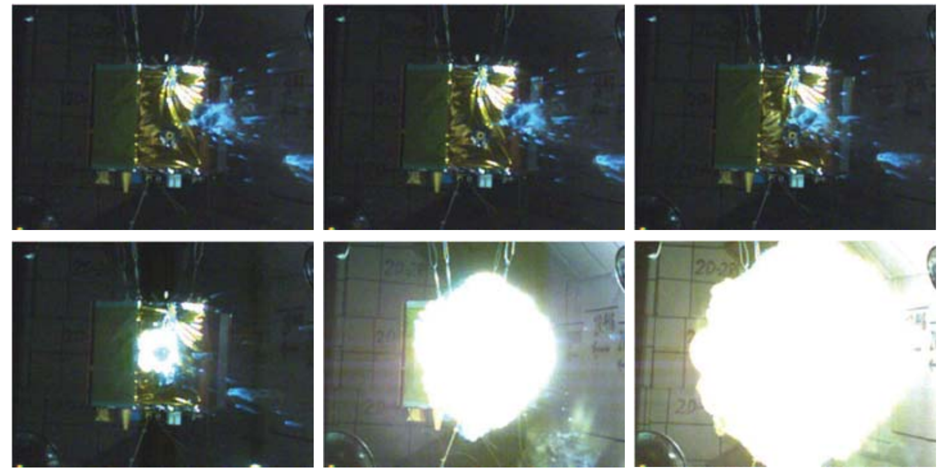
FUTURE WORK
- Survey the "containerized" satellite community to assess their impact on space debris in LEO
- Complete analysis of survey results
- Report findings to FAA, NASA ODPO, IADC, AIAA SmSTC

DebriSat – Hypervelocity Impact

- Performed at USAF Arnold Engineering Development Complex Range-G which operates the largest two-stage light gas gun in the U.S.
- Diagnostic instruments include X-rays, high-speed Phantom cameras, lasers, IR cameras, piezoelectric sensors, witness plates, etc
- Polyurethane foam panels of various densities were installed inside target chamber to “soft catch” fragments

DebriSat – Hypervelocity Impact

- **DebriSat hypervelocity impact conducted on April 15, 2014**
  - Projectile travelling at 6.8 km/sec at impact with DebriSat
  - Impact released 13.2 MJ of energy



DebriSat – Hypervelocity Impact

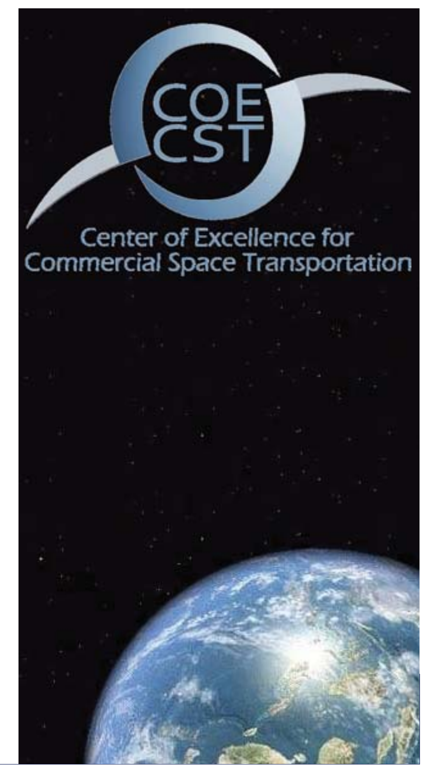
- **After impact, all intact foam panels, broken foam pieces, loose fragments, and dust were carefully collected, documented, and stored**
  - Estimated ≥ 2 mm DebriSat fragments are on the order of 85,000
  - All fragments will be characterized and used to update orbital debris models

COE CST Fourth Annual Technical Meeting

High Temperature Pressure Transducers

William Oates
Justin Collins

October 29-30, 2014
Washington, DC



Outline

- Team Members
- Motivation
- Background
- Experimental results and microscopy
  - Indentation characterization
  - Electron microscopy (SEM, TEM)
- Computational mechanics and uncertainty analysis
  - 1-D low fidelity model
  - 2-D high fidelity model
- Conclusions and future work

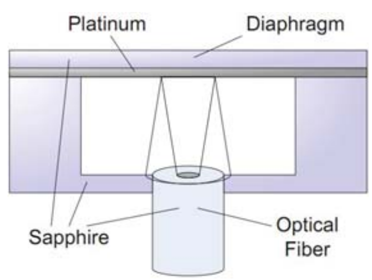
Team Members

- University of Florida
  - Mark Sheplak (PI)
  - David Mills
  - Daniel Blood
- Florida State University
  - William Oates (PI)
  - Justin Collins

Motivation

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

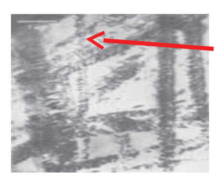
Kulite Pressure Transducer



Conceptual Design

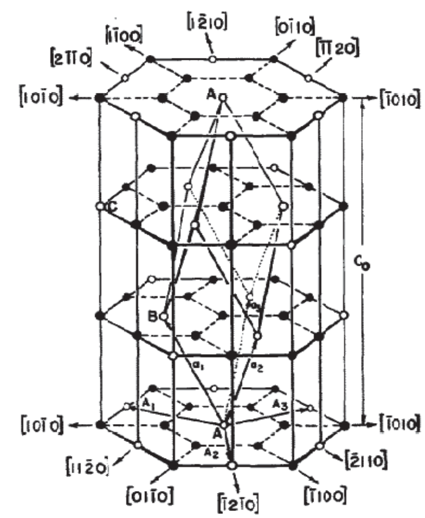
Background

- Sapphire crystallographic structure
  - Complicated by hexagonal cage & internal rhombohedral structure
- *Anisotropic elastic behavior
  - Rhombohedral—not hexagonal
- Melting temperature 2030 °C



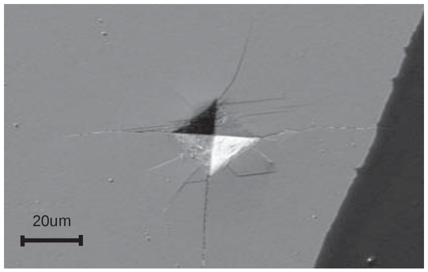
Basal half loop dislocation

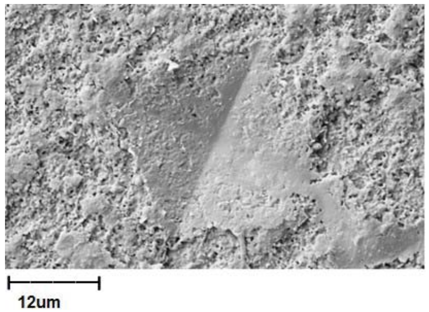
Hockey, Journal of the American Ceramic Society, May 1971, Vol. 54, No. 5



Experimental Results-SEM

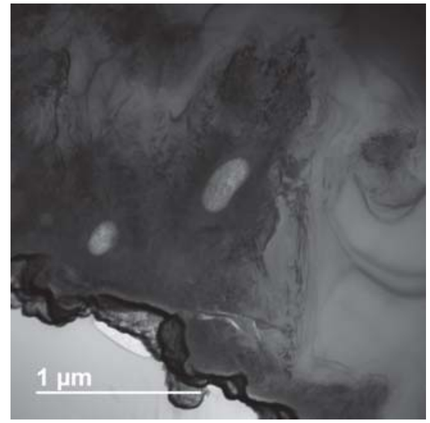
- Vicker's indentation characterization
- No visible cracks in laser machined specimens
- Laser machining parameters
  - 10 kHz rep rate, 10 mm/s scanning speed, 3.8 J/cm2 fluence, 3um stepover

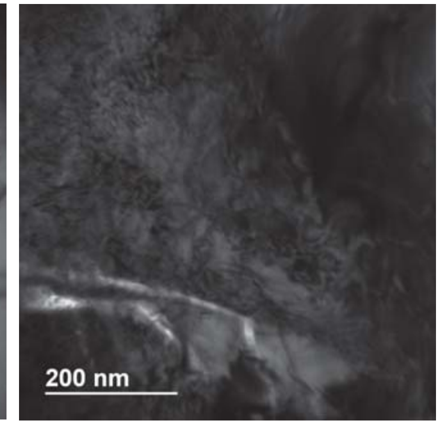




Experimental Results-TEM

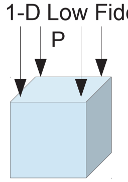
- High resolution TEM located at the NHMFL
  - 0.8 Angstrom resolution



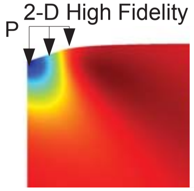


Computational Mechanics Modeling

- Simulate the mechanisms associated with toughening
- Two models
  - 1-D Low Fidelity Model



  - 2-D High Fidelity Model



- Key equations
  - Conservation of Linear Momentum

$$T_{ji,j}=0$$

  - Slip rate density evolution

$$\xi_{i,i}-(\eta-\tau)=\beta\dot{\gamma}$$

  - Plastic deformation

$$\dot{F}^{p}_{iK}-\dot{\gamma}(s_i m_j)F^{p}_{jK}=0$$

Low Fidelity Model

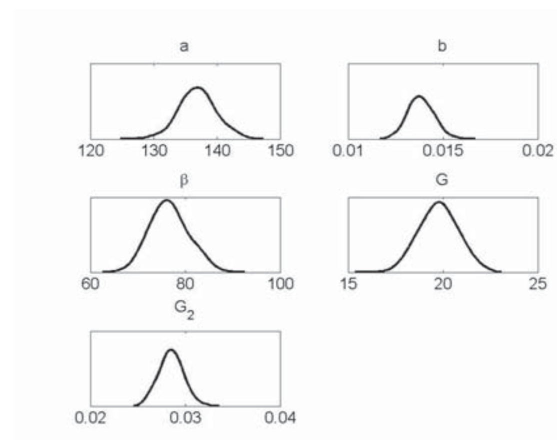
- 1-D Analysis using Bayesian statistics
- Quantifies uncertainty in model parameters

$$\xi_{i,i}-(\eta-\tau)=\beta\dot{\gamma}$$

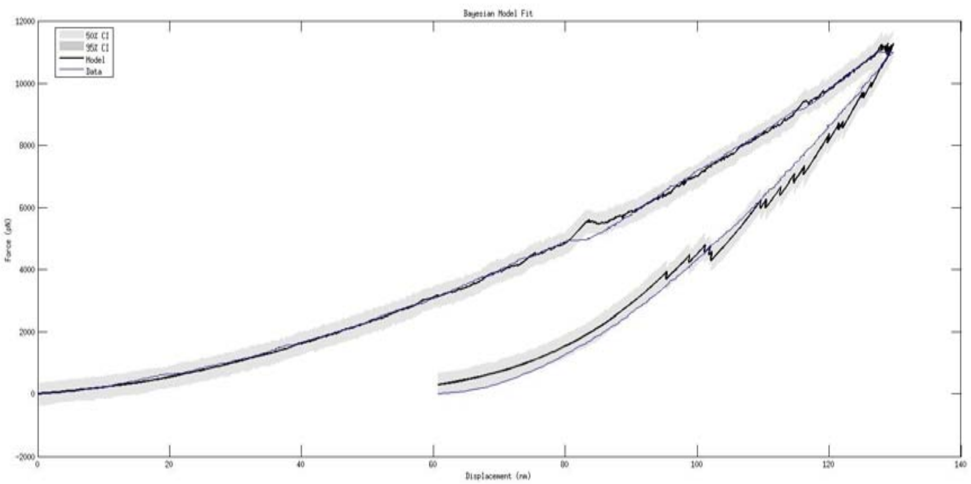
- Where

$$\eta=A\gamma+B\gamma^3$$

$$\tau=Ds_i\sigma_{ij}m_j\approx G\epsilon+G_2\epsilon^2$$

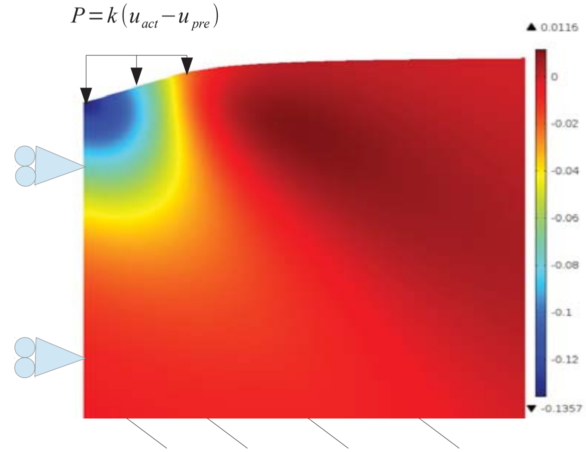


Low Fidelity Model

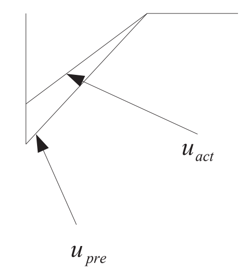


High Fidelity Model-Finite Element Analysis

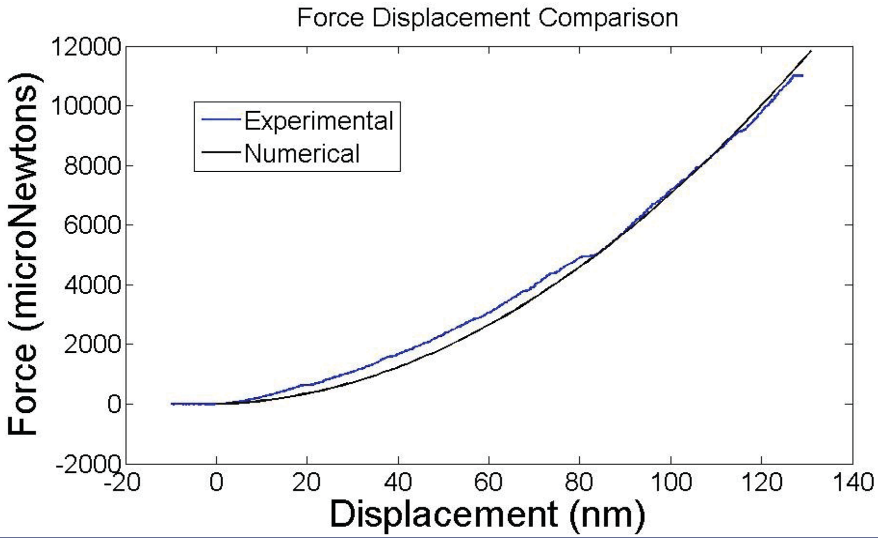
$P=k(u_{act}-u_{pre})$



Schematic of Indentation



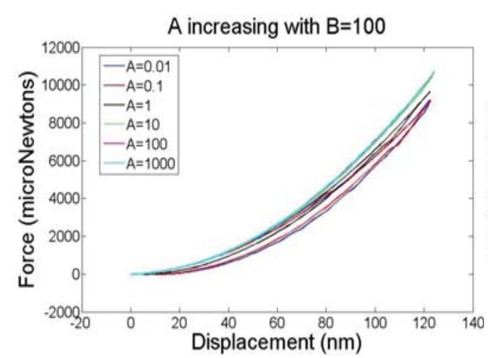
High Fidelity Model-Data Comparison

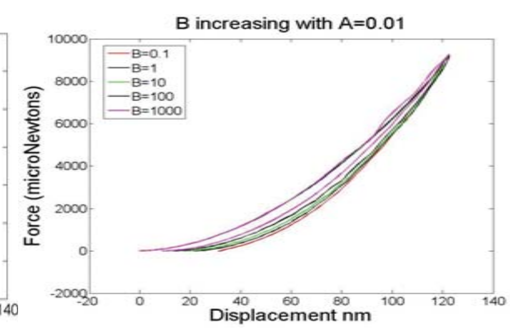


High Fidelity Model-Parameter Analysis

$$\xi_{i,i}-(\eta-\tau)=\beta\,\dot{\gamma}$$

$$\eta=A\gamma+B\gamma^3$$





Summary and Conclusions

- Experimental data showed that there were dislocations in the material due to laser machining process.
- 1-D low fidelity model developed to estimate model parameters and their uncertainty
- 2-D finite element model developed to quantify single crystal dislocation evolution due to a nanoindent during loading

Future Work

- Quantify material hysteresis under different states
  - Material property effects on constitutive behavior sensitive to mechanical damage and laser damage

Contact Information

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  - Associate Professor
  - Email: woates@eng.fsu.edu
  - Phone: (850) 645-0139
  - Fax: (850) 410-6337

High Fidelity Model-Governing Equations

- 2-D Finite Element Model
- Key equations
  - Conservation of Linear Momentum

$$\sigma_{ji,j} = 0$$

  - Slip rate density evolution

$$\xi_{i,i} - (\eta - \tau) = \beta \dot{\gamma}$$

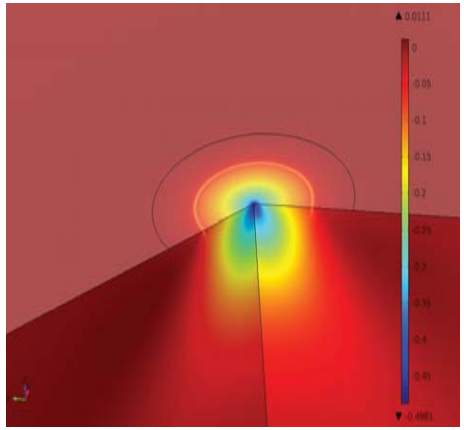
  - Plastic deformation

$$\dot{F}^p_{iK} - \dot{\gamma}(s_i m_j) F^p_{jK} = 0$$

High Fidelity Model-Strain Fields

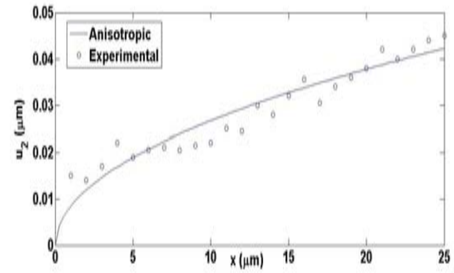
2-D Ezz

3-D Ezz



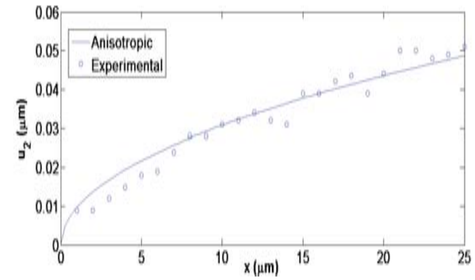
Fracture Toughness

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



Indentation at ~0°

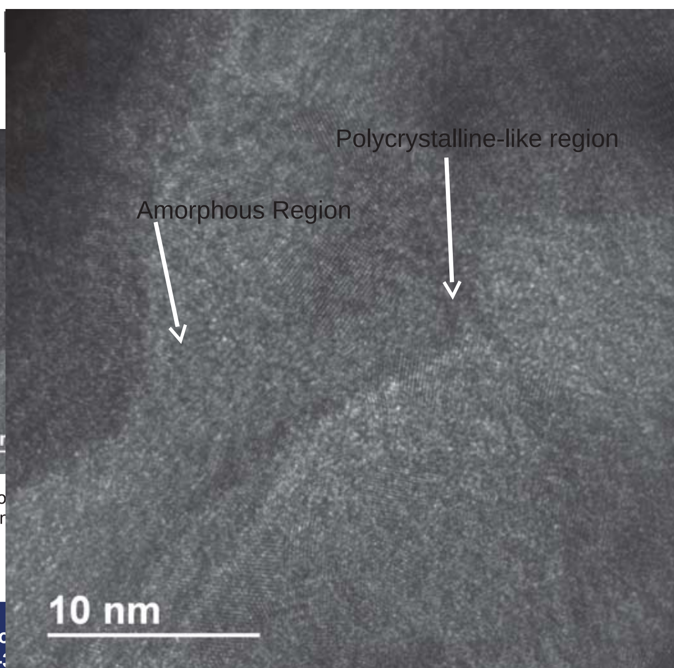
- $K_{1c} \cong 2.50\ MPa * m^{\frac{1}{2}}$
- $J_c \cong 15.25\ \frac{N}{m}$



Indentation at ~45°

21

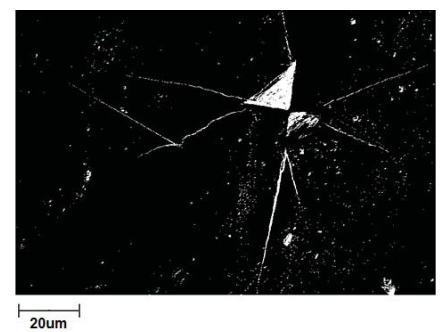
TE



High Reso... like region... between. ...alline

SEM Characterization

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



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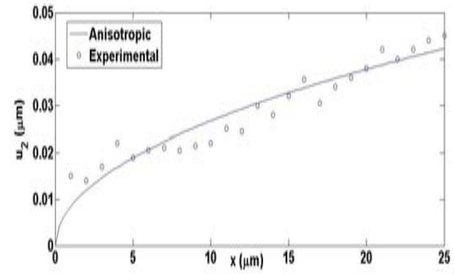
Anisotropic Fracture Stroh's Formalism

- 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
  - $u_i = 2\sum_{j=1}^{3} Re\{Aijf(z_j)q_j\}$
- Generalized Stress potential
  - $\varphi_i = 2\sum_{j=1}^{3} Re\{B_{ij}f(z_j)q_j\}$

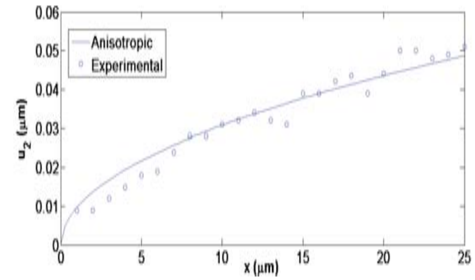
Fracture Toughness

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



Indentation at ~0°

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



Indentation at ~45°

24

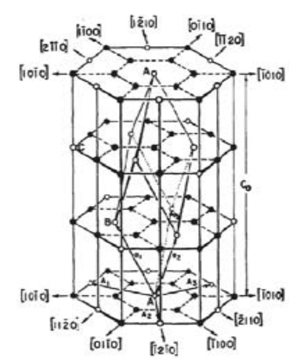
Background

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

25

Introduction

- Crystallographic Structure
  - Hexagonal
  - Rhombohedral



Kronberg, acta metallurgica, vol.5, 1957

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	500.5 ± 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]

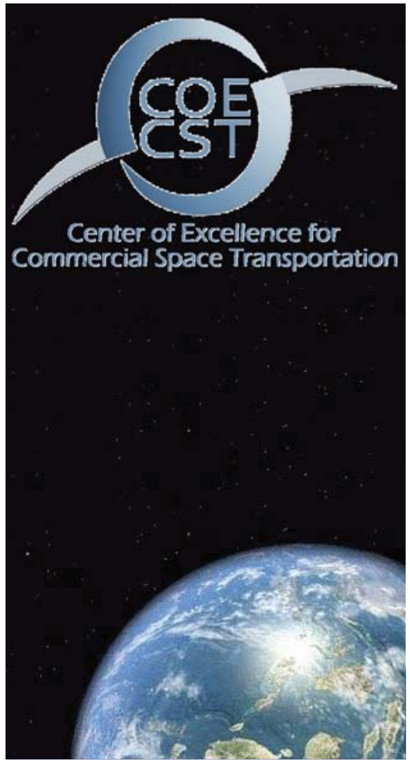
Ohno, *Phys. Chem. Solids Vol. 47, No. 12. pp.* I ION 108. *1986*

COE CST Fourth Annual Technical Meeting

Autonomous Rendezvous and Docking

Dr. Penina Axelrad
Dr. Jay McMahon
Heather LoCrasto
Steve Gehly
Caleb Lipscomb

October 29-30, 2014
Washington, DC



Agenda

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

Team Members

- PI: Dr. Penina Axelrad, University of Colorado Boulder
- Dr. Jay McMahon
- Students: Aerospace Engineering Sciences
  Heather LoCrasto (MS student)
  Steve Gehly (PhD student)
  Caleb Lipscomb, Ricky Rohr (Undergraduate students)

- Industry Partner: Ball Aerospace

Task Description

- Understand the requirements for autonomous rendezvous and docking of commercial spacecraft in LEO for the purposes of material transfer, servicing, or retirement.
- Develop description, requirements, and list of key technologies for ARD mission phases.
- Provide tools for the FAA to establish architecture, requirements, and processes for future ARD operations.
- Evaluate FLASH LIDAR as key technology for ARD and investigate performance for relative navigation and attitude estimation.

Schedule for task completion

- No-cost extension provided through May 2015.
- Complete remaining mission phase requirements and technology gap analysis by Dec 2014.
- Complete LIDAR image processing to be integrated with OLTAE algorithms by Dec 2014.
- Establish complete case study for LIDAR use in approach phases by February 2015.
- Evaluate methods and requirements for non-cooperative unknown targets by May 2015.

Goals

- **Motivation**:
  - 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**
  - Develop an approach for ARD standards and identify/resolve 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

Commercial AR&D Mission Types

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

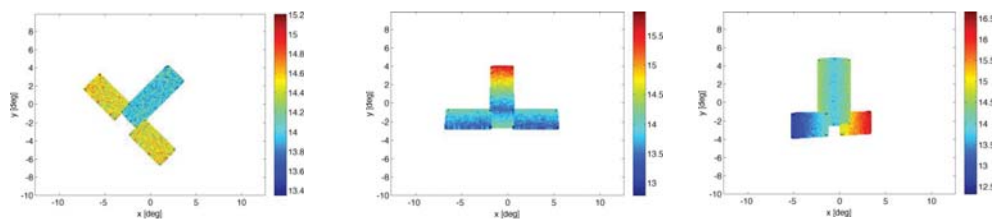
Phase	~Range	Objective	Sensor	Safety
Launch	>10,000 km	• Insert chaser into orbit in same orbit plane, below target	GPS	Resume mission on nav failure
Phasing	>5 km	• Reduce range to target • Chaser acquires initial aimpoint for approach	GPS	
Homing/Closing	3500-250 m	• Relnav • Reach then enter approach 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 Concepts for Requirements

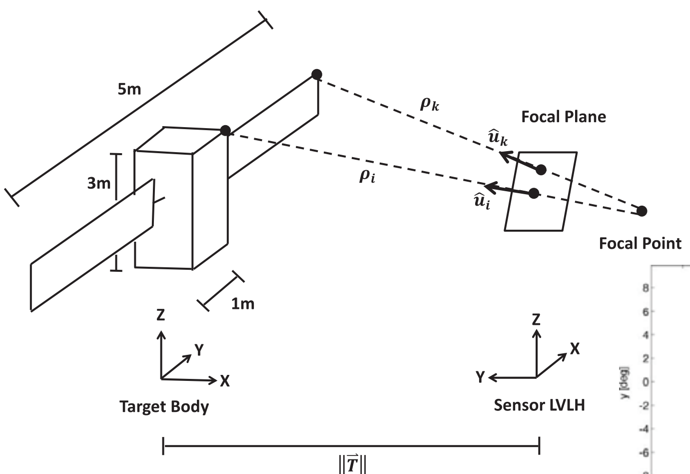
- Availability of sensors for long-range phases not required 100% because hold can be used
- Closing phases require 100% availability
- Use of passive-safe trajectories in final approach phase.
  - When aimpoint is at the target
  - Thruster failure only to off
  - Loss of communications or sensors (stops thruster firing)
- Timing of ARD is flexible if visual sensors and ground monitoring are not required
- Max relative velocity for final approach, mating, & joint maneuvers, must be determined to avoid damage to vehicles

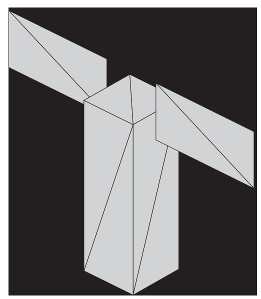
Flash LIDAR Use for ARD

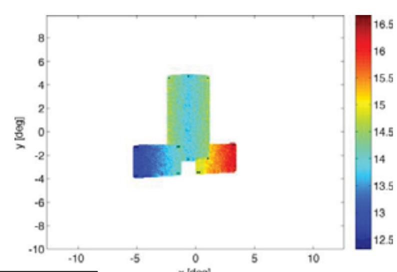
- Flash LIDAR instrument serves as a “3D Camera” with intensity and range for each pixel
- High frame rates (up to ~30 Hz)
- Eliminates slewing/pointing/search requirements of single-beam systems
- Not dependent on ambient lighting conditions
- Can be used from mating to few km range



FLASH LIDAR & TARGET S/C

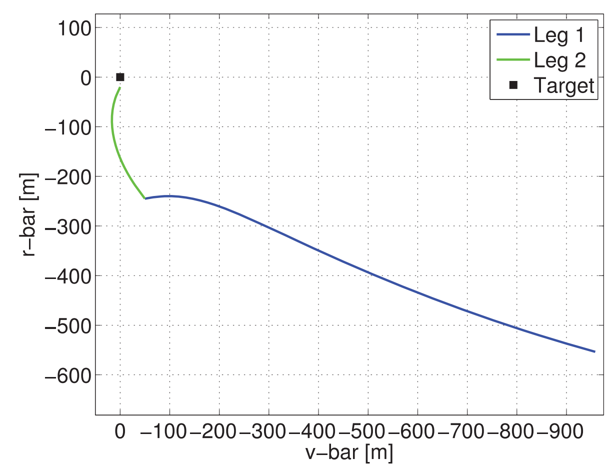






128 x 128 pixels, 20 degree FoV, 30 Hz
Range noise ~ 1% of range (from R. Rohrschneider at Ball)

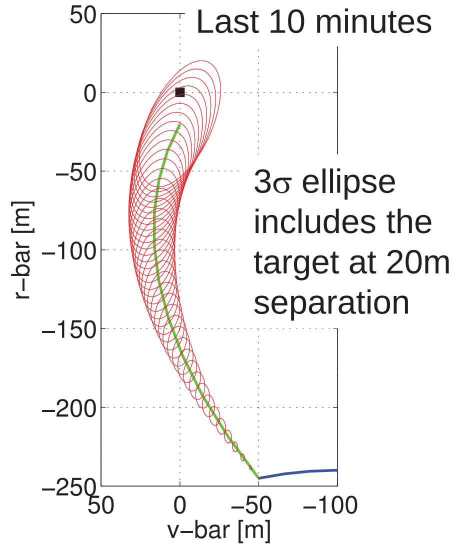
Approach Trajectory

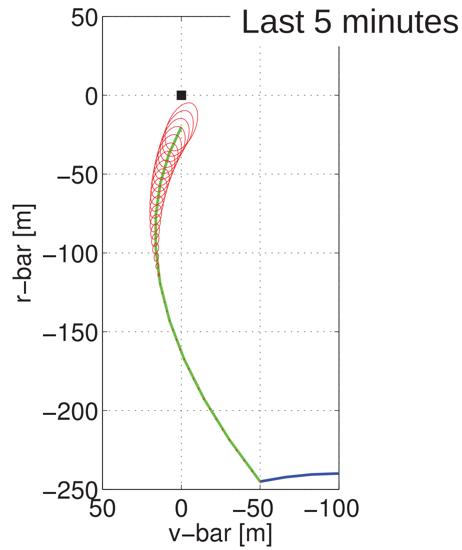


- **Leg 1:** 1.1km to 250m in 30 minutes
- **Leg 2:** 250m to 20m in 10 minutes
- For most of the approach target dimension is negligible
- Estimate the position of the center of figure, which is offset from the true center of mass.
- Accuracy is well within requirements with continuous observations

3σ pos err < 1m at 100m range, vel err < 10cm/s with 1-s updates

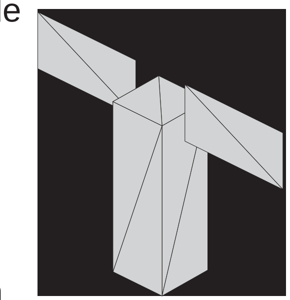
Loss of Measurements

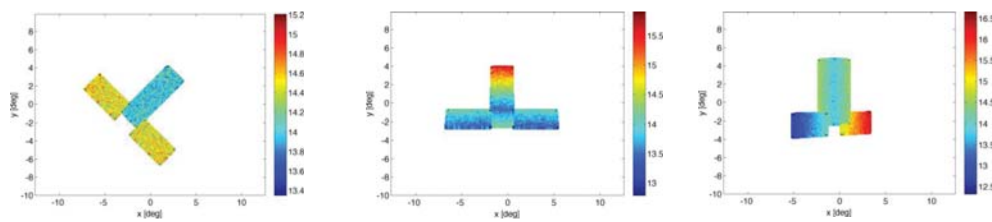




Relative Position and Attitude

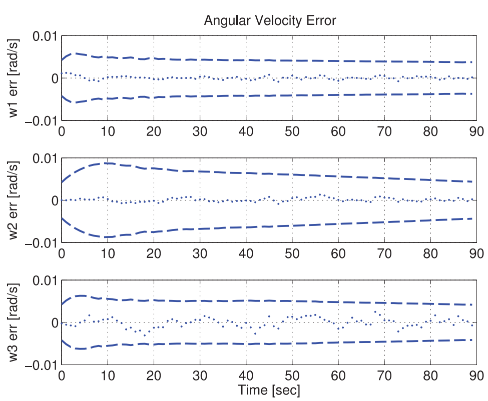
- Within 250 m start solving for pos + attitude
- Use corners of s/c as feature points
- Assume 1cm 1-σ ranging errors, and 1 pixel 1-σ angle errors
- Range from 20 m to 5 m in 90 s
- We assume features are matched
- Use OLTAE algorithm to get point solution

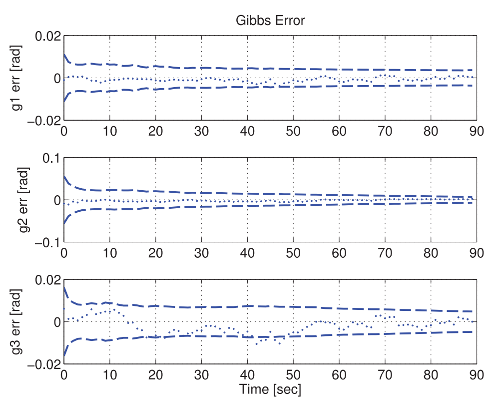




Filtering

- Use EKF or UKF with OLTAE solutions for position and Gibbs vector as measurements





Reports and Papers

- McMahon, J., S. Gehly, and P. Axelrad, "Enhancing Relative Attitude and Trajectory Estimation for Autonomous Rendezvous Using Flash LIDAR," *AIAA/AAS Astrodynamics Specialist Conference*, San Diego, CA, August 4-8, 2014.

LoCrasto, H. and P. Axelrad

- CU_FAA_Task244_Background_Summary_Report_2013-06-19
- CU_FAA_Task244_Mission_Phases_Report_2013-10-01
- CU_FAA_Task244_Requirements_Report_2014-07-24

Conclusions and Future Work

- Continuing to work to identify and quantify key requirements for ARD missions using existing requirements and standards documents and lessons learned from past missions
- Optimize approach trajectories for maximum information gain/robustness
- Currently working on Flash LIDAR image processing for feature identification, using Argos P100 time-of-flight camera

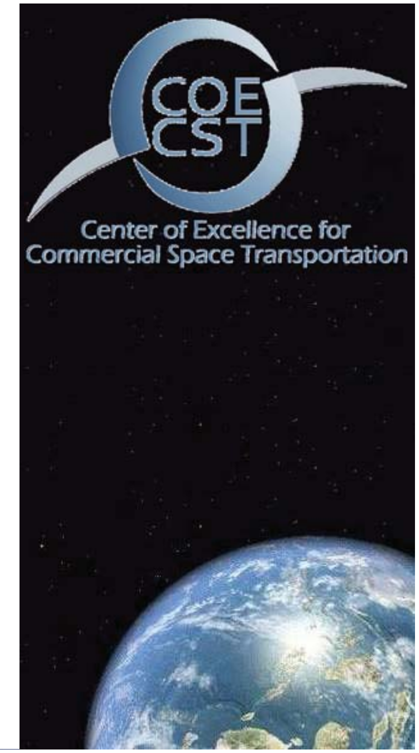
COE CST Fourth Annual Technical Meeting:

Ultrahigh Temperature Composites for Thermal Protection Systems (TPS)

Hongjiang Yang, Donovan Lui,
Jay Kapat, Jan Gou

Department of Mechanical and Aerospace Engineering
University of Central Florida

October 29-30, 2014
Washington, DC



Agenda

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

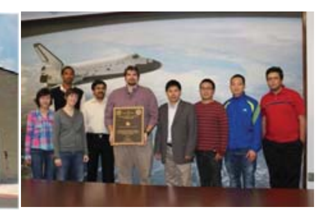
Team Members

Principle Investigators

- **Jan Gou -** Composite materials and structures, nanocomposite materials, advanced composites manufacturing: PMCs, CMCs and C/C composites
- **Jay Kapat -** Heat transfer, film cooling, aerodynamics testing

Graduate Students

- **Hongjiang Yang**: nanocomposite materials, design, manufacturing, characterization and testing of composite materials
- **Donovan Lui**: Ablation testing and CMC fabrication



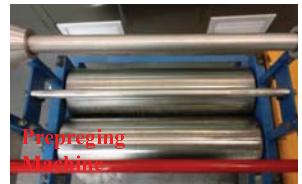
Task Description

Develop **anisotropic** thermal conductivity, **ultrahigh temperature**, **light weight** and **cost effective** carbon nanotube preform reinforced polymer derived ceramics (PDC) matrix composites for thermal protection systems.

STATEMENT OF WORK

- Develop carbon nanotube preforms (vertically aligned carbon nanotube (VACNT) arrays and buckypapers) for ceramic composites
- Design and fabrication of polymer derived ceramics (PDC) based ceramic matrix composites.
- Ground testing of CMC thermal protection systems with Oxyacetylene Exposure Test, Shock Tube Test and Hot Jet Facilities.
- Multi-scale modeling of CMC thermal protection systems.

Manufacturing of CMCs



Manufacturing of Fiber Reinforced Polymer Derived Ceramics (PDC) Composites

Prepregging with Resin Impregnator

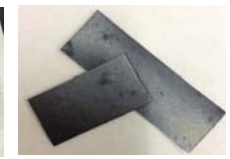
Prepreg woven fiber fabrics (ceramic fiber, carbon fiber, glass fiber, etc.) with polymer derived ceramics (PDC) resin

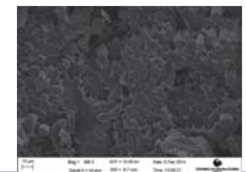
Autoclave Curing

PDC resin curing in an autoclave with computer control over all process variables (max pressure 200 psi, max temperature 800ºF) to become a greenware

Pyrolysis in Kiln

Pyrolyze the greenware into a ceramic part (max temperature 1,200 ºC)





Polymer Derived Ceramics Matrix

Property	Starfire System Polysiloxane(PSO)	Starfire System Polycarbosilane (PCS)
Denotation	SPR-688/SPR-212	SMP-10
Operating temperature	1,100 °C	1,800 °C
Density	1.11 g/cm^3	0.998 g/cm^3
Catalyst	Platinum CAT-776	Dicumyl Peroxide

Ceramic Precursor → Cure Cycle → Pyrolysis Cycle

High performances:

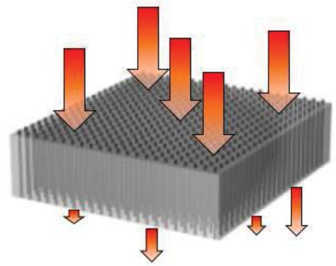
- Low cost
- Near net shape manufacturing
- Outstanding thermo-chemical stability

High Temperature Ceramic Fibers

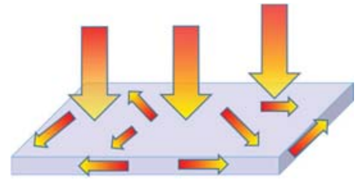
Trade-Name	Manufacturer	Use Temperature	Cost ($/Kg)	Filament Diameter (μm)	Density(g/cc)	Tensile Strength (MPa)	Tensile Modulus (GPa)	Composition	Thermal Expansion (Ppm/°C)
T300	Toray	300~350 °C	68	7	1.74	3100	230	C	-0.7
Nextel 720	3M	1204 °C	660	10~12	3.4	2930	260	Al_2O_3/SiO_2	6
SCS-Utra	Specialty Material	1371 °C	~9000	142	3.08	3900	380	SiC	4.1
SiC-1900X	MATECH	~ 1482 °C	-	10~12	3.14	2500	367	β-SiC	-
Nicalon NL-200	Nippon Carbon	1100 °C	~2000	14	2.55	3000	220	SiC	3.1-3.2
Hi-Nicalon	Nippon Carbon	1230 °C	8000	14	2.74	2800	270	SiC	3.3-3.5
Hi-Nicalon Type S	Nippon Carbon	1450°C	13000	12	3.1	2600	420	SiC	3.5
Sylramic	COI Ceramics	1420 °C	10000	10	3.55	3200	380	SiC	5.4
Tyranno SA 1-3	Ube Industries	1700 °C	5000	10	3.02	2800	375	SiC	-

Research Methodology

Control the direction of heat transfer "pathway" by arranging the orientation of carbon nanotubes: through-thickness direction and in-plane direction



VACNT Array



Buckypaper

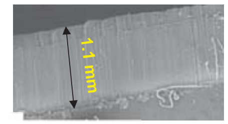
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

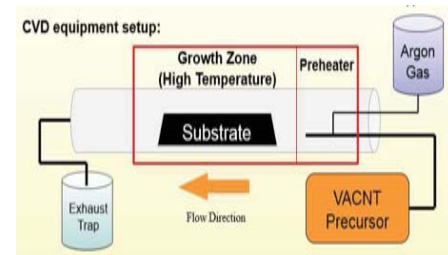
Ultra-high temperature, light weight, highly anisotropic thermal properties and cost effective thermal protection systems (TPS) are enabling technologies for viable commercial space transportation vehicles and their high-temperature systems.

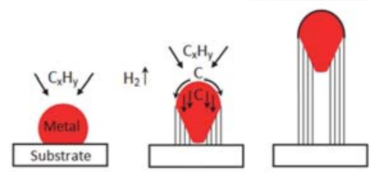
Research Methodology

Vertically Aligned Carbon Nanotubes (VACNT)

- Grown by Chemical Vapor Deposition (CVD)
- Highly anisotropic properties







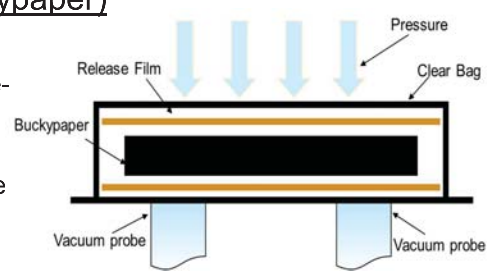
Chemical Vapor Deposition (CVD) Mechanism

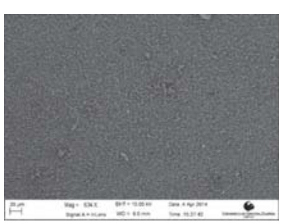
Tube Furnace

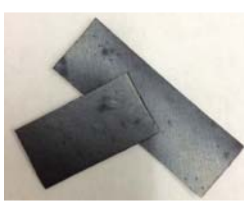
Research Methodology

Carbon Nanotube Paper (Buckypaper)

- Manufactured by using the pressure-assisted infiltration process
- Carbon nanotubes are aligned in the plane





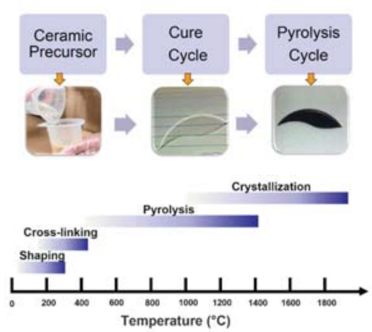


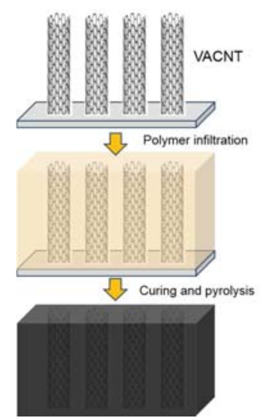
Buckypaper + PDC matrix

Autoclave

Research Methodology

Polymer Infiltration Process(PIP)





- ➢ Near net shape manufacturing
- ➢ Outstanding thermochemical stability
- ➢ Lower pyrolysis temperature, lower energy consuming

Kiln

VACNTs + PDC matrix

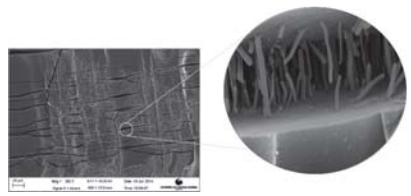
Results

Electrical conductivity in two directions

Sample	Conductivity Through-thickness σ (S/m)	Conductivity In-plane σ (S/m)
Buckypaper/PDC	~ 0	0.161
VACNT/PDC	80.1	~ 0

Hardness

Samples	Hardness (GPa)
Buckypaper/PDC	2.5
VACNT/PDC	1.85
Pure PDC	8.5



- Alignment in the nanocomposite
- VACNTs have a good bonding with PDCs

Conclusions

- Vertically aligned carbon nanotube (VACNT) forest was successfully grown with good quality.
- The VACNT/PDC ceramic composite was fabricated through curing and pyrolysis procedures.
- The highly anisotropic conductivity was observed.
- Scanning electronic microscopic images indicate that small cracks and pores have been developed after the PDC pyrolysis. The fracture toughness of the ceramic composite could be improved.

Future Work

- Resin transfer molding (RTM) process with carbon nanotube preforms will be designed to solve the shrinkage problem in PDC curing and pyrolysis cycles.
- Thermal conductivity in both in-plane and through-thickness directions will be characterized.
- Ground testing of ceramic composites will be conducted with Oxyacetylene Exposure Test, Shock Tube Test and Hot Jet Facilities

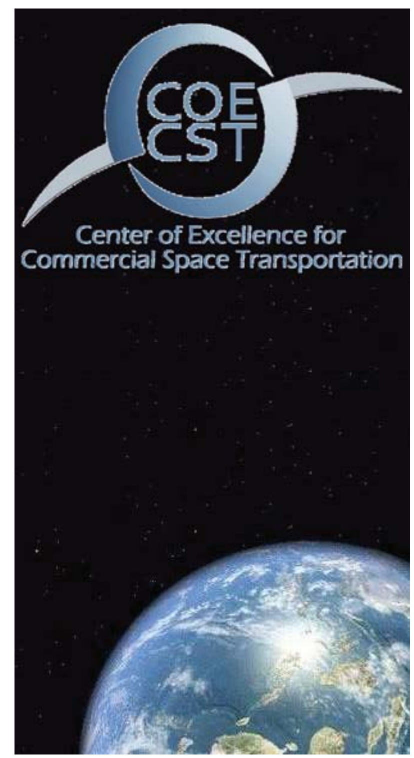
COE CST Fourth Annual Technical Meeting

Analysis Environment for Safety Assessment of Launch and Re-Entry Vehicles

Task 258

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

October 29-30, 2014
Washington, DC



Overview

- Team Members
- Purpose of Task
- Research Methodology
  - -Range Safety Assessment Tool (RSAT)
  - -Surrogate Modeling for Uncertainty Quantification (UQ) and Optimization
- Results / Progress to Date
- Conclusions / Future Work

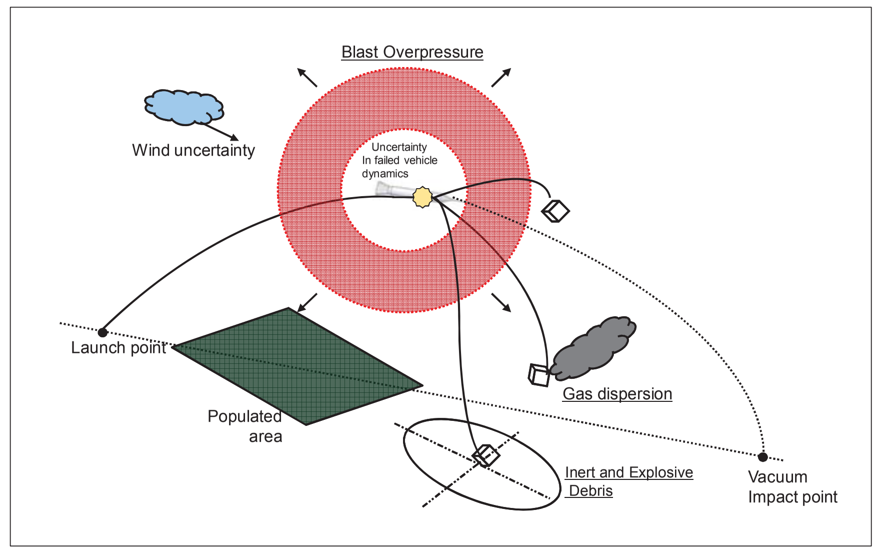
Team Members

- 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 analysis tool capable of quantifying the safety of the uninvolved public due to launch and re-entry vehicle malfunctions.
- To study uncertainty effects on the current safety metrics and evaluate if they are appropriate for a 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.

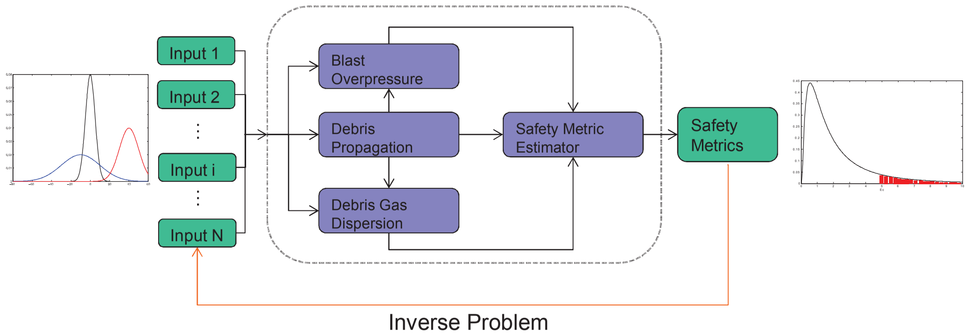
Range Safety Assessment Tool (RSAT)



Safety Analysis Environment Schematic

RSAT

- Main focus is on safety to the uninvolved public (expected casualties).
- There are 3 main modeling modules.



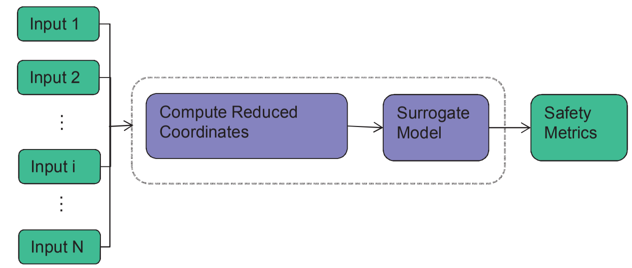
- Results obtained by solving the inverse problem could be used to inform licensing restrictions or influence design.

*Details in "Range Safety Assessment Tool (RSAT): An analysis environment for safety assessment of launch and reentry vehicles (AIAA 2014-0304), Francisco M. Capristan, Juan J. Alonso, 52nd Aerospace Sciences Meeting, 2014, 10.2514/6.2014-0304"

UQ and Optimization

Some of the challenges include:
- The cost for each evaluation, coupled with the large number of samples required for UQ demand large computational resources.
- The value of interest tends to be noisy due to the stochastic nature of the problem.
- Most methods suffer from the curse of dimensionality.

We are proposing the use of Active Subspaces to decrease the dimensionality of the problem and apply Gaussian Process Regression (GPR) as the surrogate to decrease the computational cost.



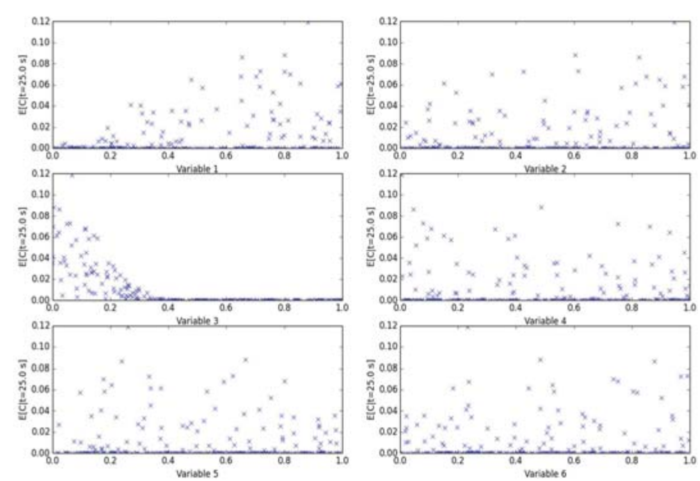
Results

- Generic ELV vehicle launching towards ISS orbit.
- Aerodynamic data obtained from Missile Datcom.
- SPOT was used to generate optimal trajectories.
- Wind variations obtained from Earth GRAM.
- Performed Ec calculation due to inert and explosive debris.

95

Results

- Uncertainty effects on E(C|t=25 sec)

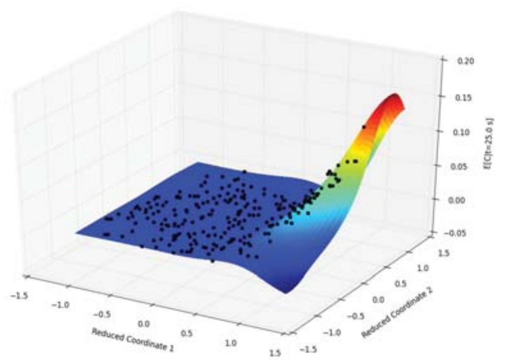


Only 6 variables shown from a total of 47.

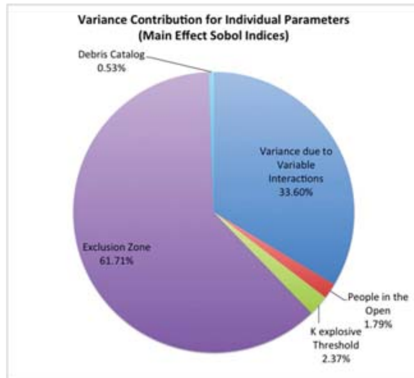
Can we do anything with this data?

Results

E(C|t=25 sec) can be approximated by two reduced coordinates. The surrogate model does a good job capturing the location of the test points.

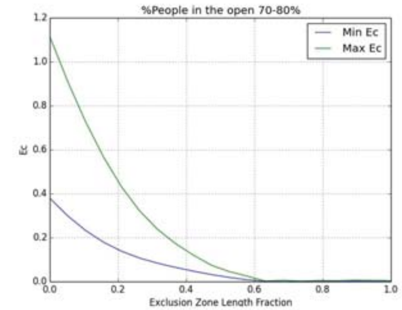


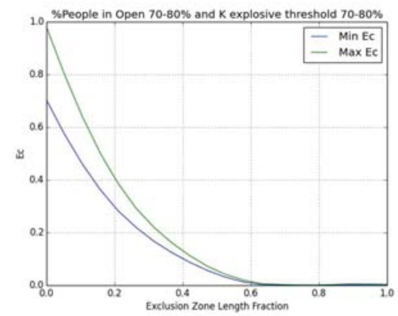
Surrogate Model with Reduced Coordinates

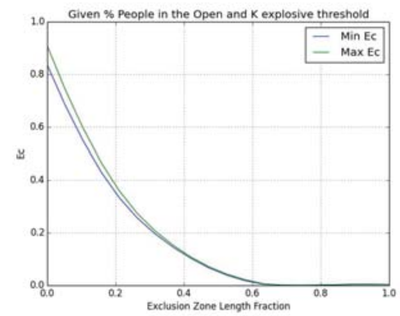


Results

- Consider the best and worst possible E(C) scenarios given different exclusion zones sizes.
- The surrogate model is used to do the optimization.
- The low cost of evaluating the surrogate allows the creation of histograms for E(C|params).







Conclusions

- The Range Safety Assessment Tool (RSAT) considers:
  - Nominal and off-nominal trajectories
  - Failure Probabilities
  - Wind variations
  - Population density
  - Sheltering (roof types)
  - Debris Catalogs
  - Exclusion zones
- Active subspaces coupled with GPR help provide surrogate models that can be used to perform UQ and optimization.
- RSAT can compute global sensitivity analysis for an entire trajectory.
- Initial optimization runs suggests that the current methodology could help identify inputs that could lead to worst case scenarios.

Ongoing and Future Work

- Further investigate how input uncertainties affect E(C) calculations.
- Use RSAT to analyze other vehicle configurations (e.g. suborbital vehicles).
- Identify parameters of interest to solve the inverse problem.
- Demonstrate how inverse solutions can be used in the context of licensing or setting mission requirements.

Contact Information

- Juan J. Alonso jjalonso@stanford.edu
- Francisco M. Capristan fcaprist@stanford.edu

Backup Slides

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

Safety Assessment Tool

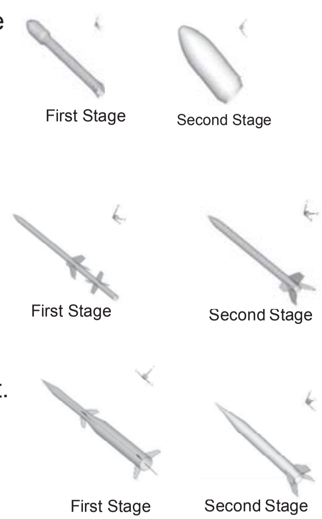
- Inputs
  - Nominal and off-nominal trajectories
  - Failure Probabilities
  - Wind variations
  - Population density
  - Sheltering (roof types)
  - Debris Catalogs:
    - Size/number of pieces
    - Aerodynamic characteristics
- Outputs
  - Monte-Carlo-like debris locations
  - Expected Casualties

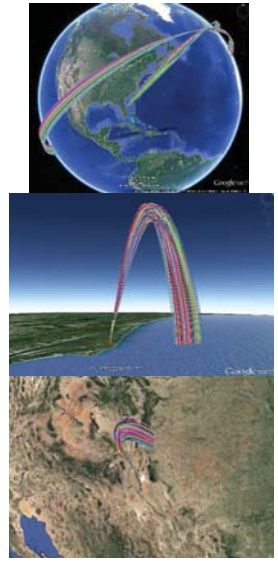
Sample Trajectories

Falcon 9 type vehicle to the ISS orbit

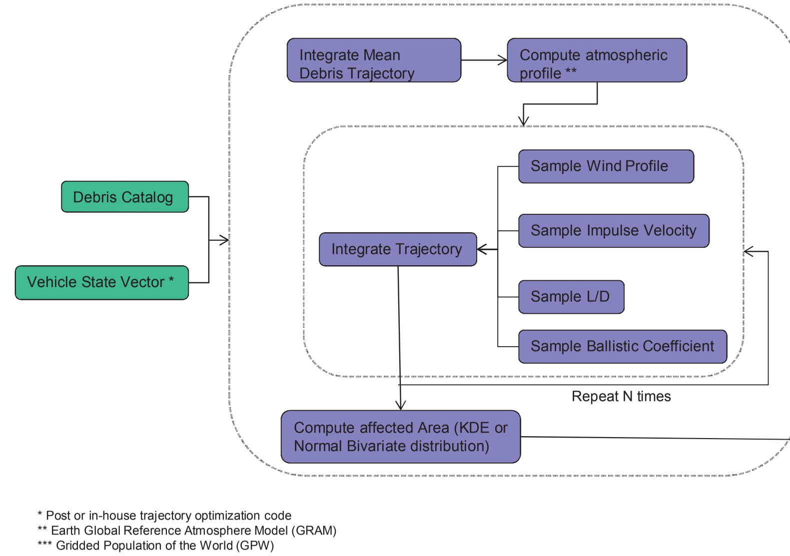
Stratos II Sounding Rocket. ~60 km Altitude

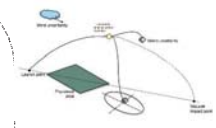
SONDA III Sounding Rocket. ~600 km altitude





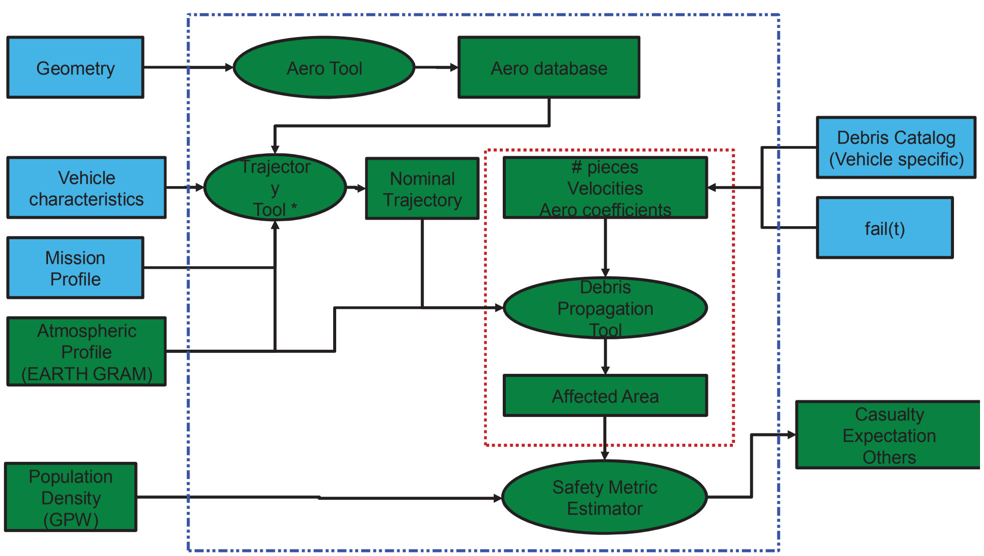
Analysis Environment: Debris Propagation





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

Debris Modeling



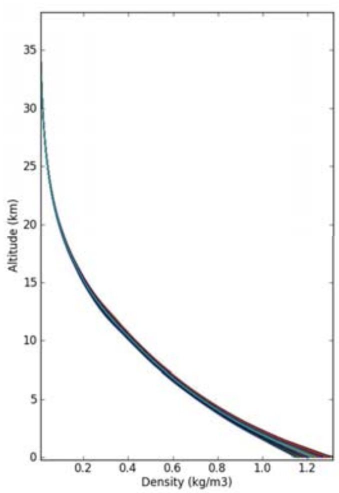
* Access to POST or Stanford Trajectory Optimization Program (STOP)

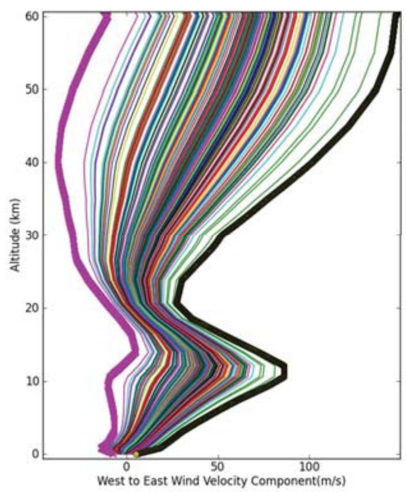
Debris Modeling

- 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.
  - Affected ground area obtained by using Kernel Density Estimation or assuming a Normal Bivariate distribution

Debris Propagation

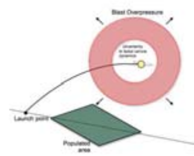
Uncertainty in atmospheric parameters



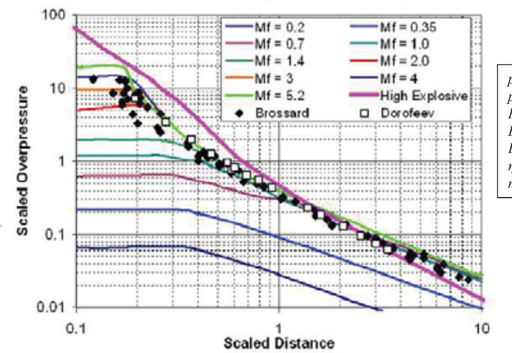


Analysis Environment: Blast Overpressure

- 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.



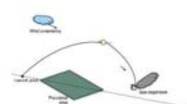
$$E_t = \eta_p m_p E_{TNT} \qquad \bar{P} = \frac{p - p_0}{p_0} \qquad \bar{R} = \frac{R}{E_t / p_0^{1/3}}$$



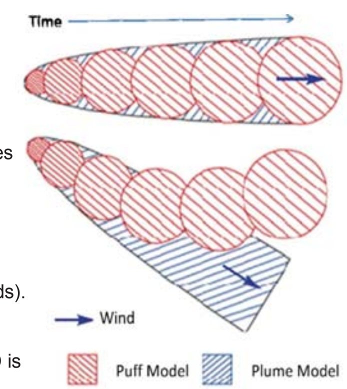
p_0 atmospheric pressure
p absolute peak pressure
R stand-off distance
E_{TNT} blast energy per unit mass of TNT
E_T blast energy
η_p yield factor
m_p propellant mass

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

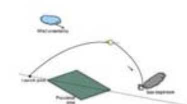


- The most common air dispersion models are Plume and Puff types.
- Modeling systems considered :
  - CALPUFF => Puff
  - AERMOD => Plume
- AERMOD :
  - Steady state model which assumes that a plume disperses in the horizontal and vertical directions.
  - Plume follows the wind direction in a straight 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.

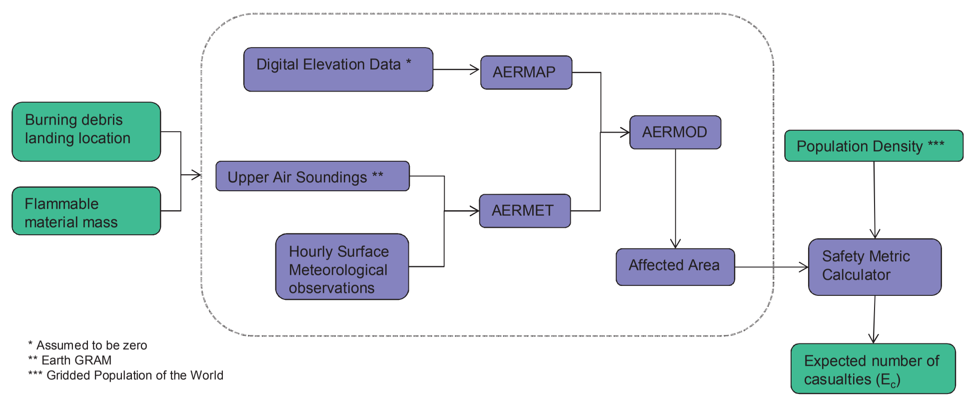


*Integrated Environmental Solutions White Paper – Puff and Plume Models

Analysis Environment: Gas Dispersion



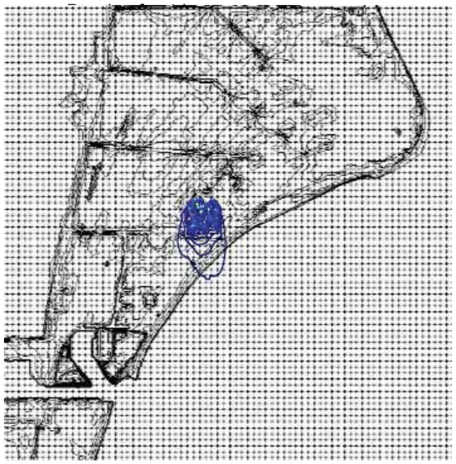
- Currently using AERMOD (Atmospheric Dispersion Modeling):
  - Tool used by the U.S Environmental Protection Agency (EPA) for regulation purposes.
  - It incorporates air dispersion based on planetary boundary layer turbulence structure and scaling concepts, including treatment of both surface and elevated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

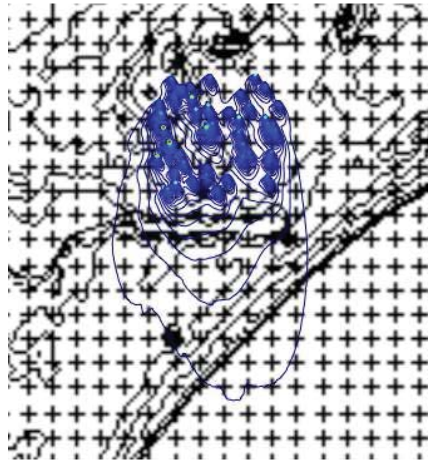


* Assumed to be zero
** Earth GRAM
*** Gridded Population of the World

Gas Dispersion Simulation

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





Technical Approach

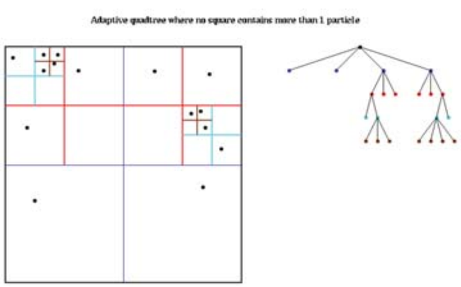
Risk area debris formulation

$X_i = [Latitude_i, Longitude_i]^T$

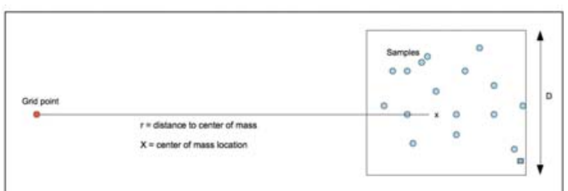
Normal Bivariate	Kernel Density
$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$	$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$
$S = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})(X_i - \bar{X})^T$	$S = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})(X_i - \bar{X})^T$
$\hat{f}(x) = \frac{1}{2\pi\sqrt{det(S)}} e^{\frac{1}{2}(x-\bar{X})^T S^{-1}(x-\bar{X})}$	$\begin{bmatrix} S_1 & 0 \\ 0 & S_2 \end{bmatrix} = U^{-1} S U$ Compute eigenvalues and eigenvectors
	$U = \begin{bmatrix} s_x & -s_y \\ s_y & s_x \end{bmatrix}$
	$[P_i \quad Q_i] = X_i^T U$ 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 Clonek, 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

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

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

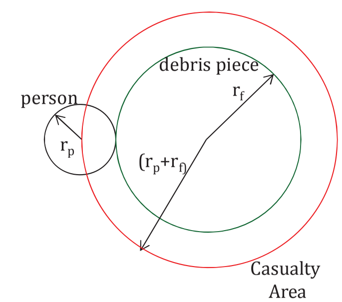
Expected Casualty Calculation

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

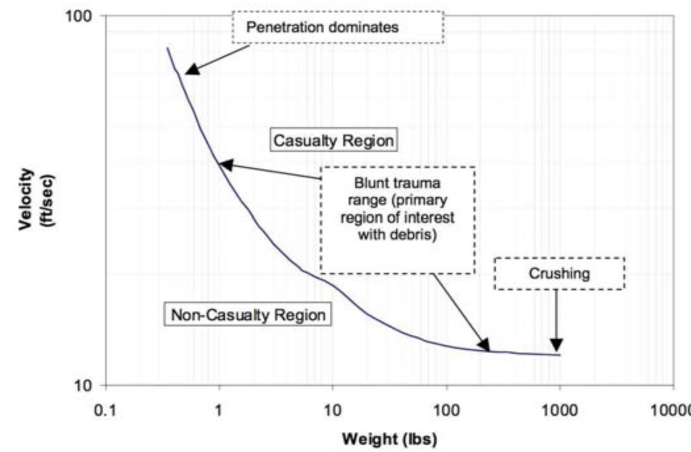
* "A Hazard Model for Exploding Solid-Propellant Rockets" J.C. McMunn, et al.

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

$$P_{I_{ij}} = f(\vec{r}, \vec{v}, a\vec{e}ro)$$
$$A_{C_{k_r}} = g(m) \quad , r \geq 1$$
$$E_{1k}(\vec{A_{C_k}}, \vec{r}, \vec{v}, a\vec{e}ro) = \sum_{i=1}^{n}\sum_{j=1}^{m}(P_{k_{I_{ij}}}[A_{C_{k_0}}\rho_{ij}c_0 + \sum_{r=1}^{\#roofs}(A_{C_{k_r}}\rho_{ij}c_r)])$$
$$E_k(\vec{r}, \vec{v}, a\vec{e}ro) = \sum_{i=1}^{n}\sum_{j=1}^{m}(P_{k_{I_{ij}}}[E(A_{C_{k_0}})\rho_{ij}c_0 + \sum_{r=1}^{\#roofs}E(A_{C_{k_r}})\rho_{ij}c_r])$$
$$E(A_{C_{k_r}}) = \int_0^{\infty} g(m)p(m)\,dm \quad , r \geq 1$$

$P_{I_{k_{ij}}}$ => 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

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

$$\vec{c} = e_1 e_2 O\vec{o} + s_1 s_2 \vec{q} + (1 - e_1 e_2 - s_1 s_2)[(1 - d - v)H\vec{h} + (0\ \ 0 \ldots v\ \ d)^T]$$

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

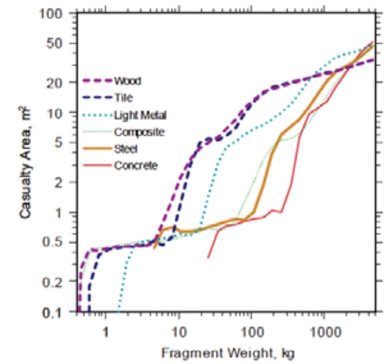
*Formulation from "Large Region Population Sheltering Models for Space Debris Risk Analysis. Eric W.F Larson"

Safety Metric Estimator

.Roof Models

- Casualty Area of Roof Penetration Models

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



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

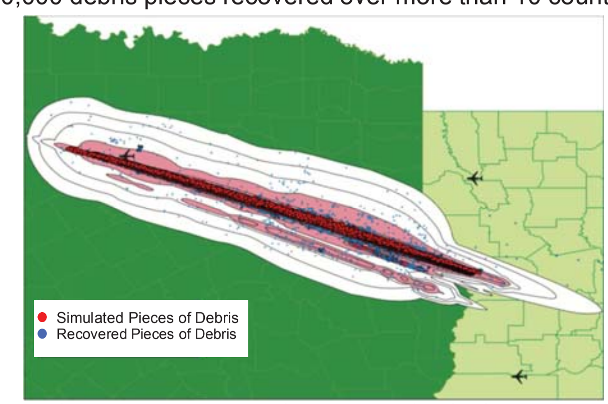
Validation Test Cases

- 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

Validation Test Case

STS-107 Columbia Accident

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

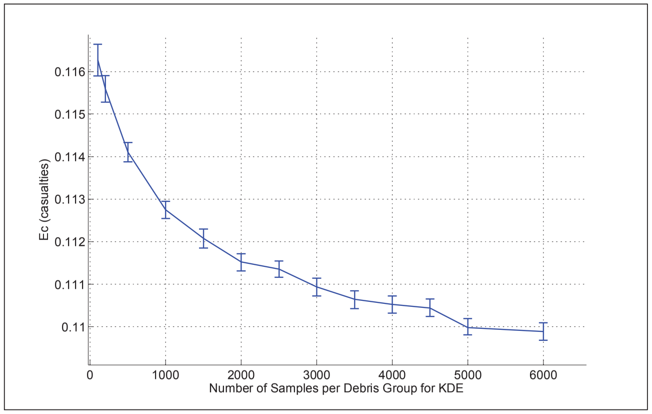


Columbia Accident Debris Locations Comparison (original figure from CAIB Report)

Validation Test Case

STS-107 Columbia Accident

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



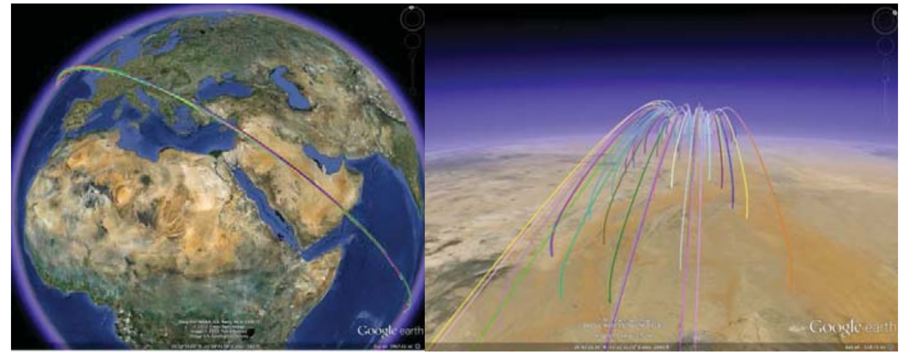
Casualty Expectation Convergence

	% People in the open	E_c
CAIB Report*	18.7	0.14
Simulation	18.7	0.11

*Results from Columbia Accident Investigation Board

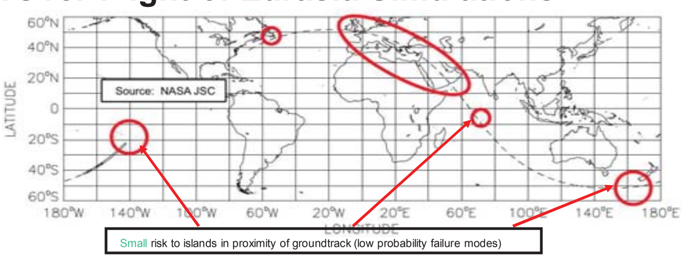
STS-111Over-Flight of Eurasia Simulations

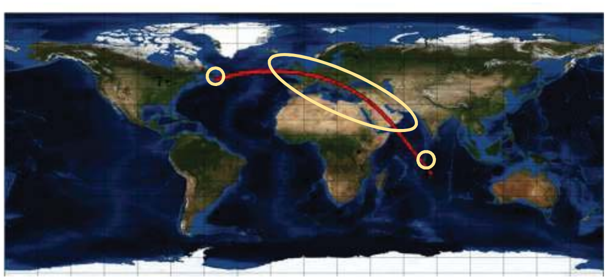
- Stage II, on trajectory, orbiter failures.
- Reentry breakup altitude ~ 250,000 ft.
- Failure times 490-500 seconds.
- Orbiter debris catalog from Columbia accident.
- 3-sigma trajectories provided by Paul Wilde.



Simulated Debris Trajectories

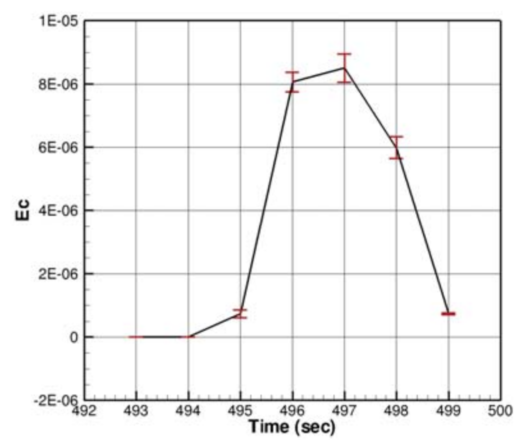
STS-111Over-Flight of Eurasia Simulations





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.

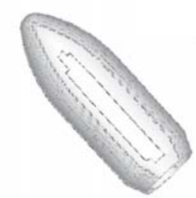
Debris Location spread due to uncertainties in initial debris velocity

Debris location spread due to uncertainties in :
- Ballistic coefficient.
- L/D.
- Wind.
- Atmospheric density.

Sample Test Case
ELV to ISS orbit

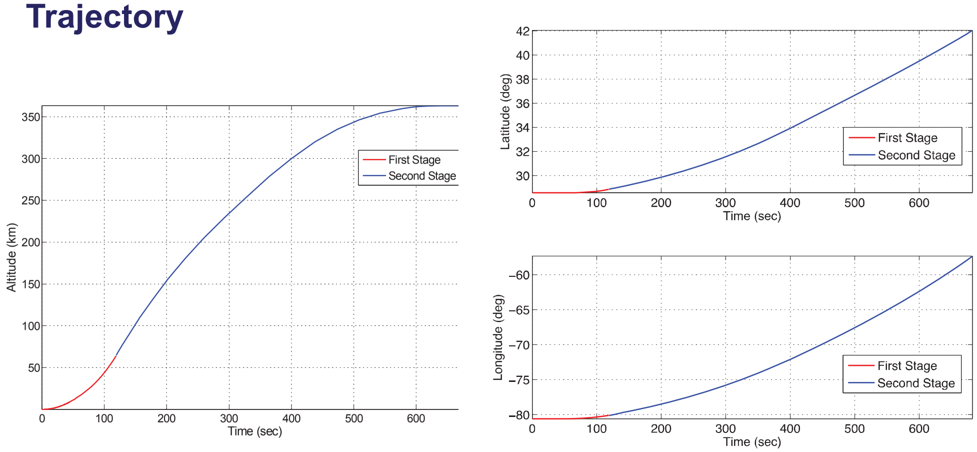
- Generic ELV vehicle launching towards ISS orbit.
- Aerodynamic data obtained from Missile Datcom.
- SPOT was used to generate optimal trajectories.
- Wind variations obtained from Earth GRAM.
- Performed expected casualties calculation due to inert debris impacts, gas dispersion, and blast overpressure.

First Stage



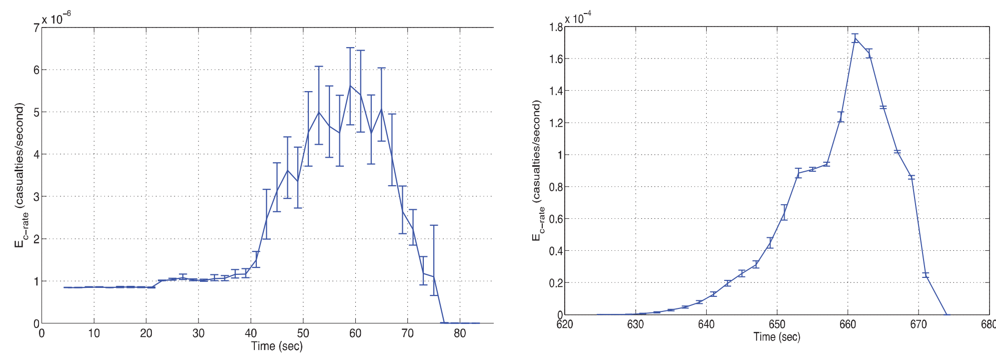
Second Stage

Sample Test Case
ELV to ISS orbit
Trajectory



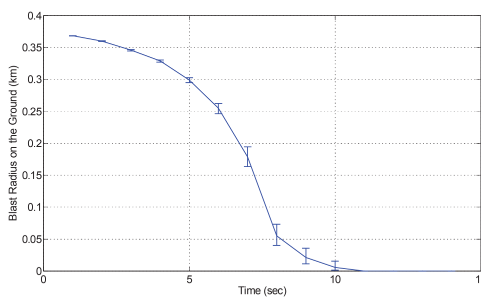
Nominal Trajectory

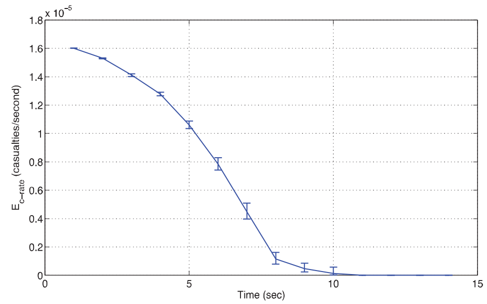
Sample Test Case
ELV to ISS orbit
Debris Propagation



Expected Casualty Results

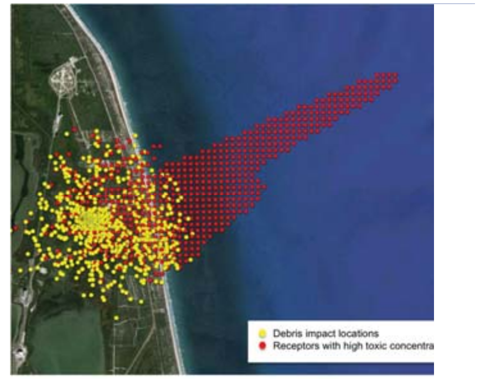
Sample Test Case
ELV to ISS orbit
Blast Overpressure

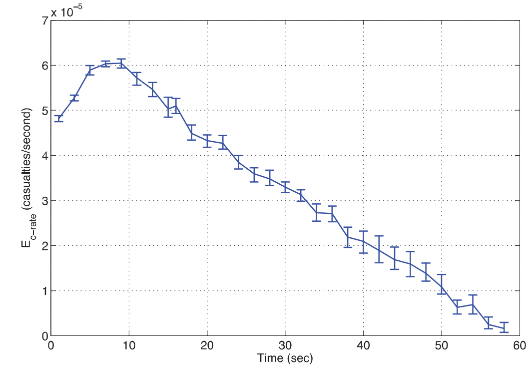




Blast Radius and Expected Casualty Results

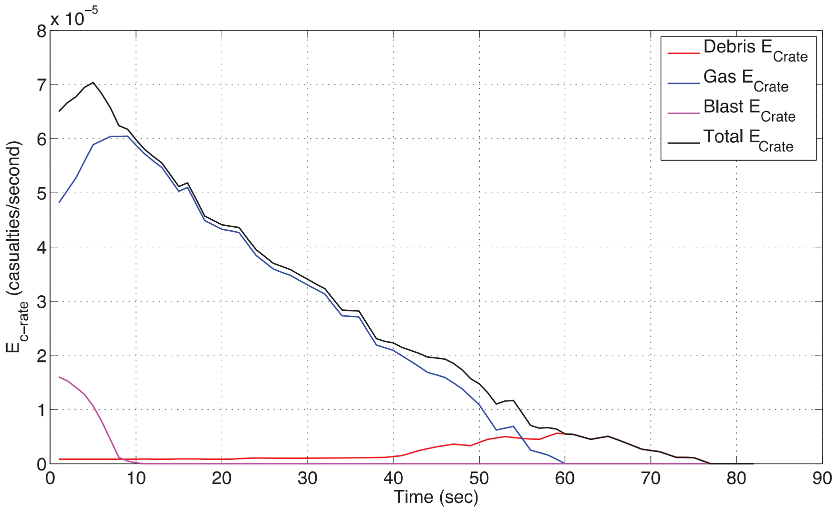
Sample Test Case
ELV to ISS orbit
Gas Dispersion





Receptor locations and expected casualties results

Sample Test Case
ELV to ISS orbit



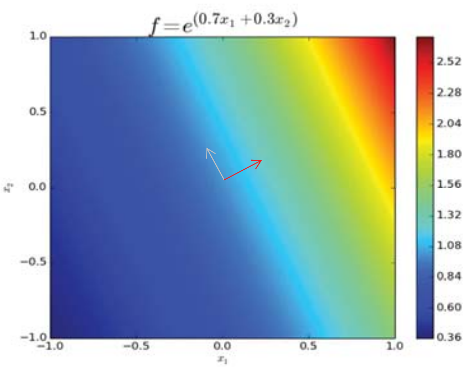
E_{crate} comparison for different hazards

Research Methodology

- Currently the FAA uses procedures and tools to assess the 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 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.

Surrogate Modeling

Active Subspaces



-The goal is to determine the orthogonal directions that describe the variability of the objective

Gaussian Process Regression (GPR)

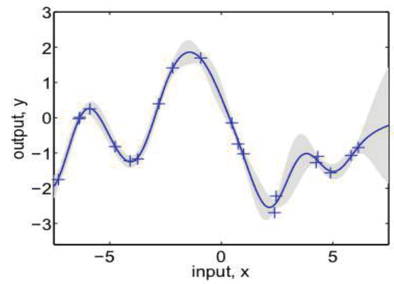


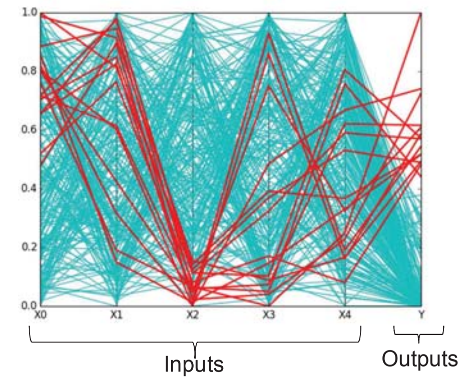
*Figure from C. E. Rasmussen & C. K. I. Williams, Gaussian Processes for Machine Learning.

-Provide a way of characterizing functions by using the relation between each point on the function.

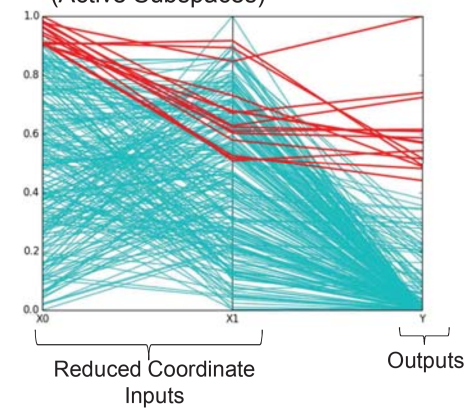
Results

- Cobweb Graph: Allows to visually inspect the input parameter combination that leads to worst case scenarios.

Regular Inputs



Reduced Coordinates Input (Active Subspaces)



COE CST Fourth Annual Technical Meeting

Task 293
Nonlinear Structural Models

Dr. A. Keith Miller,
Dr. Warren Ostergren,
And Mr. Lance Hernandez

October 29-30, 2014
Washington, DC

NEW MEXICO TECH
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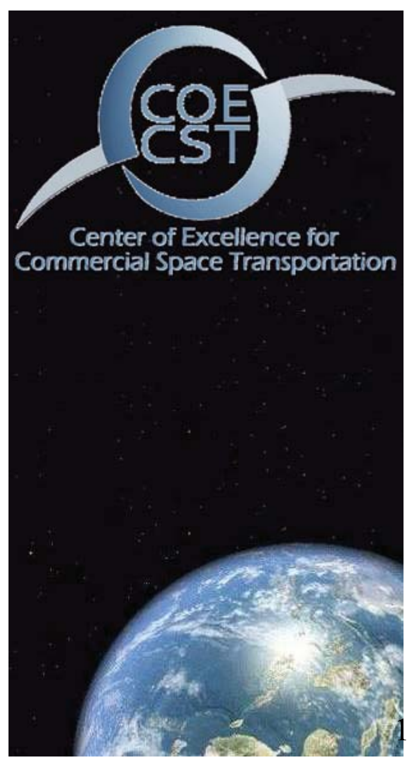


Agenda

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

Team Members

- **Principal Investigators**
  - Dr. A Keith Miller, Adjunct Research Professor of Mechanical Engineering, NMT
  - Dr. Warren Ostergren, Associate Professor of Mechanical Engineering and Vice President of Academic Affairs, NMT
- **Students**
  - Mr. Lance Hernandez, BS MENG (Dec. 2014)
  - Mr. Joshua Mendoza, MS MENG (May 2013)
- **FAA Technical Monitor:** Mr. Nickolas Demidovich
- **Research Partners:** Sandia National Laboratories
- **Industry Partners:** United Launch Alliance, Ball Aerospace

Task Description

The purpose of this task is to 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.

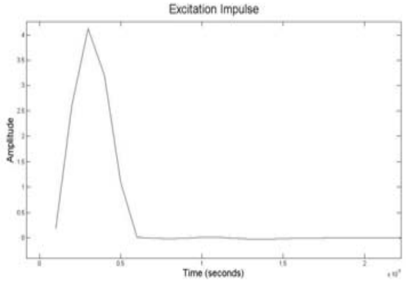
Schedule

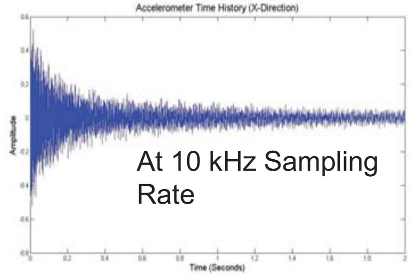
- **Spring 2014**
  - Developed Matlab code to extract modal parameters from simulated FEA model of complex beam structures
- **Fall 2014**
  - Current physical testing of beam structure has validated the modal extraction codes
- **Spring 2015**
  - Test modal parameters of second, identical beam structure and begin sub-structuring process

Goals

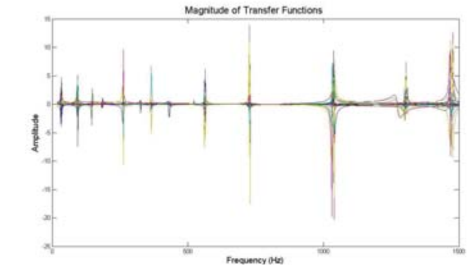
- **Task Specific Goals**
  - The main goal of this task is to combine reduced-order finite element models of substructure components directly with experimentally derived modal substructure components
- **Relevance to Commercial Space Industry**
  - This methodology will aid in determining the performance and safety margins of commercial space vehicles

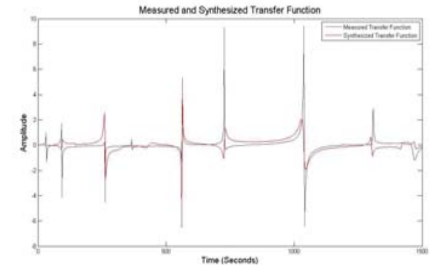
Results (Physical Setup and Time Responses)

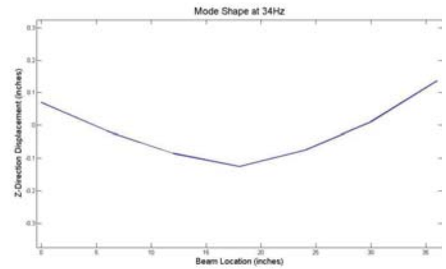


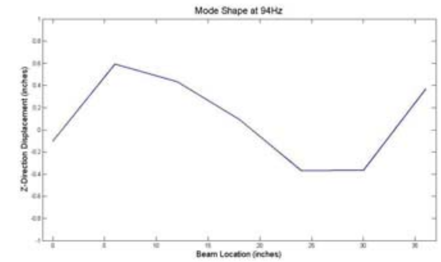


Results (Transfer Functions and Mode Shapes)









Conclusions and Future Work

- The physical testing has successfully validated the modal extraction codes.
- More physical testing will take place with increased damping on the beam structure to further validate our results.
- Next step is to begin testing second beam structure and begin the sub-structuring phase of the project.

TASK 293 Nonlinear Structural Models

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PROJECT AT-A-GLANCE

- **UNIVERSITY**: New Mexico Tech
- **PRINCIPAL INVESTIGATORS**: Dr. A. Keith Miller, Dr. Warren Ostergren
- **STUDENTS:** Mr. Lance Hernandez
- **FAA TECHNICAL MONITOR:** Mr. Nickolas Demidovich

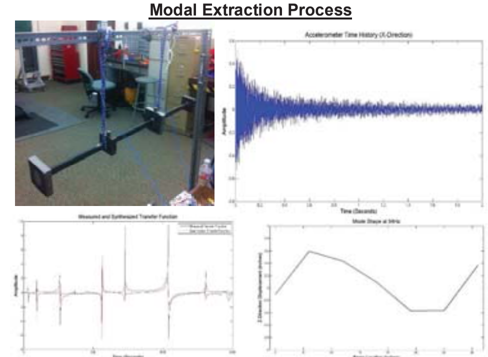
RELEVANCE TO COMMERCIAL SPACE INDUSTRY

- The structural integrity of commercial launch platforms must be assessed for each mission, i.e. safety certification or recertification. A significant amount of structural response data must be collected in order to state confidence bounds on the computed safety margins. Experimental data will very likely need to be supplemented with data generated by numerical simulations of the structural response of the launch platforms to the anticipated flight environments. Efficient, cost-effective methods for generating non-linear structural models of CST platforms will result from this effort.

STATEMENT OF WORK

- Solicit Industrial Working Group feedback to guide implementation of system computational assembly methods.
- Generate non-proprietary code to extract relevant structural features from experimental test data i.e. modal extraction software using rational fractional polynominals (RFP)
- Provide Matlab™ scripts for combining finite element modelled components with experimentally defined (modal) components in structural assemblies.
- Provide help to commercial companies desiring to use modal extraction an assembly codes.

Modal Extraction Process



STATUS

- Modal extraction codes have been validated by physical testing of beam structure.

FUTURE WORK

- More physical testing will take place with increased damping on the beam structure to further validate our results.
- Next step is to begin testing second beam structure and begin the sub-structuring phase of the project.

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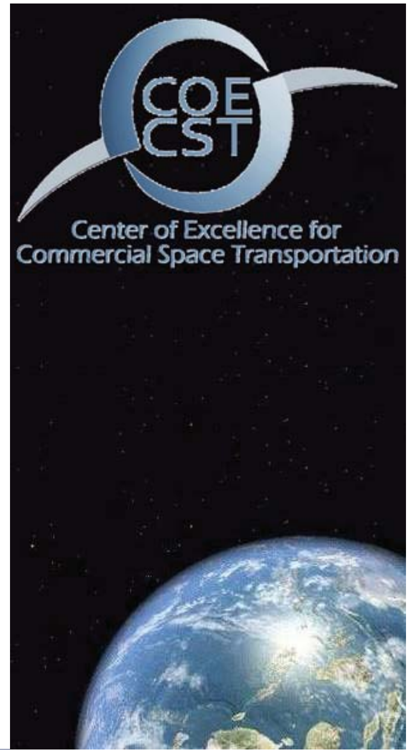
Task 298—Evaluation of ADS-B Payloads

PI: Pat Hynes
Investigators: Laura Boucheron, Joshua Michalenko

October 29-30, 2014
Washington, DC



Team Members

- People
  - AST RDAB POC: Nick Demidovich, Ken Davidian
  - Principal Investigator: Pat Hynes
  - Technical Investigator: Laura Boucheron
  - Undergraduate Researcher: Joshua Michalenko

  - Mitre Corporation



Task Description

- FAA will request truth data (acceleration) from Up Aerospace payload on SL6 on board avionics (IMU)
  - Dr. Boucheron will do comparative analysis of data transmitted from SL-6, SL-7 and SL-8
- Develop a plan, for integration of ADS-B receivers and data flow for use by commercial spaceports based on lessons learned from this task.

Goals

Relevance to Commercial Space Industry:

Once procedures and separation standards are developed in conjunction with ADS-B for various classes of rockets, air traffic control would not have to sterilize air space and disrupt other NAS users for most rocket launches (large expendable rockets would be the exception). Most reusable rockets would be able to file a flight plan, making them much easier to launch, as aircraft are today, enabling routine commercial space operations in the NAS.

Results

SL-8 launch: 12 November 2013

Data received:

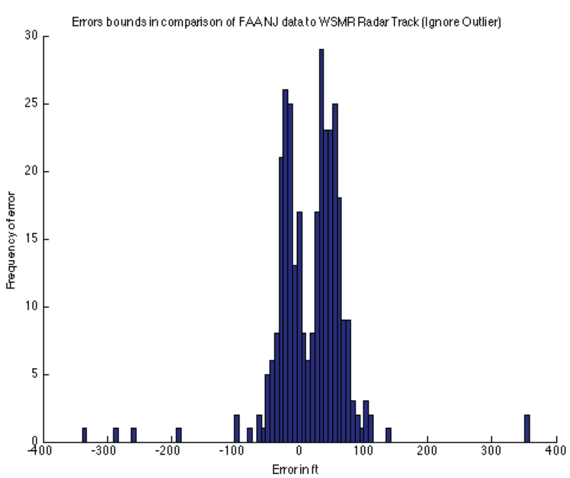
- WSMR radar
- FAA New Jersey Tech Center ADS-B data, including reentry and descent
- ERAU ADS-B data, including reentry and descent
- UpAerospace ADS-B data recorded from FAA Tech Center on-site mobile receiver, including reentry and descent

Results

- WSMR data has a relative rather than absolute timestamp. We shift ADS-B data relative to WSMR data and search for shift with minimum mean-squared error (MSE).

Results

FAA NJ data



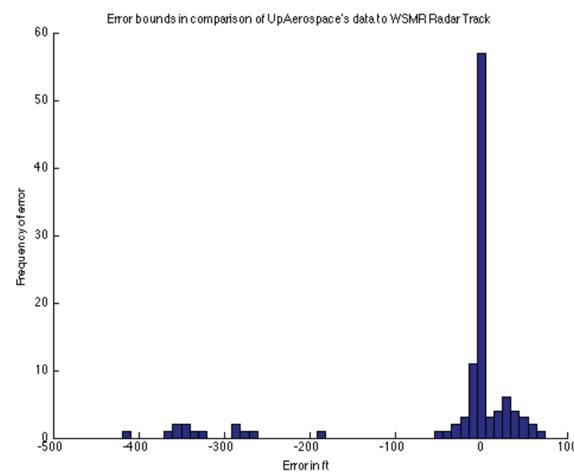
Minimum MSE of 5.7421e+06 ft for shift of 298 seconds.

Minimum MSE alignment of WSMR and ADS-B data,

- Maximum absolute error with outlier = 1706.8 ft
- Maximum absolute error without outlier = 358.3 ft
- Mean error without outlier = 47.0922 ft
- Standard deviation= 102.45 ft

Results

UpAerospace Data



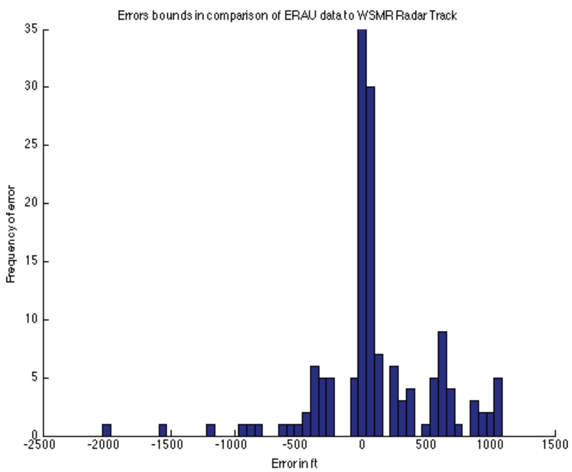
Minimum MSE of 6.1454e+07 ft for shift of 334 seconds.

Minimum MSE alignment of WSMR and ADS-B data,

- Maximum absolute error = 419.3 ft
- Mean error= -33.2 ft
- Standard deviation=108.1 ft

Results

ERAU data



Minimum MSE of 1.6203e+07 ft for shift of 332 seconds.

Minimum MSE alignment of WSMR and ADS-B data,

- Maximum absolute error= 2020.3 ft
- Mean error= 102.1 ft
- Standard deviation= 311.95 ft

Conclusions and Future Work

- ADS-B data from SL-8 displays errors with mean absolute value ~tens of feet compared to WSMR radar
- A few errors ~hundreds of feet
- Lack of absolute time-stamps in WSMR radar complicate analysis and computation of the alignment of data and MSE analysis may introduce a bias to the accuracy results
- Future work will continue analysis of the altitude errors, as well as latitude and longitude errors for all data received for both SL-7 and SL-8 launches.

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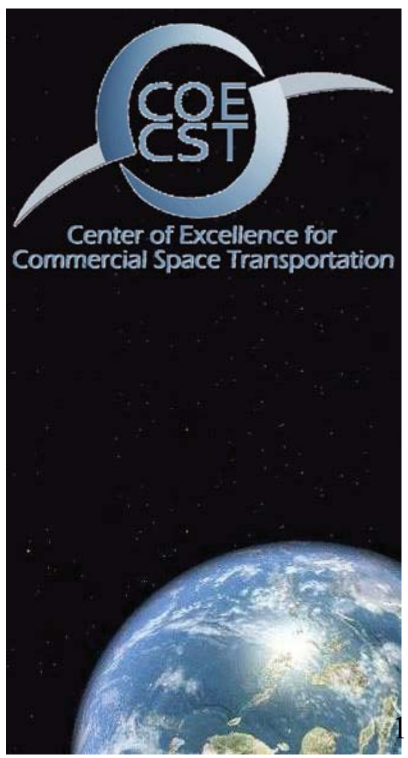
Task 299: Nitrous Oxide Composite Case Testing

PI: Warren Ostergren
Co-PIs: Michael Hargather
Robert Abernathy
Andrei Zagrai

October 29-30, 2014
Washington, DC



Agenda

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

Team Members

- PI: Warren Ostergren (NMT)
- Co-PI: Robert Abernathy (EMRTC)
- Co-PI: Michael Hargather (NMT)
- Co-PI: Andrei Zagrai (NMT)
- Faculty: Seokbin Lim (NMT)
- Test Engineer: Paul Giannuzzi (EMRTC)
- Student: Jesse Tobin (NMT)
- Student: Steven Bayley (NMT)
- COE CST Program Manager: Ken Davidian (FAA)
- Technical Monitor: Yvonne Tran (FAA)
- Technical Monitor: Don Sargent (FAA)

Task Description

- 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

Schedule

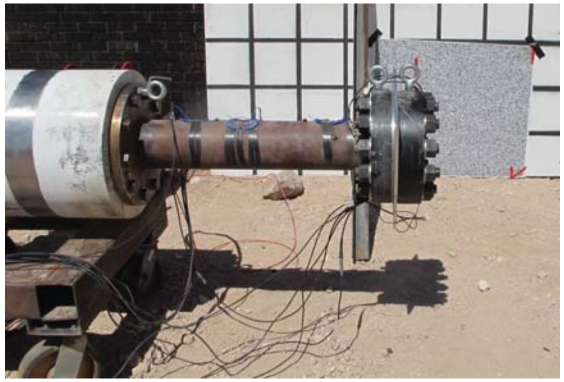
- Fixture construction: October 2013-May 2014
- First successful aluminum test: May 29, 2014
- Second aluminum test: June 29, 2014
- Initial simulations complete: July 2014
- First composite test: October 3, 2014
- Second composite test: November 2014

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

Results: Fixture construction

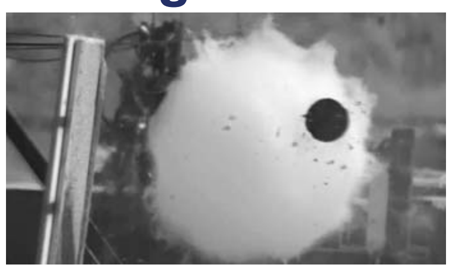
- High-pressure driver up to 3000psi
- Low-pressure driven section to 700psi
  - Models the N2O storage container
  - Test plate fixed to end of tube
- Burst disk fails and produces shock wave

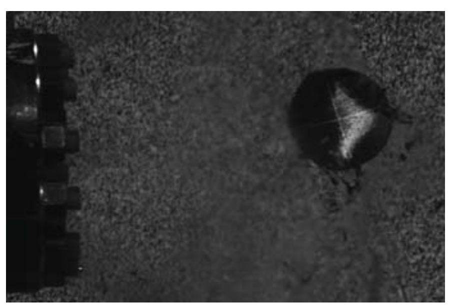


Results: Instrumentation

- Pressure gages along low-pressure section
- Thermocouple in low-pressure section
- High-speed imaging of plate failure
- Low-speed imaging of overall test
- Acoustic emission measurements

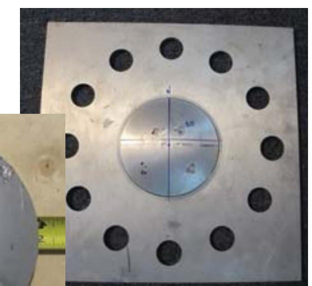
Results: Videos of testing

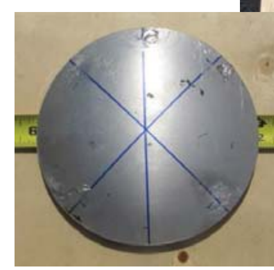


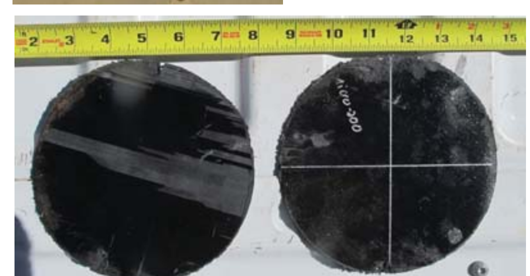


Results: Failure of plates

- 0.375” thick Aluminum test 1
- 0.25” thick Aluminum test 2
- Composite test 1
  - Composite material had thickness and glass transition temperature similar to sample of composite tank from a manufacturer

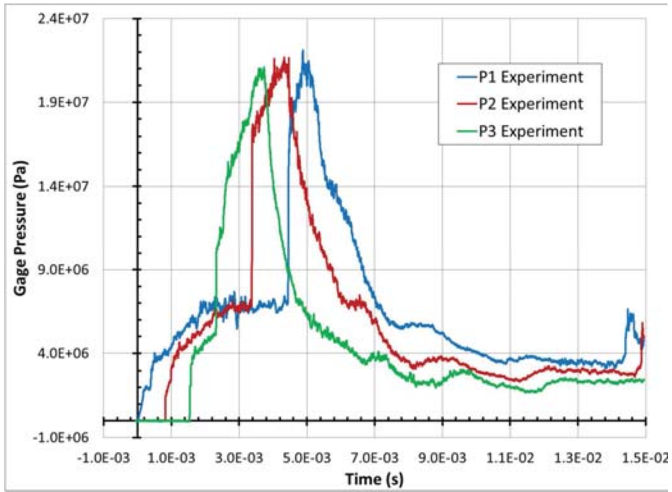






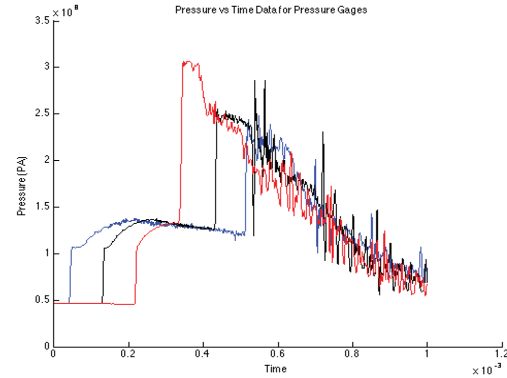
Results: Pressure profiles

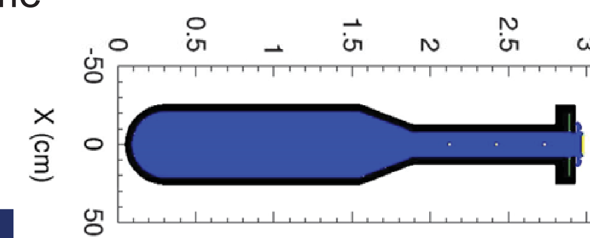
- Shock wave is formed in driver section
- Shock wave reflects from plate
- Plate failure occurs after reflection and results in pressure relief



Results: Simulations

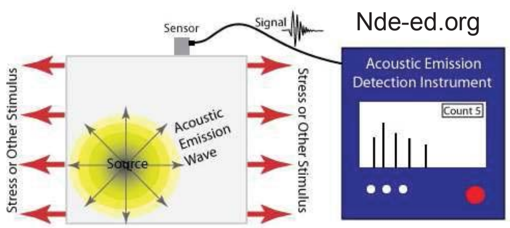
- Simulations using CTH
- Pressure traces are similar to experimental measurements
- Failure of aluminum plate is in the same mode





Results: Acoustic Emission Testing

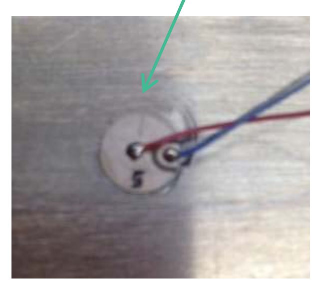
- Acoustic emission (AE) is passive sensing technology that allows for monitoring acoustic activity in structural material
- NMT hardware includes state-of-the-art Mistras Micro-II Digital AE System and a variety of conventional (Micro-80) or new (PWAS) acoustic emission sensors



Nde-ed.org

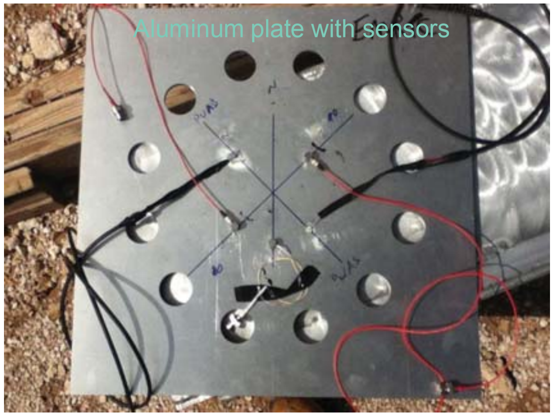
AE Testing of Aluminum Plates

- Goals of the test:
  - Explore feasibility of utilizing AE sensors to record high-strain event.
  - Investigate performance of conventional (Micro-80) and embeddable (PWAS) sensors during high-strain event.

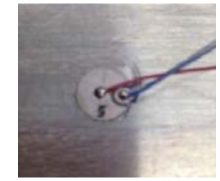


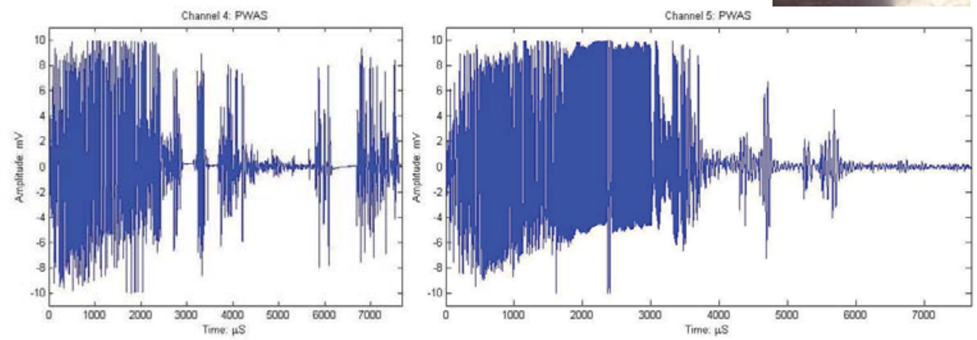
AE Sensor on Aluminum Plates

- Sensors were glued to aluminum plate with special epoxy
- Adaptors allow for connecting sensors with very long cables



Test 2 Results Ch4/Ch5 PWAS Sensors





Piezoelectric wafer active sensors (PWAS) show comparable, but less stable signal features. This may be due some damage to fragile PWAS.

AE Test Results

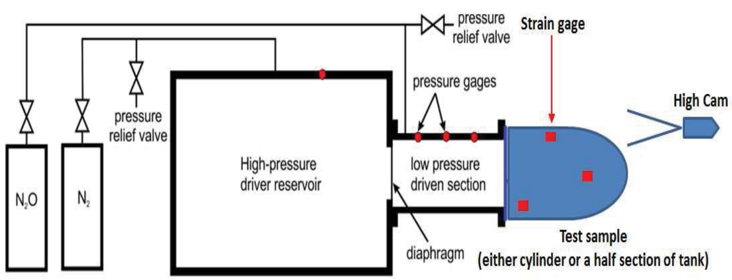
- Acoustic emission sensors are capable of recording high-strain events
- These event produces many signals, which are often indistinguishable from one another
- Signal features are similar when sensors are positioned symmetrically
- Data from conventional Micro 80 sensors is more stable than from PWAS, but PWAS is more economical

Conclusions

- High pressure rapid failure events of composite vessels can be simulated
- Initial evaluation completed on flat plate samples
  - Shear failure of aluminum liner
  - Shear and some fragmentation of composite material
- Test and analysis agree
- Failure mode likely sensitive to type of loading

Next Steps

- Test and analysis of cylindrical sections



- Develop predictive models
- Validate with full composite vessel test

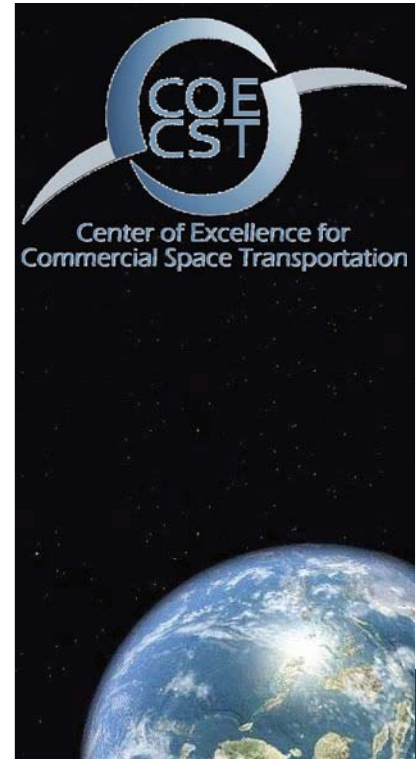
COE CST Fourth Annual Technical Meeting

Advanced ADS-B Prototype for Commercial Space: Status Update and Future Opportunities

Richard S. Stansbury

Brandon Neugebauer
Richard P. Day
Yosvany Alonso
Dominic Tournour

October 29-30, 2014
Washington, DC



Agenda

- Team Members
- Task Description
- SpaceLoft 8 Launch Campaign
- Follow-on work and conclusions

Team Members

- **People**
  - Principal Investigators: Richard S. Stansbury
  - Students: Brandon Neugebauer, Richard P. Day, Yosvany Alonso, and Dominic Tournour
  - FAA: Nick Demidovich, Chuck Greenlow, John Dinofrio, and others.
  - MITRE: Dave Edwards

- **Organizations**
  - Industry and Research Partners:
    - Terminal Velocity Aerospace, LLC.
    - NASA Flight Opportunities Program
      - Up Aerospace
      - Near Space Corporation

Purpose of Task

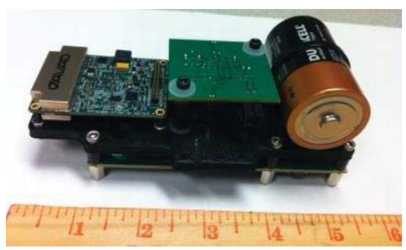
- Support of suborbital reusable launch vehicles (sRLVs) for commercial space transportation requires considerations for safe integration into the national airspace system (NAS)
- ADS-B technology is used for surveillance by air traffic control and situational awareness for pilots
- This research presents the potential for adaptation of existing ADS-B technology to support operations for sRLVs operations exceeding current technology limits (primarily altitude, velocity and acceleration)

MITRE UBR-TX

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

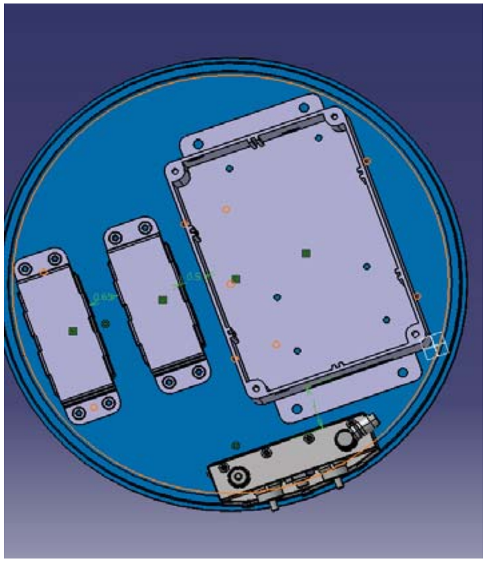
MITRE TECHNOLOGY APPLIED

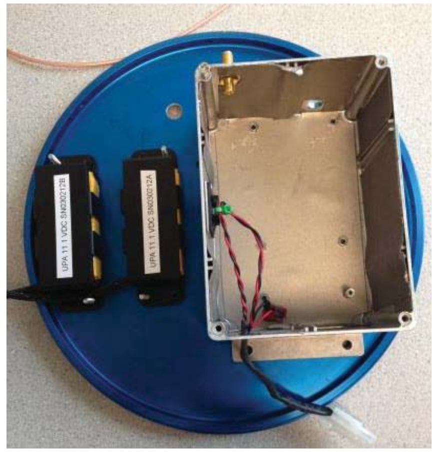
Parameter	Specification
Length	5.75" (14.6 cm)
Width	2.5" (6.35 cm)
Height	2.5" (6.35 cm)
Weight (UBR board, daughter board, GPS, battery, and enclosure)	790 g (27.9 oz)
Weight (cables, antennas, etc.)	85-300g est.
Nominal power Consumption	840mA @ 3VDC
Nominal battery capacity	7.75 Ah



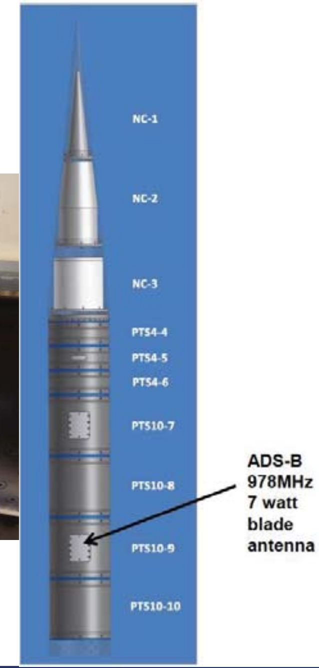
INTEGRATION FOR SPACELOFT XL

PTS-10 Rocket Segment





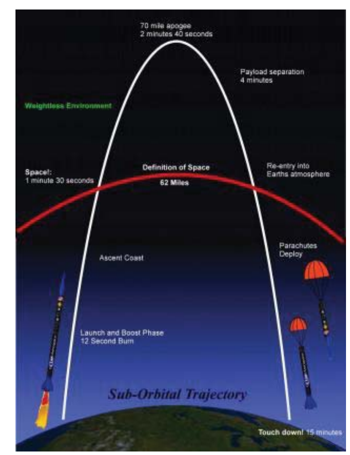
Vehicle Integration



SL-8 FLIGHT DATA AND ANALYSIS

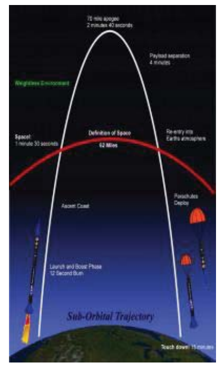
SL-8 Flight Profile

Event	Time (seconds)
Launch	T + 0
Despin initiated	T + 55
Apogee (384,100 ft.)	T + 162
Payload separation	T + 240
Drogue deployment	T + 442
Chute Deployment	T + 452
Touchdown	T + 751



Flight Analysis

Phase of flight	Metric	Result
Full flight	% tracked by ADSB	73.8%
T + 62 (7 seconds post-despin initiation)	% of flight tracked by ADS-B	80.5
	Avg. time between message	1.27 s
	Max. time between message	8.00 s
	Max receivers tracking (FAA/Excelis Ground-based Transceivers GBTs only)	8
	Max receivers tracking (FAA GBTs and portable)	10
	Avg. latitude error	16.145E-05 deg.
	Avg. longitude error	9.170E-05 deg.
	Avg. altitude error (below 101,350 ft.)	54.31 ft.
After T+315 (descent and deceleration to less than 1000 ft./sec)	% of flight tracked by ADS-B	95.9%
	Avg. time between message	1.04 s
	Max. time between message	3.00 s



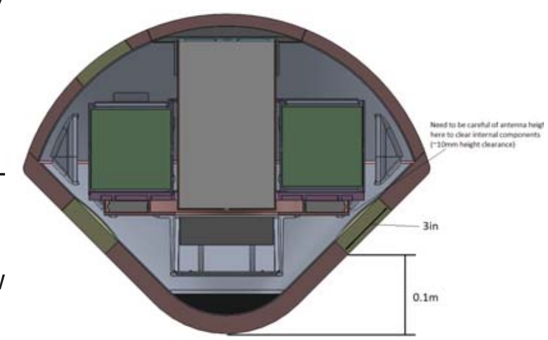
Performance vs. Success Criteria

Criteria	Pass / Fail	Comments
Broadcasts well-formed messages	Pass	ITT GBTs and two portable Garmin GDL 90 successfully parsed data
Vehicle tracking for 90% of flight	Fail	73.8% of full flight, 80.5% post-despin, and 95.9% on descent.
Characterization of data loss	Pass	Primary characterization of data loss was configuration onboard spacecraft and NOT ADS-B unit itself.
Correlated with other data sources	Pass	Utilized truth data from WSMR primary radar. Position/altitude accuracy measured.

FOLLOW-ON WORK AND CONCLUSION

Terminal Velocity Aerospace

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



Proposed Future Work

- Taking Advanced ADS-B to glass
  - Goal: identify gaps in current Advanced ADS-B implementation versus DO-282B standard and implement changes
- Dual antenna configuration
  - Goal: update Advanced ADS-B to meet DO-282B standard for dual antenna while ensuring sufficient transmit power to meet performance requirements
- Commercial Space Message Format for ADS-B
  - Goal: better express the state of a commercial spacecraft and bypass current limits for altitude and climb rate
- ADS-B for tracking of Cubesat
  - Goal: provide real-time low-cost tracking of LEO spacecraft, and demonstrate utilizing a free flying cubesat
  - Previous proposal through CASIS did not make it through first phase

Schedule

- Development of Advanced ADS-B Units
  - Preparing for future flights
    - NSC HASS, Q4 2014
    - SpaceShip2, TBA
    - Up Aerospace, SL10, TBD
  - Completing remaining ADS-B Units, 12/15/2014
- RED-4U
  - System integration, Q3 2014
  - System testing, Q4 2014

Questions?

Image courtesy of UpAerospace Inc.

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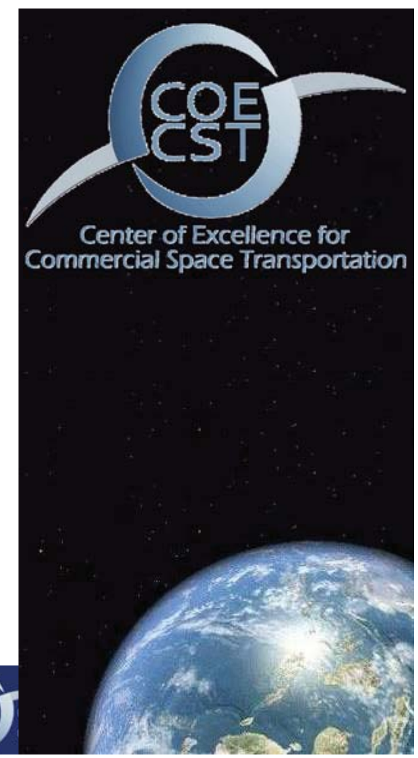
MITRE
Dave Edwards, davee@mitre.org

COE CST Fourth Annual Technical Meeting

Flight Test of Communications in Space via Commercial Satellite Networks on Suborbital Spacecraft: Implications for Space Traffic Management

M. Brian Barnett,
Satwest Satellite Communications and Aerospace

***October 29-30, 2014
Washington, DC***



Agenda

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

Team Members

- Principal Investigators
  - M. Brian Barnett, Satwest - PI
  - Dr. Pat Hynes (NMSU) – Co-PI
- Organizations
  - Satwest llc
    - >$150K matching funds to date
  - New Mexico Space University

Flight Opportunities

Commercial Participants

- Lead commercial participant

Satwest

- Other commercial participants
  - Iridium, Globalstar, UP Aerospace, Virgin Galactic

Task Description

- 4. Theme 1: Space Traffic Management & Operations
  - Can commercial satellite networks in LEO and GEO provide data and voice communications to/from suborbital and orbital spacecraft in space and at rocket velocities?
- 5. Theme 2: Space Transportation Operations, Technologies & Payloads (Program 2.4 Payload Safety Research)
  - Task NEW-ND1 INTEGRATION AND EVALUATION OF IRIDIUM PAYLOADS
  - Task NEW-ND2. Integration and Evaluation of GLOBALSTAR PAYLOADS

Schedule

- June 2013-NASA Flight Opportunities Program (FOP) selects Satwest's technology proposal
- September 2013-Flight test on Near Space Corp. high altitude balloon to 97,000 feet.
- November 2013-Sent first commercial text to space . UP Aerospace sounding rocket
- Q2, 2015, Flight test on Virgin Galactic SS2

Goals

- Research goal
  - To conduct enough flight testing to prove the efficacy of providing data and voice communications services in space via commercial satellite networks.
  - Relevance to Commercial Space Industry
    - Space Traffic Management (ADS-B)
    - On-board Wi-Fi/Internet and voice communications for commercial crew
    - Two-way payload communications for ground-based researchers
    - Commercial communications services for spacecraft operators and government agencies

Results

- Successfully tested Iridium based payloads in sub orbit
  - Proved that two-way data works
- Preparing more tests of Iridium and Globalstar payloads.

Results

1ST Known COMMERCIAL TEXT TO SPACE, 67.4 miles

Satwest high altitude balloon flight test, Sept. 2013, 97,000 ft.

NASA/UP Aerospace flight test, Nov. 12, 2013, 72.7 miles 383,556 ft.

Landing Site of payload

Results

- Technical reports and journal articles resulting from this task.
  - "Flight Test of Communications in Space via Commercial Communications Satellite Networks on-board Suborbital RLV and High Altitude Balloon: Implications for Space Traffic Management", Emory Riddle Space Traffic Management Conference, Florida, Nov. 2014
  - "Flight test of Satwest's Space Communications Technology on Suborbital RLV and High Altitude Balloon", NASA SBIR Technology Commercialization conference, Cleveland, Sept. 2014
  - Next Generation Suborbital Researchers Conference, Colorado, July 2013
  - NASA Flight Opportunities Program (FOP), post flight reports

Conclusions and Future Work

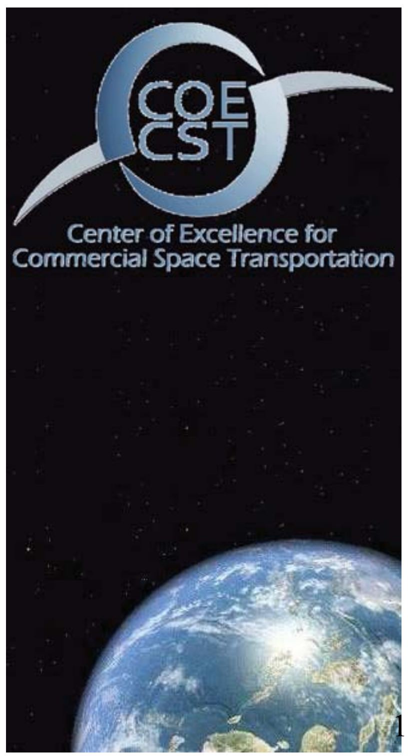
- Final Remarks
  - Satwest's tests demonstrating that commercial satellite networks are a promising means for providing space traffic management and payload/crew/researcher communications
- Next Steps
  - Flight test through NASA's FOP (Q2 2015)
    - Virgin Galactic's Spaceship 2 (SS2)
    - Testing Wi-Fi, tracking, voice calls
  - Look forward to further partnering with FAA in of space-based ADS-B capabilities.

COE CST Fourth Annual Technical Meeting

Robust and Low-Cost LED Absorption Sensor for Simultaneous, Time-Resolved Measurements of CO and CO_2

Dr. Subith Vasu (PI)
Dr. Jayanta Kapat (Co-PI)
Dr. Bill Partridge Jr. (Collaborator)
Kyle Thurmond (Graduate Student)
Zachary Loparo (UG Student)

October 29-30, 2014
Washington, DC



Agenda

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

Team Members

Principal Investigators

Dr. Subith Vasu 
University of Central Florida

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

Students

Kyle Thurmond 
University of Central Florida

Zachary Loparo 
University of Central Florida

Collaborator

Dr. Bill Partridge Jr. 
Oak Ridge National Laboratory

Organizations

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

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

Task Description

Relevance to Commercial Space Industry

- CO/CO_2 measurements are relevant to the health and safety of the crew.
- In addition to being toxic, time-resolve measurements of CO could be used to detect fuming which may lead to fire or explosion.

Statement of Work (Project starterd: September 2014)

- Bench scale development and testing. Sensor sensitivity (minimum detection limit), time-response, and stability.
- Develop quantitative spectroscopic models that can be used to accurately derive concentration information based on absorption.
- Models for heat transfer will be developed and utilized to minimize radiation effects that could impair the sensor to function properly. Such models will be implemented in commercially available software (e.g., ANSYS)
- Sensor design and housing design must be optimized for spacecraft environment. This would require a caged design that will house every component keeping the weight to the allowable values. We will use Zemax software to arrive at the best design which will maximize sensor sensitivity.

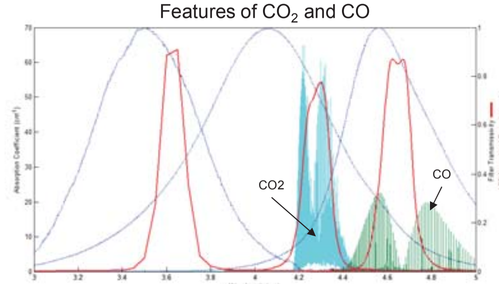
Schedule

- Bench scale development and testing. Sensitivity, time-response, and stability.
  - Complete
- Develop quantitative spectroscopic models that can be used to accurately derive concentration information based on absorption.
  - January 2015
- Sensor and housing design must be optimized for spacecraft environment. We will use Zemax software to arrive at the best optical design which will maximize sensor sensitivity and minimizes overall size
  - March 2015.
- Models for heat transfer will be developed and utilized using commercially available software (e.g., ANSYS) to minimize radiation effects that could impair the sensor to function properly
  - April 2015
- To reduce the likeliness of failure during high altitude balloon, the system will be operated and evaluated using a laboratory environmental chamber which can simulate these conditions.
  - August 2015
- High altitude balloon testing.
  - Fall 2015

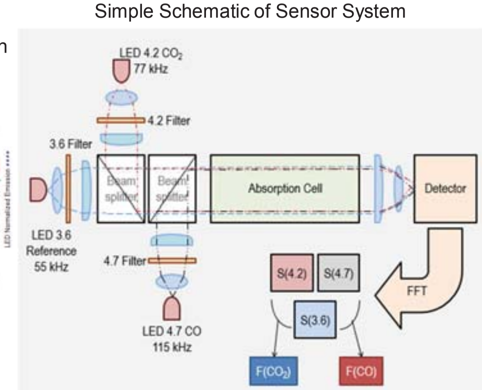
Sensor Design

- Three MIR LEDs centered at
  - 3.6μm (for reference)
  - 4.2μm (CO_2)
  - 4.7μm (CO)
- Band pass filters
- Collimating lenses
- Pellicle beam splitters
- Thermo-electrically cooled photovoltaic detector

LED and Filter Spectral Profiles Overlapping Absorption Features of CO_2 and CO

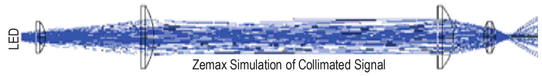


Simple Schematic of Sensor System



Goals

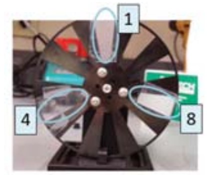
- Maximize sensitivity and reduce noise by optimization of optics and electronics.

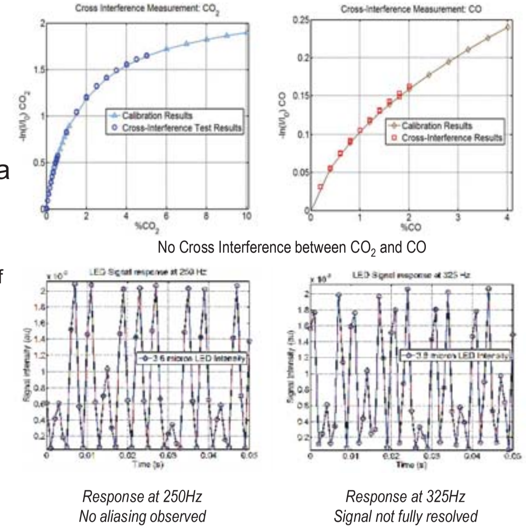


- Explore models for broad-spectrum absorption for greater flexibility in design.
- Adapt sensor and housing design for spacecraft environment.
- Validate optimization and ruggedized design:
  - Species interference study
  - Simulated conditions in environmental chamber
  - Balloon testing in high altitude, microgravity environment

Results

- Early evaluation testing done at ORNL
- Measurements were taken using a flow cell with a path length of 8cm
  - Neat CO_2 measurements
  - Neat CO measurements
  - Simultaneous measurements/evaluation of cross-interference
- Time resolution testing
  - Chopper wheel with plastic to simulate absorption





No Cross Interference between CO_2 and CO

Response at 250Hz
No aliasing observed

Response at 325Hz
Signal not fully resolved

Related Publications

- 2013 Eastern States Section of the Combustion Institute Fall Technical Meeting – Presentation
  - Development of a LED-based sensor for simultaneous, time-resolved measurements of CO and CO_2 from combustion exhausts
- 35th International Symposium on Combustion – Work In Progress Poster
  - Design and Validation of LED-Based Absorption Sensor for Simultaneous Detection of CO & CO_2

Conclusions and Future Work

Measurements of CO/CO_2 will be highly valued for determining air quality effecting crew health and detecting fires.

Future Work

- Developing current sensor design for spacecraft environment and requirements.
- Construction of caged sensor system.
- Validating spacecraft ready sensor design using environmental chamber and high altitude balloon.
- Improve performance and possibly extend to measuring other species (e.g., N_2O oxidizer leak).

COE CST Research Roadmap 2.0

Task SU-193: Professor Scott Hubbard[1], Jonah Zimmerman[1] and Andrew Ow[2]

Stanford Department of Aeronautics and Astronautics[1], Stanford Graduate School of Business[2]

Charter

Update the original research roadmap and build on it in order to increase its usefulness to the community and to the FAA COE CST.

There are three main components:

1. **Revisit** the 2011 research roadmap and update as necessary
2. **Identify and differentiate** short term (1-3 years), medium term (3-6 years) and far term (>6 years) research tasks
3. **Define** research priorities to the extent possible

Roadmap 1.0 – Previous Roadmapping Effort and Current Motivation

Purpose: Direct the COE's research program towards achieving its goal of identifying solutions for existing and anticipated commercial space transportation problems. These solutions will in turn inform research investment and regulations, increase safety, and facilitate the CST industry.

Methods: Input from 100+ CST stakeholders was captured at two workshops: spring 2011 at Stanford University and fall 2011 at LM Global Vision Center in Washington DC. This was then reformatted into the research roadmap report and presented to the community.

Problems: The bulk of information in the report is now 4 years old, and must be updated to reflect changes in the CST industry landscape. The roadmap would have more utility if it identified timescales associated with research priorities.

Roadmap 2.0 Workshop Format

Number and Length: 5 workshops that focus on single research themes as shown below will be held across the country, each 1 – 2 days long.

Hosts and Participants: Lead Theme PIs were chosen that are domain experts. Participants from non-COE academic, government and industry experts are being recruited.

Adobe Connect

Virtual Collaboration: In order to facilitate collaboration with as many people as possible, videoconferencing technology will be leveraged to allow remote participation at all workshops. We will use the Adobe Connect software package.

Deliverables: The host PIs will compile and distill the input from workshop participants for delivery to the Stanford Research Roadmapping team. A summary report by the overall Roadmap 2.0 lead (Hubbard) will be presented to the FAA by NLT March, 2015.

People and Places

Theme: 1a – Space Traffic Management

Lead PI: Juan Alonso

Location: Stanford and NASA Ames

Theme: 1b – Spaceports

Lead PI: Pat Hynes

Location: New Mexico State University

Theme: 2 – Vehicle Technology

Lead PI: Farrukh Alvi

Location: Florida State University

Theme: 3 – Human Spaceflight

Lead PI: Jim Vanderploeg

Location: University of Texas Medical Branch at Galveston

Theme: 4 – Industry Viability

Lead PI: Tristan Fiedler

Location: Lockheed Martin Global Vision Center

Theme 3 Workshop Recap – Broad Participation

Spaceflight Companies
- Virgin Galactic
- SpaceX
- Blue Origin

Spaceflight Support
- Wyle
- SAIC
- NASTAR Center
- QinetiQ

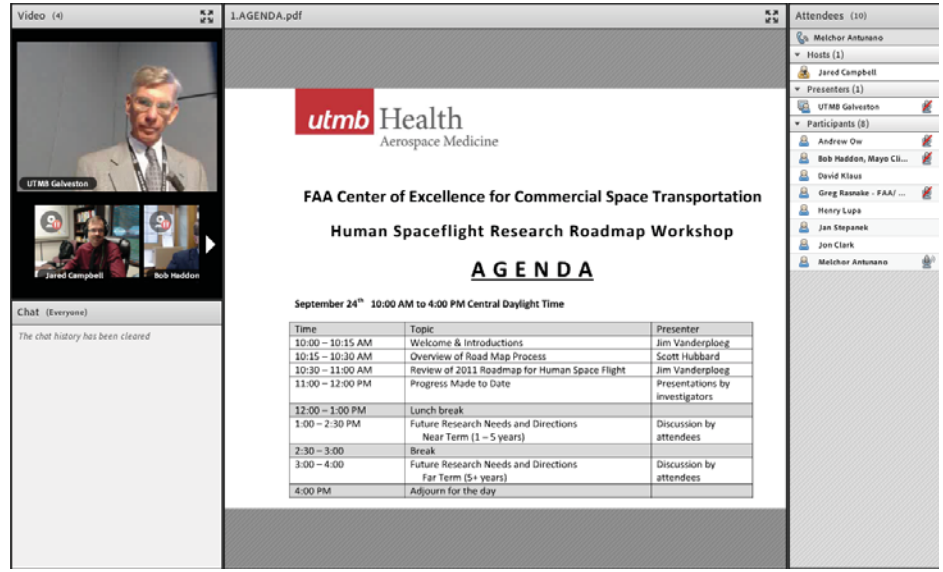
Spaceflight Consultants
- Henry Lupa, MD
- Richard Jennings, MD
- Michael Bungo, MD
- Kevin Fong, MD

COE PIs
- James Vanderploeg, MD
- Tarah Castleberry, DO
- Johnene Vardiman
- David Klaus
- Scott Hubbard
- Farrukh Alvi

Government
- NASA JSC
- FAA AST
- FAA CAMI

Academia
- University of Texas Medical Branch
- Baylor College of Medicine - Center for Space Medicine
- Wright State University
- University of Colorado Boulder
- Mayo Clinic - Rochester and Scottsdale

Theme 3 Workshop Recap – Virtual Experience



Schedule

Tasks	Start	End
Workshops	**Sep-24**	**Dec-3**
Theme 1a - Stanford/Ames	Nov-13	Nov-14
Theme 1b - NMSU	Nov-17	Nov-17
Theme 2 - FSU	Nov-3	Nov-3
Theme 3 - UTMB	Sep-24	Sep-25
Theme 4 - FIT/DC	Dec-2	Dec-3
Output	**Jan-15**	**May-15**
Draft summaries from lead PIs	Jan-15	-
Workshop summary presentation	Mar-15	-
Delivery of Roadmap 2.0	May-15	

Task 193: ROLE OF COE CST IN ENCOURAGE, FACILITATE AND PROMOTE (Research Roadmap 2.0)

PROJECT AT-A-GLANCE
- UNIVERSITY: Stanford University
- PRINCIPAL INVESTIGATOR: Prof. Scott Hubbard
- STUDENTS: Andrew Ow, Jonah Zimmerman

RELEVANCE TO COMMERCIAL SPACE INDUSTRY
- The COE-CST Research Roadmap directs the COE's research program towards achieving its goal of identifying solutions for existing and anticipated commercial space transportation problems. These solutions will in turn inform research investment and regulations, increase safety, and facilitate the CST industry.

STATEMENT OF WORK
- Goals:
  - Revisit the 2011 research roadmap and update as necessary
  - Identify and differentiate near term (1-3 years), medium term (3-6 years), and far term (>6 years) research tasks
  - Define research priorities to the extent possible
- Methods:
  - 5 workshops (1-2 days) hosted by theme PIs who are domain experts
  - Distribute workshops across the country
  - Leverage virtual collaboration software to increase participation
  - Compile and distill input from the workshops into Roadmap 2.0

Workshop Lead PIs and Locations

Theme: 1a – Space Traffic Management
Lead PI: Juan Alonso
Location: Stanford and NASA Ames

Theme: 1b – Spaceports
Lead PI: Pat Hynes
Location: New Mexico State University

Theme: 2 – Vehicle Technology
Lead PI: Farrukh Alvi
Location: Florida State University

Theme: 3 – Human Spaceflight
Lead PI: Jim Vanderploeg
Location: University of Texas Medical Branch at Galveston

Theme: 4 – Industry Viability
Lead PI: Tristan Fiedler
Location: Lockheed Martin Global Vision Center

STATUS
- Theme 3 workshop held on 9/24-9/25
- Planning underway for other workshops

FUTURE WORK
- Upcoming workshops:
  - Theme 1a – 11/13-11/14
  - Theme 1b – 11/17
  - Theme 2 – 11/3-11/4
  - Theme 4 – 12/2-12/3
- Obtain summaries from lead PIs – 1/15/14
- Presentation summarizing workshop output – 3/15/14
- Delivery of Roadmap 2.0 – 5/15/14

COE CST Fourth Annual Technical Meeting (ATM4)

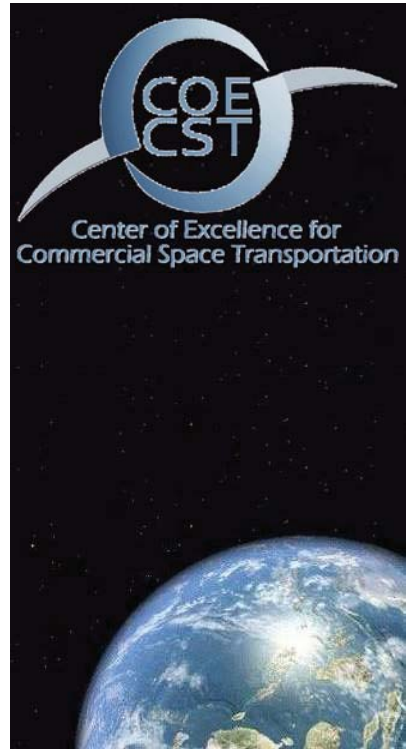
Center of Excellence for Commercial Space Transportation

COE CST Fourth Annual Technical Meeting

Task 193:Role of COE CST in EFP

PI: George H. Born
Bradley Cheetham

October 29-30, 2014
Washington, DC



Agenda

- 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

Stanford Support:

- **Jonah Zimmerman**
- **Andrew Ow**

Team Members – Sponsors

LOCKHEED MARTIN

SIERRA NEVADA CORPORATION
Space Systems

Team Members – Supporters

- William Pomerantz – Virgin Galactic
- Greg Autry – UC Irvine
- Scott Hubbard – Stanford Univ.
- Dan Lopez – Urthecast
- Julian Mann – Skybox
- Art Anisimov – Dauria Aerospace
- Jordon Croom – SSL
- Ward Hanson – SIEPR
- Bruce Pittman – NASA
- Steve Jurvetson – DFJ
- Robert Lightfoot – NASA
- George Nield – FAA
- David Brandt – LMCO
- A.C. Charania – Virgin Galactic
- Charles Miller
- Mischa Fisher
- Carissa Christensen – Tauri Group
- Richard Dalbello - OSTP
- Lori Garver - ALPA

Task Purpose

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 Research 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

ESIL Workshops

- Emerging Space Industry Leaders Workshop series
- Objectives:
  - Inform – perspective, background, context
  - Perform – group analysis
  - Network – internal and external to industry
- Impact:
  - 83 participants
  - 3 publications complete

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

ESIL-03 – November 2012

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

ESIL-04 – June 2013

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

ESIL-05 – November 2013

- 5 Participants
- Industry focus:
  - Smallsat dedicated launcher
- Guest Contributors:
  - William Pomerantz – Virgin Galactic

ESIL-06 – May 2014

- 7 Participants
- Industry focus:
  - Commercial remote sensing
- Guest Contributors:
  - Greg Autry – UC Irvine
  - Scott Hubbard – Stanford Univ.
  - Dan Lopez – Urthecast
  - Julian Mann – Skybox
  - Art Anisimov – Dauria Aerospace
  - Jordon Croom – SSL
  - Ward Hanson – SIEPR
  - Bruce Pittman – NASA
  - Steve Jurvetson – DFJ

ESIL-07 – May 2014

- 12 Participants
- Industry focus:
  - Student non-profit strategy
- Guest contributors:
  - Robert Lightfoot – NASA
  - George Nield – FAA
  - David Brandt – LMCO
  - A.C. Charania – Virgin Galactic
  - Charles Miller
  - Mischa Fisher
  - Carissa Christensen -Tauri Group
  - Richard Dalbello - OSTP
  - Lori Garver - ALPA

Impact

Support Other Events

- SpaceVision Conference (2011, 2012, 2014)
  - Logistics/planning/speaker support
- Space Generation Fusion Forum (2012, 2013, 2014)
  - Logistics/planning/speaker support
  - Video recording support
  - Badge lanyards

Publications/Presentations

- Bandla, Sirisha, Bradley Cheetham, Rachel Hakeem, and Luis Zea, **Applying Insights of Game Theory to the Microgravity Utilization Market**, 65th International Astronautical Congress, Toronto Canada, IAC-14,E6,3,3,x24346
- Henwood, Brienna, Nathan Wong, John Stark, Ken Davidian, Bradley Cheetham, Kaizad Raimalwala, Matt Cannella, Liz Kennick, Sirisha Bandla, Jules Feldhacker, and 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, and 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.

Next Steps

- To be determined…

Contact Information

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Bradley Cheetham
Bradley.Cheetham@Colorado.edu

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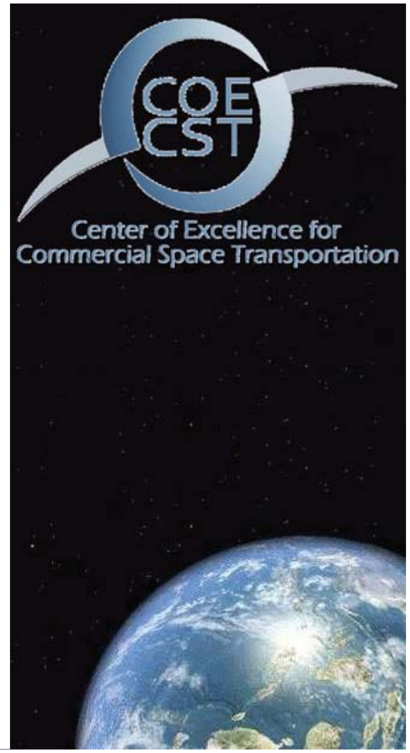
COE CST Fourth Annual Technical Meeting

Definition and Delimitation of Outer Space

Dr. Ram S. Jakhu
Andrea DiPaolo

October 29-30, 2014
Washington, DC



Agenda

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

Team Members

Institute of Air & Space Law

Dr. Ram Jakhu

Peace Through Governance
Arsenault Family Foundation

Andrea DiPaolo

Task Description

- What are the frontiers of outer space?
- Given that said frontiers are not yet established, is there a dilemma in their absence?
- What is the impact of the lack of a line of demarcation on near-space activities?
- Is a functional or spatial approach (which spatial approach?) more favorable to the CST industry?
- How can the growth of the commercial space transportation industry be encouraged in the existing regulatory environment?

Schedule

- Initial paper for the purpose of raising awareness of the timeliness of the issue was prepared earlier this year, particularly in response to new high altitude ballooning activities
- A presentation was offered at UN COPUOS in March 2014 about the issue by the McGill IASL (Dr. Yaw Nyampong)
- Continue to update paper/research as industry and regulations evolve

Goals

- Raising awareness to the new arising challenges regarding near-space activities
- Promoting the development of an international standard for the limits of airspace and outer space
- Offering legal expertise surrounding the issue of a lack of demarcation, and the various options with regard to particular limits

Results

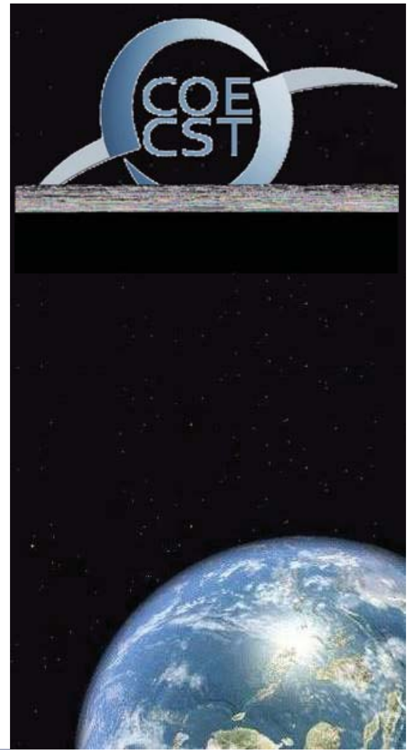
- Near space activities, such as suborbital transportation enterprises and high altitude ballooning endeavors have raised the urgency of the question. The FAA response to one such company (WVE) is potentially problematic in the uncertain legal and regulatory environment.
- *The Definition and Delimitation of Outer Space: The Present Need to Determine Where "Space Activities" Begin* (presented at UN COPUOS March 2014)

Conclusions and Future Work

- Science will not solve this problem.
- Practically and politically, the beginning of outer space could be set at 100/110km.
- The uncertainty created for commercial enterprises, and "forum shopping" for favorable decisions on air/space activities will be problematic for the burgeoning industry.
- Maintain research as the situation evolves
- Seek new areas to provide research (ITARs?)

Industrial Analysis of Orbital And Suborbital Commercial Space Transportation

October 29-30, 2014
Washington, DC



Agenda

- Team Members
- Task Description
- Objectives & Goals
- General Environmental
- Industry Structure
- Future Work & Deliverable

Team Members

Scott Benjamin (PI) Florida Institute of Technology

Taylor Smith, MBA Student
Florida Tech

Greg Autry, USC Marshall School
Of Business

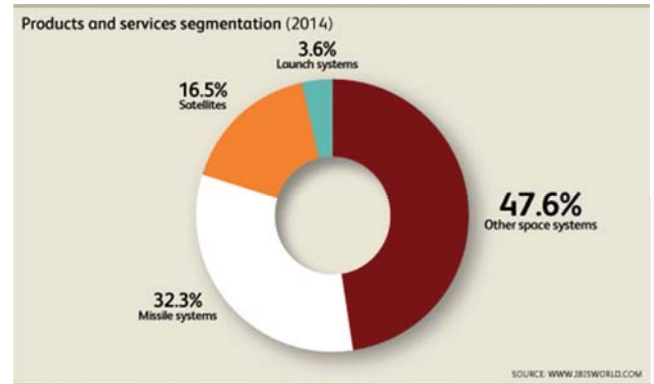
Task Description

- This project focuses on the subcategory of suborbital commercial space transportation that will have categories of tourism, payloads, and launch sites/spaceports.
- Analyses of new and existing industry segments will utilize the academic framework of “Five Forces that Shape Industry Competition” developed by Michael E. Porter (1979; 2008).

Goals

- **Task Specific Goals**
  - The main goal of this task is understand the general environmental characteristics which affect the commercial viability.
  - Evaluate the competitive landscape that affect competition within each segment of the industry.

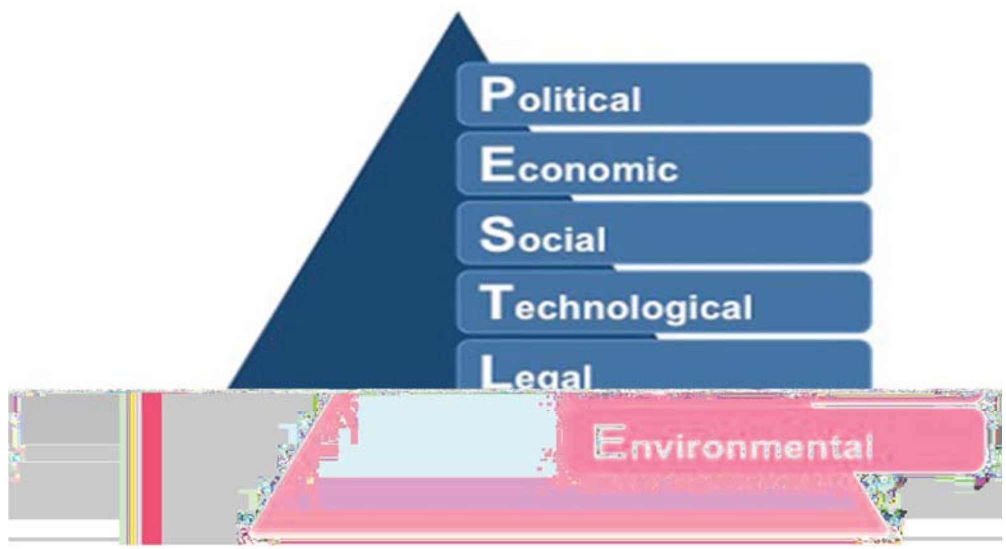
Space Vehicle and Missile Manufacturing Industry $21.9 Billion



Industry and Market Structure

- Industry Segmentation
  - Competitors
- Overall Market Size/Demand in each Segment
  - Segmentation Size
- Market Share Distribution – Industry Structure
- Cost Controls
  - Supply Chain

General Environmental Characteristics



Porter's Five Forces Model

Final Deliverable

- A comprehensive industrial analysis of the commercial space transportation industry.
  - Segmented
  - Structural

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