Florida Institute of Technology

Florida State University

NM State University

New Mexico Tech
Science • Engineering • Research • University

Leland Stanford Junior University

CU

University of Central Florida

UF University of Florida

utmb Health

www.coe-cst.org

COE CST Center of Excellence for Commercial Space Transportation

Federal Aviation Administration Center of Excellence for Commercial Space Transportation

Year 2 Annual Report

Volume 2. Annual Technical Meeting Presentations

December 31, 2012

COE CST YEAR 2 ANNUAL REPORT – VOLUME 2

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

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

- The Executive Summary gives an overview of the FAA AST, the FAA COE program and the COE CST. A brief description of the member universities precedes a series of “quad charts,” one for each task conducted by the COE CST during the second year of operation. The document ends with a listing of the Year 2 students, supporting organizations and technical publications.
- Volume 1 gives a description of the FAA COE CST, its research, structure, member universities and research tasks.
- Volume 2 is a comprehensive set of presentation charts of each research task as presented at the second Annual Technical Meeting in November 2012 held on the campus of New Mexico Institute of Mining and Technology (NMT) in Socorro, New Mexico.
- 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 presentation charts of each research task as presented at the second Annual Technical Meeting in November 2012 held on the campus of New Mexico Institute of Mining and Technology (NMT) in Socorro, New Mexico.

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

- “FAA Centers of Excellence Program Review” presented by Ken Davidian from the Federal Aviation Administration (FAA) Office of Commercial Space Transportation (AST) for Dr. Patricia Watts of the FAA.
- “FAA AST R&D Overview & Status” presented by Ken Davidian from FAA AST.
- “FAA COE CST Overview & Status” presented by Ken Davidian from FAA AST.
- “FAA COE CST Affiliate Member Overview” presented by Ken Davidian from FAA AST.
- “FAA AST R&D Overview & Status” with a focus on COE CST subcommittees and strategic planning activities, presented by Ken Davidian from FAA AST.

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

- Task 181 “Physiologic Database Definition & Design” presented by James Vanderploeg, MD of the University of Texas Medical Branch (UTMB).
- Task 182 “Human System Risk Management Approach” presented by James Vanderploeg, MD of UTMB.
- Task 183 “Flight Crew Medical Standards and Spaceflight Participant Medical Acceptance Guidelines” presented by Richard Jennings, MD of UTMB.
- Task 184 “Human-Rating of Commercial Spacecraft” presented by Prof. David Klaus of the University of Colorado, Boulder (CU).
- Task 184 “Human-Rating of Commercial Spacecraft” presented by Christine Fanchiang, CU Ph.D. student.
- Task 185 “Unified 4D Trajectory Approach for Integrated Traffic Management” presented by Tom Colvin & Dr. Juan J. Alonso of Stanford University (SU).
- Task 186 “Mitigating Threats through Space Environment Modeling/Prediction” prepared by Tim Fuller-Rowell of CU.
- Task 186 “Space Environment MOD Modeling and Prediction” presented by Dr. Sigrid Close of SU.
- Task 187 “Space Situational Awareness” presented by D.J. Scheeres of CU.
- Task 193 “Role of COE CST in EFP: Defining the Future by Engaging Emerging Leaders ” presented by CU Ph.D. student, Bradley Cheetham.
- Task 193 “Role of COE CST in EFP: Secondary & Hosted Payloads Market Characterization” presented by Prof. Scott Hubbard and Ph.D. student Jonah Zimmerman from SU.
- Task 220 “Spaceport Operational Framework” presented by PI: Patricia C. Hynes, Ph.D. of New Mexico State University (NMSU).
- Task 228 “Magneto-Elastic Sensing for Structural Health Monitoring” presented by Dr. Andrei Zagrai and Warren Ostergren of NMT.
- Task 241 “Fracture Mechanics of Sapphire for High Temperature Pressure Transducers” presented by FSU Ph.D. student, Justin Collins.

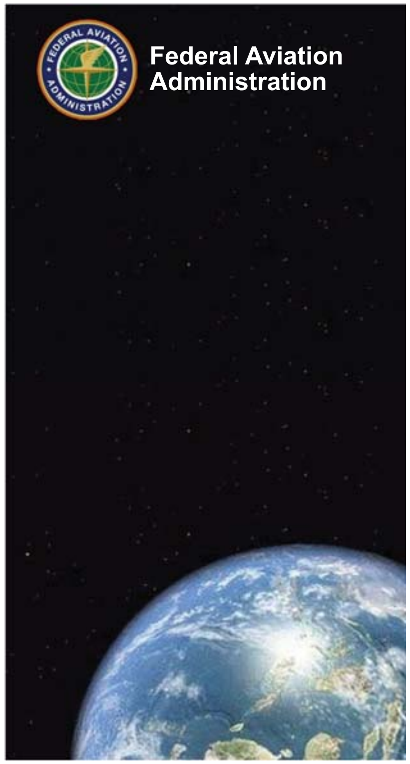
- Task 241 “High Temperature Pressure Sensors for Hypersonic Vehicles” presented by Ph.D. student David Mills from the University of Florida (UF).
- Task 244 “Autonomous Rendezvous and Docking for Space Debris Mitigation: Rapid Trajectory Generation” presented by Dr. Emmanuel Collins, PI of Florida State University (FSU).
- Task 244 “ Autonomous Rendezvous and Docking for Space Debris Mitigation” presented by Prof. Steve Rock of SU.
- Task 244 “Autonomous Rendezvous & Docking for Space Debris Mitigation” presented by Dr. Norman Fitz-Coy of UF.
- Task 247 “Determine Baseline National Airspace System Impacts from Space Operations” presented by Dr. Nathaniel E. Villaire of the Florida Institute of Technology (FIT).
- Task 253 “Ultrahigh Temperature Composites for Thermal Protection Systems” presented by Dr. Jan Gou from the University of Central Florida (UCF).
- Task 255 “Wearable Biomedical Monitoring Equipment for Spaceflight Participants on Suborbital & Orbital Flights” presented by Richard T. Jennings, MD of UTMB.
- Task 256 “Tolerance of Centrifuge Induced G-force by Disease State” presented by James Vanderploeg, MD of UTMB.
- Task 257 “Commercial Spaceflight Operations Curriculum Development” presented by CU Ph.D. student Bradley Cheetham.
- Task 258 “Analysis Environment for Safety of Launch and Re-Entry Vehicles” presented by Ph.D. student Francisco Capristan and Dr. Juan J. Alonso of SU.
- Task 259 “Flight Software Validation & Verification for Safety” presented by Dr. Juan J. Alonso of SU.
- Task 293 “Non-Linear Structural Models” presented by Dr. Keith Miller and Ph.D. student Mr. Joshua Mendoza from NMT.
- Task 294 “Development of a Minor Injury Severity Scale (MISS) for Orbital Human Spaceflight” presented by Richard T. Jennings, MD of UTMB.
- Task 295 “Effects of EMI and Ionizing Radiation on Implantable Medical Devices” presented by James Vanderploeg, MD of UTMB.
- Task 301 “Spaceport Regulation in a Post-modern Pluralistic World” presented by Ph.D. student Diane Howard from McGill University (MU).
- Task 302 “Inner Space: ICAO’s New Frontier” presented by MU Ph.D. student Paul Fitzgerald.

FAA Centers of Excellence Program Overview

COE CST Second Annual Technical Meeting

Presented by Ken Davidian for Dr. Patricia Watts, FAA COE Program Director

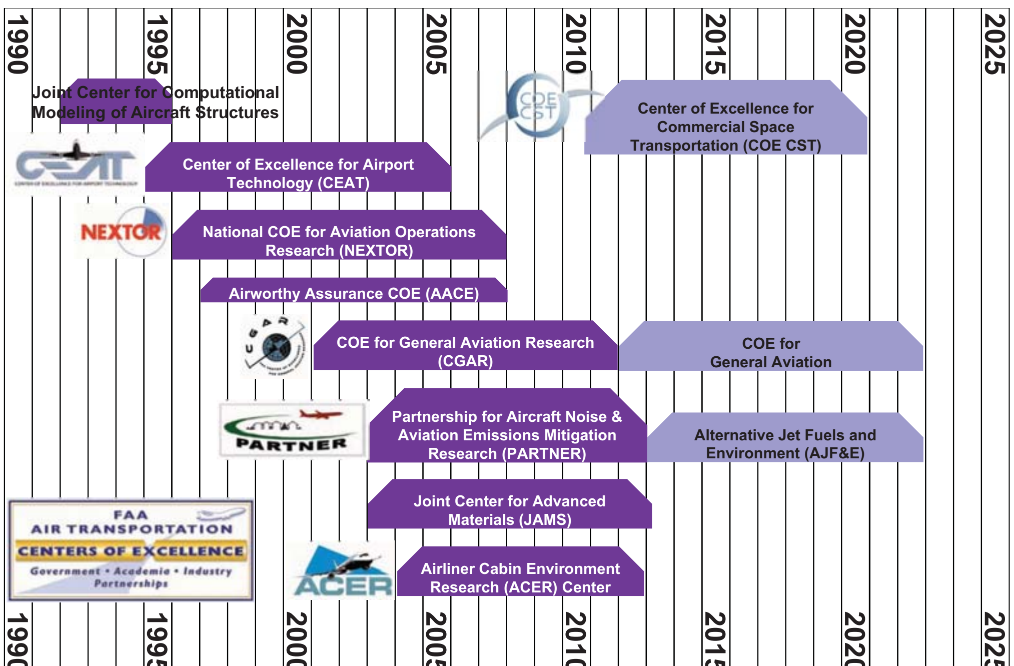
Date: October 31-November 1, 2012
New Mexico Tech, Socorro, NM



COE PROGRAM OVERVIEW

Legislative Authority
Requirements & Outcomes
Geographic Distribution
University Members
Unique Funding Combination
Role of Industry & Affiliates
Annual Meetings
Benefits

Attachment – Established Centers
Contact Information



Upcoming COEs

- General Aviation
  - Selection of Purdue/Ohio State Team
  - Announced September 27, 2012
- Alternative Jet Fuels and Environment (AJF&E)
  - Public Meeting Nov 15-16, 2012
- Unmanned Aerial Systems
  - Coming Soon…

BACK-UP SLIDES

LEGISLATIVE AUTHORITY

**Omnibus Budget
Reconciliation Act of 1990
Public Law 101-508
Title IX – Aviation Safety
and Capacity Expansion Act**

↓

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

FAA COEs - Established

COE for General Aviation 2012 - TBD

COE for Commercial Space Transportation (CST) - 2010

COE for Research in the Intermodal Transport Environment (ACER/RITE) - 2004

Joint COE for Advanced Materials (JAMS) - 2004

FAA/NASA/Transport Canada COE for Aircraft Noise & Aviation Emissions Mitigation (PARTNER) - 2003

COE for General Aviation (CGAR) – 2001

COE for Airport Technology (CEAT) – 1995

COE for Airworthiness Assurance (AACE) – 1997 to 2007

COE for Operations Research (NEXTOR) – 1996 to 2007

Joint Center for Computational Modeling of Aircraft Structures – 1992 to 1996

FAA COE GEOGRAPHIC DISTRIBUTION

AIRLINER CABIN ENVIRONMENT – INTERMODAL RESEARCH

Auburn Un.- Admin Lead
Harvard Un.
Purdue Un.
Boise State Un.
Kansas State Un.
Un. of Med & Dentistry of NJ

GENERAL AVIATION

Embry Riddle Aeronautical Un - Lead
Un. of Alaska
Un. of North Dakota
Wichita State

AIRPORT TECHNOLOGY

Un. of Illinois
RPI

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.

NOISE AND EMISSIONS MITIGATION

MIT – Lead
Boston Un.
Georgia Tech
Harvard Un.
Penn State
Purdue Un.
Stanford
Un. of Illinois
Un. of Missouri-Rolla
Un. of Pennsylvania
Un. of North Carolina- Chapel Hill

COMMERCIAL SPACE TRANSPORTATION

Florida Institute of Technology
Florida State Univ.
New Mexico Inst of Mining & Technology
New Mexico State Univ.
Stanford Univ.
Univ. of Florida
Univ. of Central Florida
Univ. of Colorado at Boulder
Univ. of Texas Medical Branch

OPERATIONS RESEARCH

UC-B, MIT, UMD, VPI, Geo Mason

AIRWORTHINESS ASSURANCE

31 Equal University Partners

GENERAL AVIATION 2011

TBD

FAA COE Levels of Oversight

1) **FAA COE Program Director / Grants Officer**
FAA Sponsoring Organization

FAA/University Offices
Legal – Contracts – Financial Reps.
Public Affairs – Gov't Affairs
& Grants Officers

COE University Director(s) / Leads

2) **FAA COE Program Manager(s)**
3) FAA Technical Monitor(s)

Internal Advisors

DOT Office of Acquisition & Grants Management, M-60

COE UNIVERSITY MEMBERS

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

John Porcari – Deputy Secretary of Transportation
Chelsea He – 2011 DOT FAA COE Student of the Year

Andrew Leonard – UND
2010 DOT FAA COE Student of the Year

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

COE UNIVERSITY MEMBERS

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

Phillip Donovan – UIUC
2008 DOT FAA COE Student of the Year

Peter Sparacino – FAA CGAR Program Manager,
Daniel J. Halperin – 2008 ERAU COE Outstanding Student of the Year
Patricia Watts – FAA COE Program Director
Steven Hampton – ERAU CGAR Principal Investigator

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

UNIQUE FUNDING COMBINATIONS

- **COE Research Grants / Public Purpose - require matching funds to establish, operate and conduct research. Mandated by Congress.**
- **Cost-share contracts / FAA Purpose - awarded following competitive process. Authorized by the White House Reinvention Lab**
- **Centers receive funding from any public or private source.**
- **Each core member receives direct awards from FAA.**
- **As set forth in P.L. 101-508:** ***Centers may contract with others as appropriate***

COE FUNDING LEVELS

YEAR	CENTER OF EXCELLENCE	AMOUNT
1992 to 1996	Computational Modeling of Aircraft Structures – Airport & Aircraft Safety R&D Division, TC	$ 10 M
1995 - present	**Airport Technology** – Airport & Aircraft Safety R&D Division, TC **(Formerly: Airport Pavement Research)**	**$ 40 M**
1996 – 2007	**Operations Research*** - Systems Architecture, Hdq.	$ 47 M
1997 – 2007	Airworthiness Assurance* - Airport & Aircraft Safety R&D Division, TC	$ 135 M
2001 - present	**General Aviation*** - Airport & Aircraft Safety R&D Division, TC	**$ 36 M**
2003 - present	**Aircraft Noise and Emissions Mitigation*** - Office of Environment & Energy, Hdq.	**$ 75 M**
2004 – present	**Advanced Materials** - Airport & Aircraft Safety R&D Division, TC	**$ 40 M**
2004 – present	**Research in the Intermodal Transport Environment** – Office of Aeromedical Research, Hdq. **(Formerly: Airliner Cabin Environment)**	**$ 38 M**
2010 - present	**Commercial Space Transportation*** - Office of Commercial Space Transportation, Hdq.	**$ 5 M**
Level of Effort	**May Include: Grants, Matching Contributions, Contracts and Interagency Agreements**	**$ 426 M**

RESULTS

COE Partnerships Established	**9**
University Partners and Affiliates	**> 260**
Official Collaborations with: NASA, Transport Canada, Sandia, Iceland, DoD, Volpe, etc.	**> 12**
Projects Supported	**> 600**
Graduate Students Supported	**> 1,500**
Published Articles, Reports, Doctoral Theses	**> 2,500**
Matching Funds	**> $226M**

ROLE OF GOV'T & INDUSTRY

- **Federal Government - Commits seed funds for research, education, and tech transfer over a period of 10 ys.**
- **Private Sources -**
  - Serve on COE Advisory Boards
  - Provide matching contributions such as cash or in-kind contributions in accordance with OMB guidance such as:
    - **Labor**
    - **Materials**
    - **Lab space**
    - **Host meetings**
    - **Etc.**

COE AFFILIATES / 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 Pilotss 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 Aeronautic 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 (EA

FedEx Corporation
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 Company
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 Transp Systems Center
US EPA
Virginia Department of Transportation
Wyle Laboratories

STREAMLINED ADMINISTRATION

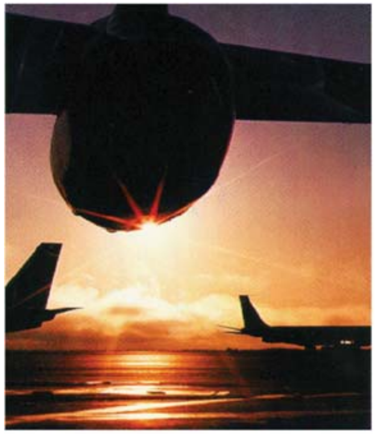
- The FAA sponsoring organization assigns a COE Program Manager to each Center. The funding source assigns a Task Monitor to each task.
- The Gov't funds COE projects on an on-going basis following proposal submission and technical evaluations conducted by the sponsoring or funding organization.
- Projects may be funded for public purpose - using grants, or for FAA purpose to obtain deliverables - using contracts.
- Members meet quarterly during first year, semi-annually thereafter. Universities or industry affiliates host meetings to enhance partnership opportunities.
- The COE management, projects, and progress are reassessed every three years; matching funds are audited.

COE Annual Meetings

- Students are provided an opportunity to highlight their work and engage in technical discussions with leaders in the field, and seek career opportunities.
- Senior scientists have a forum for disseminating research results, coordinating efforts, and fielding new research ideas amongst peers.
- Government, industry and university members have a venue to engage in discourse to enhance and expand partnership opportunities, generate matching funds, and review research direction and progress – across organizational lines on *neutral territory*.

COE 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 and facilitates aerospace recruitment opportunities
- **Provide** a formal strategy & trusted structure to coordinate a national research agenda and related education, and training
- **Advance** U.S. technology and expertise while satisfying Congressional mandate



The nation must immediately reverse the decline in and promote the growth of a scientifically and technologically trained U.S. aerospace workforce"
Final Report of the Commission on the Future of the United States Aerospace Industry

FAA CENTERS OF EXCELLENCE

Patricia Watts, Ph.D.
National Program Director
Air Transportation Centers of Excellence

FAA William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405
Telephone (609) 485-5043
Fax: (609) 485-9430
Email: patricia.watts@faa.gov
Website: www.coe.faa.gov

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

COE for Commercial Space Transportation

- **Competitively Selected by FAA Administrator – August, 2010**
- **Technology Areas:**
  - **Space Traffic Management & Operations**
  - **Launch Vehicle Systems**
  - **Human Space Flight**
  - **Space Commerce**

Sponsor: FAA Headquarters - Office of Commercial Space Transportation

Members: New Mexico State University, Stanford University, New Mexico Institute of Mining and Technology, Florida Institute of Technology, Florida State University, University of Central Florida, University of Florida, University of Colorado at Boulder, University of Texas Medical Branch

Administrative Lead: New Mexico State University
Patricia Hynes: pahynes@nmsu.edu

COE for Research in the Intermodal Transport Environment (RITE)

- **Competitively Selected by the FAA Administrator – August 2004**
- **Technology Areas:**
  - **Development of Sensors and Sensor Systems to Monitor Cabin Air Environment and Detect Potential Environment Contaminants**
  - **Investigation of the Health Effects of Potential Contaminants and Other Aspects of Contained Environments**
  - **Field and Laboratory Analysis of Potential Contaminants**
  - **Development of Databases, with Supporting Architecture, for Documentation of Contaminants and Contaminant Incidents**

Sponsor: FAA Headquarters - Office of Aerospace Medicine

Core Members: Harvard University, Purdue University, Auburn University, Boise State University, Kansas State University, University of Medicine and Dentistry of New Jersey;
Affiliate Members: Oklahoma State University, St. Louis University, University of Alabama at Huntsville

Administrative Lead: Auburn University
Tony Overfelt: overfra@auburn.edu

COE for Intermodal Transport Environment Research Affiliates

AeroClave LLC
AirOcare
Air Transport Association
Altera Inc.
Ansys
Battelle
The Boeing Company
Delta Air Lines
Donaldson Company Inc.
Goodrich Sensor Systems
Honeywell

Intergraph
InvisiMED
Keddeg Company
Microchip Technology Inc.
The MITRE Corporation
Pall Aeropower Corp.
Singapore Airlines
Southwest Airlines
STERIS Corporation
TSI Inc.
US Airways

Joint COE for Advanced Materials (JAMS)

- **Competitively Selected by the FAA Administrator – December 2003**
- **Technology Areas:**
  - **Safety and Certification Initiatives of Composites and Advanced Materials on Large Transport Commercial Aircraft**
  - **Safe and Reliable Use of Advanced Materials in Aircraft Workforce Training**
  - **Relationships Between Design, Manufacturing, Operations, and Maintenance**

Sponsor: Aircraft Research Division

Members: University of Washington, Wichita State University, Edmonds Community College, Florida International University, Northwestern University, Purdue University, Oregon State University, Tuskegee University, UCLA, University of Delaware, University of Utah, Washington State University

University Co-Leads: Wichita State U. and the U. of Washington
John Tomblin, Ph.D., john.tomblin@wichita.edu
Mark Tuttle, Ph.D., tuttle@u.washington.edu

Joint COE for Advanced Materials Affiliates

Composites and Advanced Materials Team Industry Affiliates
WICHITA STATE UNIVERSITY

Adam Aircraft
ASTM International
Boeing
Bombardier
Cessna, a Textron Company
CIRRUS Design
Hawker Beechcraft
Piper Aircraft
Spirit AeroSystems

Advanced Materials in Transport Aircraft Structures Team
Industry Affiliates
UNIVERSITY OF WASHINGTON

A&P Technology
Bell Helicopter
The Boeing Company
C&D Zodiac
Composite Solutions, Inc.
Cytec Engineered Materials
General Plastics Manufacturing Co.
Heatcon Composite Systems
Hexcel
Integrated Technologies, Inc.
Toray Composites (America), Inc.
Triumph Composite Systems, Inc.

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

- Competitively Selected by the FAA Administrator – August 2003
- Single Source Contract Authority: $6M cap
- Technology Areas:
  - Socio-economic Effects of Noise and Emissions Impacts
  - Noise Abatement Flight Procedures
  - Compatible Land Use Management
  - Airport Operational Controls
  - Noise and Emissions Measurements and Health

Sponsors: FAA Hdq - Office of Environment & Energy in partnership with NASA and Transport Canada

Members: MIT, Harvard University, Pennsylvania State University, Purdue University, Stanford University, University of Missouri-Rolla, Georgia Institute of Technology, University of North Carolina – Chapel Hill, York University of Canada, University of Illinois Urbana Champaign, Boston University, University of Pennsylvania

University Lead: Massachusetts Institute of Technology
Ian Waitz, iaw@mit.edu

COE for Aircraft Noise & Aviation Emissions Mitigation Affiliates

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)

- Competitive Selection by FAA Administrator: 2001
- Single source contract authority: $20M cap
- GA Technology Areas:
  - Aging Aircraft
  - Crashworthiness
  - Propulsion
  - Icing
  - Advanced Materials

Sponsor: Aircraft Research Division

Members: Embry-Riddle Aeronautical University, University of Alaska at Fairbanks and Anchorage University of North Dakota, Wichita State University

University Lead: Embry-Riddle Aeronautical University
Steven Hampton, hamptons@db.erau.edu

COE for General Aviation Affiliates

Industry Affiliates

Aero Shell
Aircraft Welding Works
Alaska Airmen's Association
Alaska Aviation Safety Foundation
Aviation Management Associates
Avidyne Corporation
Bombardier Aerospace
Cessna Aircraft Corporation
Cirrus Aviation
Eclipse Aviation
Elite Air Shares
Frasca International
Goodrich Corporation
HandySoft Corporation
Hartzell Propeller, Inc.
Jeppesen
Lancair
Lockheed Martin
Raytheon Aircraft Company
Sun Microsystems
SMA
The Alaska Science & Technology
The Boeing Company
Vector Training Systems

Advisory Group Members

Aircraft Owners and Pilots Association (AOPA)

Experimental Aircraft Association (EAA)

General Aviation Manufacturers Association (GAMA)

National Business Aviation Association (NBAA)

State Aviation Directors – Florida, Arizona, Alaska, Kansas, and North Dakota

COE for Airworthiness Assurance (AACE)

- **Competitively Selected by FAA Administrator:** September 11, 1997
  Operational through September 11, 2007
- **Single source contract authority: $100M cap**
- **Technology Areas:**
  - Maintenance, Inspection, and Repair
  - Crashworthiness
  - Propulsion and Fuel Systems Safety Technologies
  - Advanced Materials

Sponsor: FAA Airport & Aircraft R&D Division

Members: Phase II – Equal University Partners (following list)

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 Airworthiness Assurance
Phase II – Industry Affiliates

ABX Air, Inc.
AirTran Airways
Alaska Airlines
Aloha Airlines
American Airlines
American Eagle
Atlantic Coast Airways
Boeing
Bombardier Aerospace-Learjet
Cape Air
Cessna
Continental
Delta
Federal Express
General Electric
Honeywell
JetBlue Airways
Lufthansa
Nantucket Airlines
Northwest
Pratt & Whitney
Raytheon
United Airlines
US Airways

COE for Operations Research (NEXTOR)

- **Competitive Selection by FAA Administrator: 1996 through 2007**
- **Contract authority: $10M - Phase I + $50M - Phase II**
- **Technology Areas**:
  - **Air Traffic Management and Control**
  - **Human Factors**
  - **System Performance and Assessment Measures**
  - **Safety Data Analysis**
  - **Communications, Data Collection and Distribution**
  - **Aviation Economics**

Sponsor: FAA Hdq - Technology Development & Operations Research

Members: Un of California - Berkeley, MIT, VPI, Un of Maryland, Geoge Mason Un

University Contact: University of California at Berkeley
Mark Hansen: mhansen@ce.berkeley.edu

COE for Operations Research Partners and Affiliates

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

Industrial Affiliates

The Boeing Company
California Department of Transportation
Draper Laboratory
Federal Express
Honeywell
Leigh Fisher Associates
Logistics Management Institute
Maryland Aviation Administration
Los Angeles World Airports
Massachusetts Port Authority
Metron Aviation, Inc.
Northrop Grumman

Sabre
San Francisco International Airport
Seagull Technology
Southern California Association of Governments
Virginia Department of Transportation

COE for Airport Technology (CEAT)

- **Competitively Selected by the FAA Administrator: 1995**
- Originally established as the COE for Airport Pavement Technology R&D
- **Technology Areas:**
  - **High Performance Concrete**
  - **Non-destructive Evaluation of Pavements**
  - **Stabilized Base Material**
  - **Structural Behavior and Modeling**
  - **Airport Pavement Design Concepts/Procedures**
  - **Wildlife Research**

Sponsor: FAA Airport Technology R&D Group
Members: University of Illinois, Rensselaer Polytechnic Institute;
with Public Partners: O'Hare Modernization Program and the City of Chicago

University Lead: University of Illinois at Urbana-Champaign
(Located at the former Chanute Air Force Base, Rantoul, ILL)
David A. Lange, dlange@uiuc.edu

COE for Airport Technology University Members

CENTER PARTNERS
University of Illinois at Urbana Champaign
Rensselaer Polytechnic Institute

PUBLIC PARTNERS
O'Hare Modernization Program
City of Chicago

Joint Center for Computational Modeling of Aircraft Structures

- Members Designated by Congress: 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

P.L. 101-508 REQUIREMENTS AND OUTCOMES

FAA Requirements:
* geographic equity in the distribution of funds and location of Centers;
* consideration of minority and special groups.

Universities Must:
* match FAA grant funds from non-federal sources;
* interpret, publish, and disseminate research results.

Together we…
- strategically focus and coordinate a Nat'l research agenda with public/ private partners for 10 yrs,
- avoid duplication of effort using a tested business strategy and trusted structure,
- augment resources with the best and brightest throughout the U.S.,
- leverage scarce gov't funds,
- educate and train a pool of aviation professionals for the next generation.

Joint COE Meetings

1) Hosts 2001: GE Aircraft Engines, Cincinnati, Ohio w The Ohio State University
2) Hosts 2002: Boeing Corporation, Raytheon, Bombardier, Cessna, Wichita, Kansas with Wichita State University
   Special Guests: US Transportation Secretary Norman Y. Mineta, US Congressman Todd Tiahrt
3) Hosts 2003: The Boeing Company, Harris Corporation, Atlantic Southeast Airlines, Aviation Management Associates, Galaxy Scientific Corp.,Sensis Corporation, Jeppesen with Embry - Riddle Aeronautical University
   Keynote Speaker: Ambassador Edward Stimpson, ICAO (retired)
4) Hosts 2005: Harris Corporation, The Boeing Company, Cessna Aircraft Company, Pratt & Whitney, Lockheed-Martin, Raytheon, Tandberg Inc., General Electric, Gulfstream Aerospace Corporation, Galaxy Scientific Corporation, Engine Titanium Consortium (ETC), Aviation Management Associates, Center for Advanced Transportation Systems Simulation (CATSS) with the University of Central Florida
   Keynote Speaker: Ambassador Thomas Pickering, Sr VP, International Relations, The Boeing Co.
   Dinner Speaker: The Honorable John Goglia, NTSB (retired)

Student Awards: Student Dinner, Poster Contests, and Awards provided and presented by industry affiliates. DOT & FAA COE Outstanding Students and Faculty of the Year recognized, Paper Competitions held.

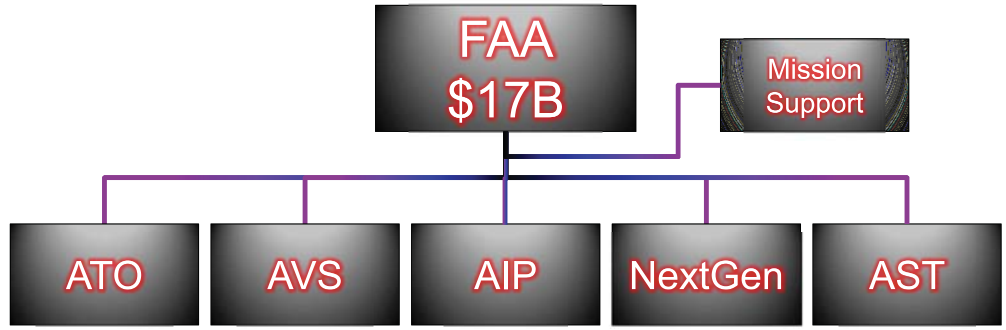
FAA AST R&D Overview & Status

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

Overview

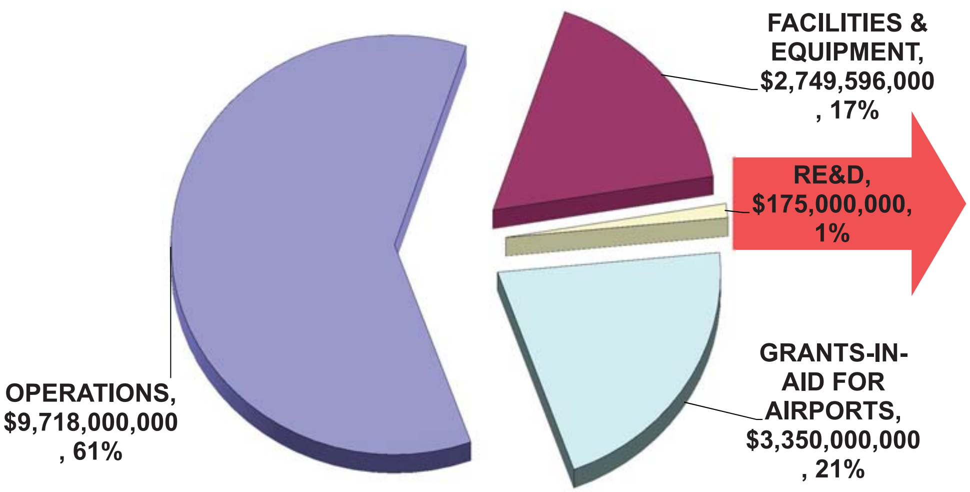
- FAA Organization
- Budget
- AST R&D Organization, Processes

FAA Organization



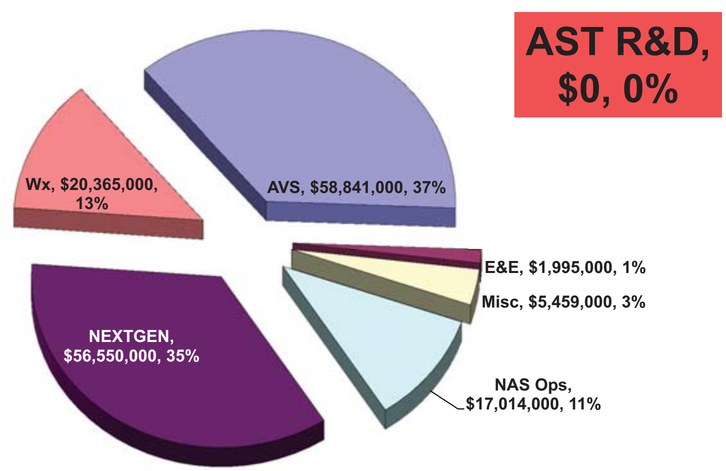
COE CST Second Annual Technical Meeting (ATM2)
October 30 – November 1, 2012
Federal Aviation Administration

FAA BUDGET ($15,992,596,000*)
*House Approps Committee Report



COE CST Second Annual Technical Meeting (ATM2)
October 30 – November 1, 2012
Federal Aviation Administration

FAA RE&D Budget by PPT ($175,000,000*)
*FY12 House Approps Committee Report



COE CST Second Annual Technical Meeting (ATM2)
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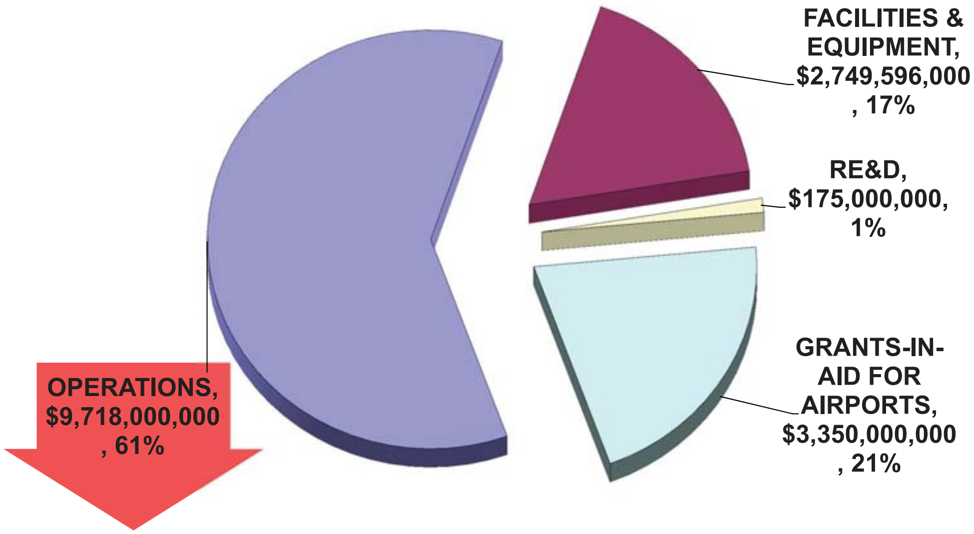
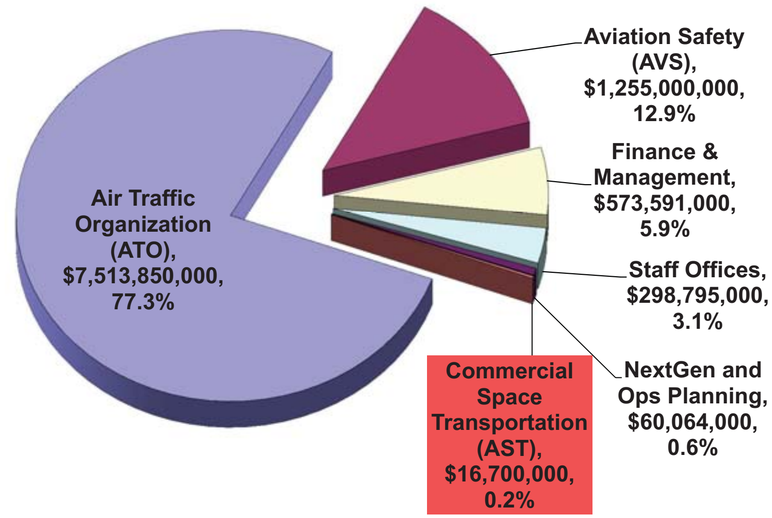
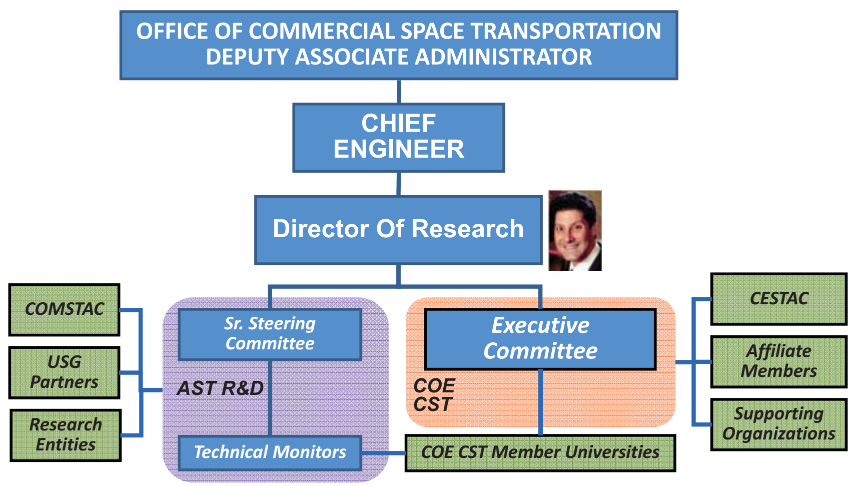
FAA BUDGET ($15,992,596,000*)
*House Approps Committee Report



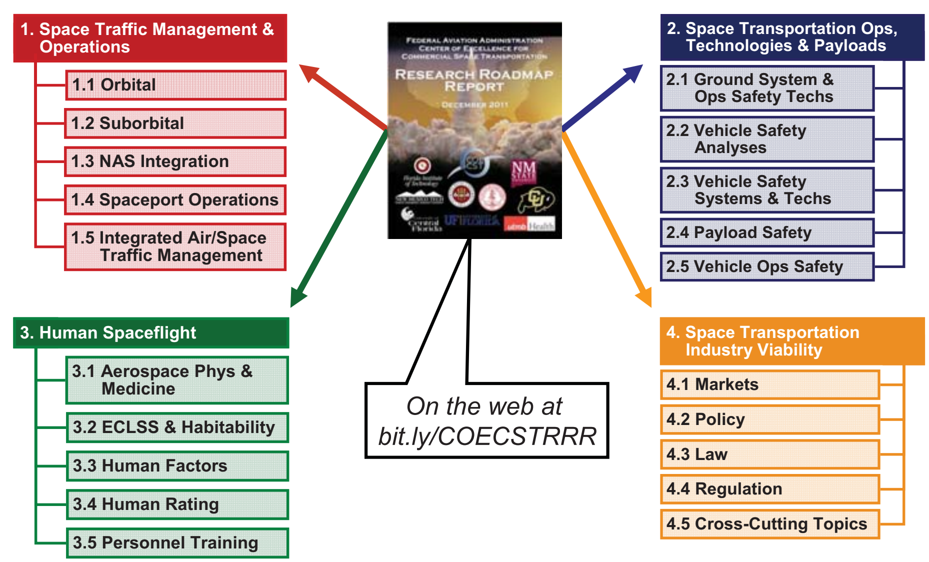
FAA Operations Budget ($9,718,000,000*)
*FY12 House Approps Committee Report



FAA AST R&D Organization



4 Commercial Space Research Areas



Three Primary AST R&D Processes

1. **Requirements Identification & Integration**
   - June-Dec: Update of 5-year R&D Plans for each Research Area
2. **Internal Solicitation of Research**
   - Jan-Mar: Proposal Solicitation
   - Mar-Apr: Proposal Evaluation
   - Apr-May: Awards for June 1 - May 31 POP
3. **Technical Monitoring**

Summary

- Budget Constraints on COE CST Growth
  - FAA continues to ask “What relevance does AST R&D have to FAA?”
  - Please help us answer those questions!
- AST R&D Organization Evolution
  - Executive Committee & Subcommittees
  - Affiliate Organizations
  - Supporting Organizations

FAA COE CST Overview & Status

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

Overview

- People
- Tasks
- Reports
- Funding
- Organization

University of Colorado

Stanford University

University of Texas Medical Branch

L to R: Richard Jennings**, Anil Menon*, Jennifer Law*, Tarah Castleberry**, Becky Blue*, Jim Vanderploeg**, James Pattarini*, James Cushman*, Charles Mathers* (via computer).
**Faculty. *Resident (student) in aerospace medicine.

New Mexico Tech

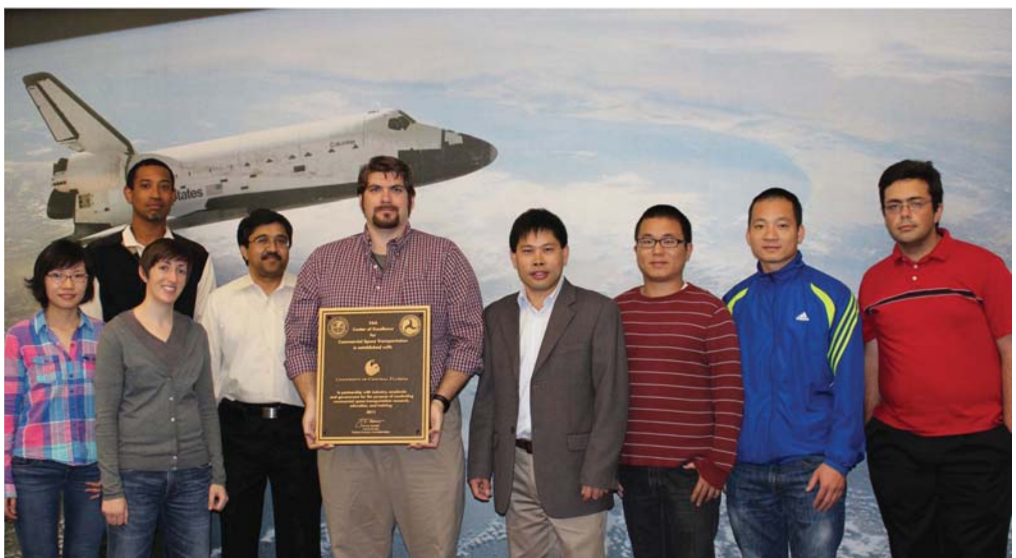
COE CST Second Annual Technical Meeting (ATM2)
October 30 – November 1, 2012

Federal Aviation Administration

6

Florida State University

University of Central Florida



Florida Institute of Technology

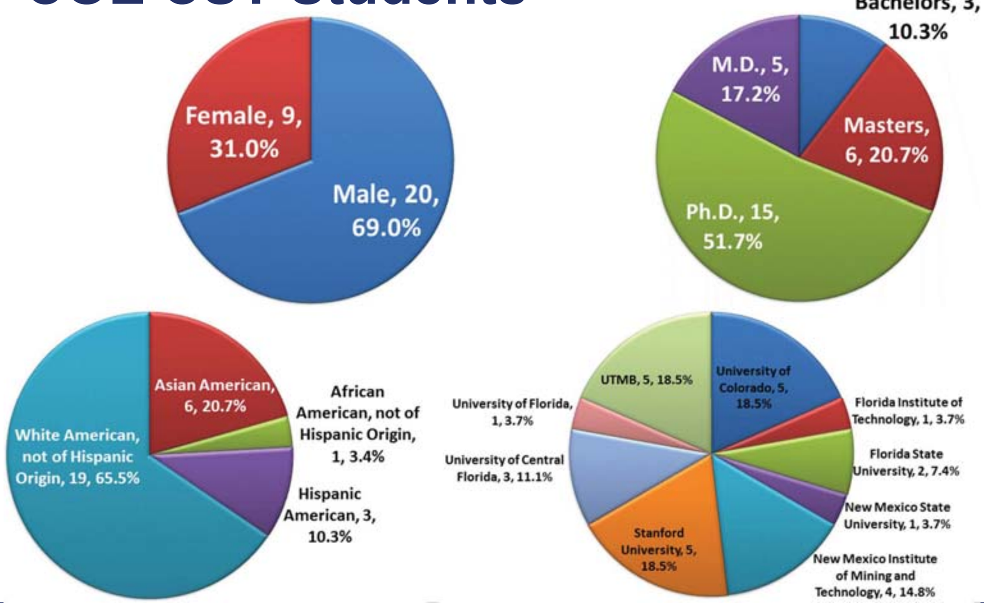
University of Florida

New Mexico State University

COE CST: It's All About the People…

26-27 March 2012, ESIL-02 Workshop, Washington DC

COE CST Students



AST Research Areas & Interdependencies

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

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

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

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

All FAA AST R&D Tasks (as of 24 Oct 2012)

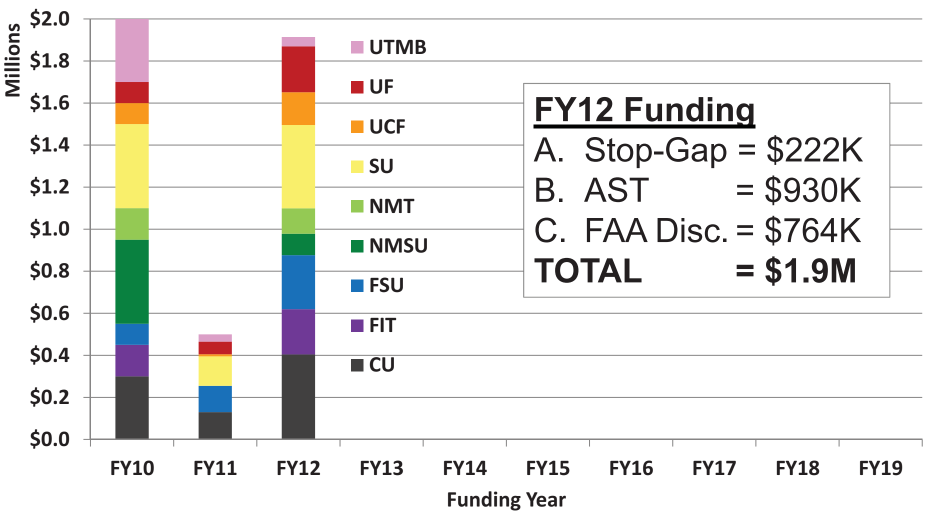
Task # Name / PI Name (Univ) - AST TM	Task # Name / PI Name (Univ) - AST TM
185 Unified 4-Dimensional Trajectory Analysis Alonso (SU) - Wilde	210 ADS-B Advanced Flight Hardware (ERAU #3) - Demidovich
186 Space Environment MMOD Modeling and Prediction Close (SU), Fuller-Rowell (CU) - Shelton-Mur	228 Magneto-Elastic Sensing for Structural Health Monitoring Zagrai & Ostergren (NMT) - Demidovich
187 Space Situational Awareness Scheeres (CU) - Earle	241 High Temperature Pressure Transducers Sheplak (UF), Oats (FSU) - Demidovich
208 Space Vehicle Debris Hazard Airspace Stratification Feasibility Study – (ERAU #1) - Murray	244 Autonomous Rendezvous and Docking Fitz-Coy (UF), Collins (FSU), Rock (SU), Axelrad (CU) - Earle
209 Aviation Impact from Space Operations Analysis Process (ERAU #2) - Murray	253 Ultra High Temperature Composites Gou & Kapat (UCF) - Demidovich
211 Key Spaceport Planning and Design Requirements Study (ERAU #4) - Rey	258 Multi-Disciplinary Analysis of Safety Metrics Alonso (SU) - Wilde
213 Correlations of Icing Potential Index to Triggered Lightning Risk - (ERAU #6) - Shelton-Mur	259 Flight Software Validation & Verification for Safety Alonso (SU) - Wilde
214 Electric-Field Triggering Conditions and Vehicle Plume Effects - (ERAU #7) - Shelton-Mur	293 Reduced Order Non-Linear Structural Modeling Miller (NMT) - Demidovich
216 Spacecraft and Propulsion Technician Training and Certification - (ERAU #9) - Rey	298 Integration Evaluation of ADS-B Payloads Hynes (NMSU) - Demidovich
220 Space Operational Framework Hynes (NMSU) - McElligott	299 Nitrous Oxide Composite Tank Testing TBD (NMT) - Tran
247 Air and Space Traffic Considerations for CST Villaire (FIT) - Murray	193 Role of COE CST in EFP Hubbard (SU), Born (CU) - Davidian
257 Master's Launch and On-Orbit Operations Laboratory Born (CU) - Lampazzi	215 Certification and Safety Analysis for Next-Generation Launch Vehicles - (ERAU #8) - Demidovich
181 Physiological DB Definition and Design Vanderploeg (UTMB) - Lampazzi	263 Commercial Space Industry Viability Research Contract Foust (Futron) - Davidian
182 Human System Risk Management Approach Vanderploeg (UTMB) - Lampazzi	301 Spaceport Regulation in a Post-modern Pluralistic World Jakhu (MU) - TBD
183 Crew and HSP Medical Standards Jennings (UTMB) - Lampazzi	302 International Commercial Space Regulations (?) Jakhu (MU) - Touré
184 Human Rating of Commercial Spacecraft Klaus (CU) - Lampazzi	XXX FATESS Contract Industry Reporting Tasks Maliga (Tauri) - Davidian
212 LEO Radiation Impacts on Humans and Safety Critical Components – (ERAU #5) - Shelton-Mur	296 CESTAC Support and Outreach Fiedler (FIT) - Davidian
255 Wearable Biomedical Monitoring Equipment Jennings (UTMB) - Lampazzi	297 Technical Oversight & OMIS Alvi (FSU) - Davidian
256 Additional NASTAR Centrifuge Testing Vanderploeg (UTMB) - Lampazzi	300 Collaborative Activities Fiedler (FIT) - Davidian
294 Minor Injury Severity Scale Jennings (UTMB) - Gerlach	Orion America Technologies Contract Gregorek - Davidian
295 EMF Effects on Implantable Devices Vanderploeg (UTMB) - Lampazzi	**Note:** There are 37 R&D tasks (26 conducted by COE CST) & 4 Admin tasks.

COE CST Year 2 Reports - On the web!

- Task 184-CU: "Evaluation of Commercial Human Spaceflight Laws and Regulations in the United States", October 2012.
- Task 184-CU: Klaus, D., Fanchiang, C. and Ocampo, R., "Perspectives on Human-Rating", 42nd International Conference on Environmental Systems, July 2012.
- Task 193-CU: Cheetham, B., et. al. "Government's Role in Commercial Space From the Perspective of Emerging Industry Leaders", IAC, October 2, 2012.
- Task 193-CU: Cheetham, B. "Theory Based Analysis of The Commercial Crew to Orbit Transportation Industry Structure and Evolution", IAC, October 3, 2012.
- Task 257-CU: Cheetham, B. "Commercial Spaceflight Operations: Graduate Level Curriculum Development", IAC, October 2, 2012.
- Task 247-FIT: Villaire, Nat. "Integration of Commercial Space Vehicle Traffic into the National Airspace System", March 31, 2012.
- Task 220-NMSU: Spaceport Operations Framework Group Video.
- Task 193-SU: Zimmerman, J. et. al., "Research Roadmap for Commercial Space Transportation", International Astronautical Congress, October 2012.
- Task 193-SU: Zimmerman, J., et. al. "FAA Office of Commercial Space Transportation Research Roadmap", Global Space Exploration Conference, April 2012.
- Task 183-UTMB: Jennings, R. "Flight Crew Medical Standards and Spaceflight Participant Medical Acceptance Guidelines for Commercial Space Flight", August 6, 2012.

Find all these reports at www.coe-cst.org under the "Publications" tab.

COE CST Funding History



FAA Center of Excellence for Commercial Space Transportation

Organizational Highlights

- **Second Annual Administrative Meeting** at FSU in Tallahassee, FL on April 25-26, 2012.
- **Creation of Executive Committee** Consolidating Coordinating, Planning Committees
- **Creation of 3 Subcommittees** Self-Governance, Strategic Planning, Collaboration
- **First Full Year of CESTAC Operation**
- **Two New Categories of Membership** Affiliate Members, Supporting Organizations

COE CST Year 2 was made possible with generous support from…

ATK
NASTAR CENTER
THE TAURI GROUP
Futron
SPACE FLORIDA
ULA United Launch Alliance
SPACE SYSTEMS LORAL
LOCKHEED MARTIN
wyle

Summary

- Year 2 finds COE CST in “full-stride”.
- Looking forward to a productive Year 3!

At-A-Glance Metrics	Year 1	Year 2
# Research Tasks	25	33
# Principal Investigators	27	24
# Students	31	~29
# Reports	0	~9
# Affiliate Members	0	1
Funding	$2M (FY10)	$0.5M (FY11) $1.9M (FY12)

FAA COE CST Affiliate Member Overview

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

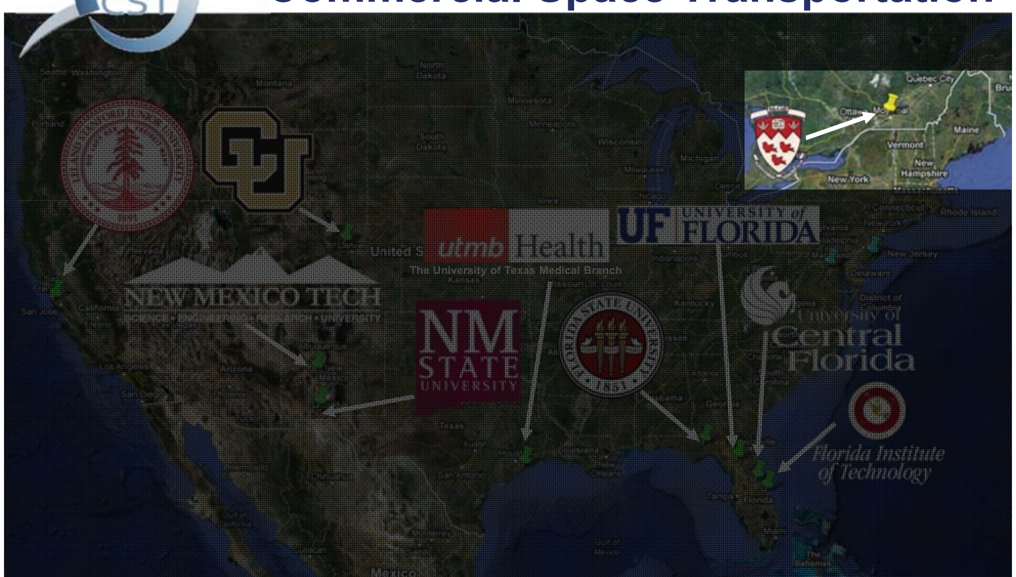
Overview

- What is an Affiliate Member
- Who is Involved
- "Gives & Gets"
- 1st COE CST Affiliate Member
- Future Plans

FAA Center of Excellence for Commercial Space Transportation

COE CST Second Annual Technical Meeting (ATM2)
October 30 – November 1, 2012
Federal Aviation Administration

FAA Center of Excellence for Commercial Space Transportation



COE CST Second Annual Technical Meeting (ATM2)
October 30 – November 1, 2012
Federal Aviation Administration

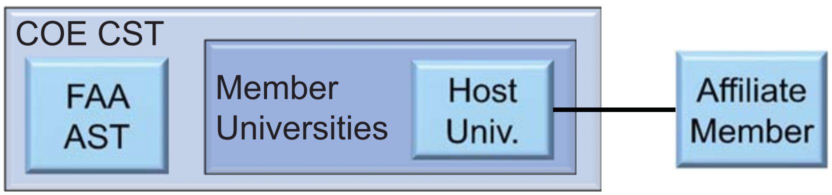
What Is An Affiliate Member?

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

COE CST Second Annual Technical Meeting (ATM2)
October 30 – November 1, 2012
Federal Aviation Administration

Involved Parties

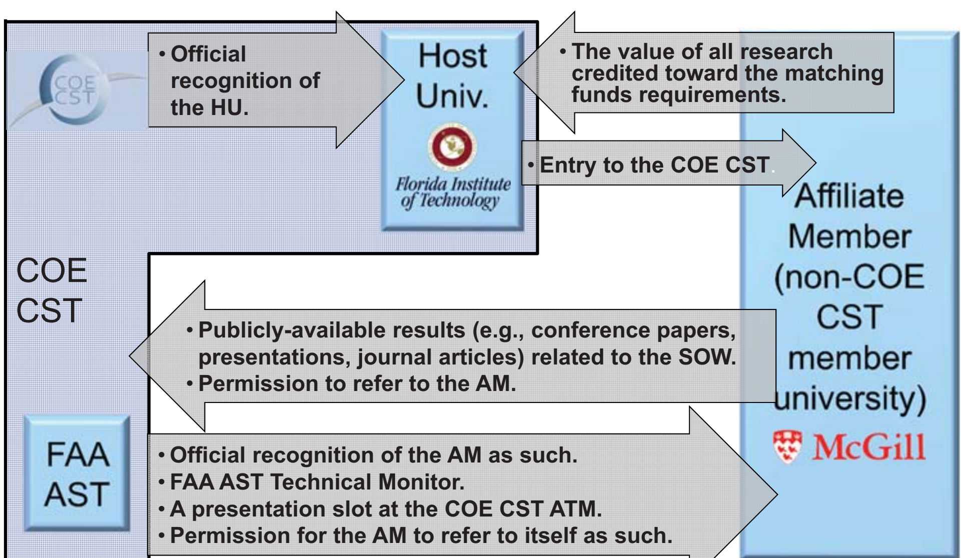
- FAA Office of Commercial Space Transportation (AST)
- Member University (MU), one of the current nine member universities
- COE CST, comprised of the FAA AST and the MUs.
- Host University (HU), an MU acting as the liaison between the COE CST and the AM.
- Affiliate Member (AM)



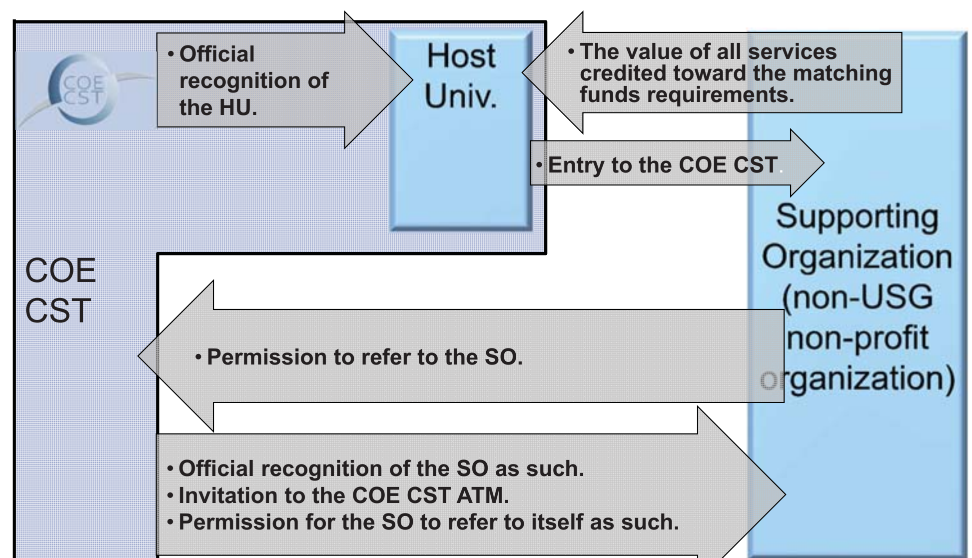
General Terms

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

Affiliate Members "Gives & Gets"



Supporting Organizations "Gives & Gets"



1st Affiliate Member: McGill University

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

Future Plans

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

Summary

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

FAA AST R&D Overview & Status

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

Overview

- Housekeeping
- Overview of EC Self-Governance Subcommittee
- Overview of EC Strategic Planning Subcommittee
  - Activity: COE CST BOS Survey
- Overview of EC Collaboration Subcommittee
- Summary

Housekeeping

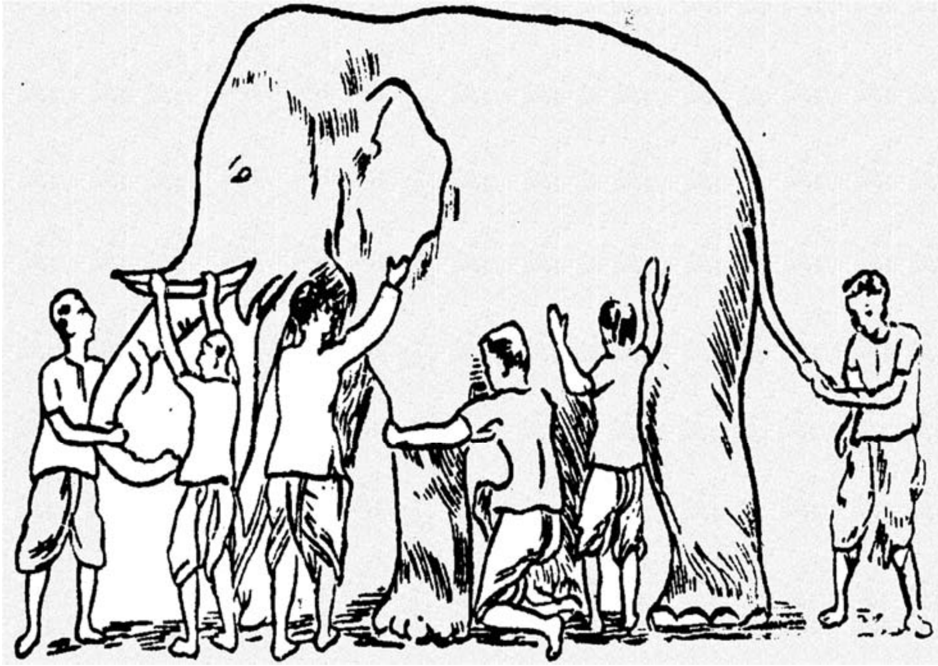
- Q4 Status Reports in OMIS
  - Let's take a look…
- Tracking Deliverables

Self-Governance Subcommittee

- Goal: To Iteratively Develop A Set Of Self-Governance Documents
  - Step 1. "EC Terms of Reference"
  - Step 2. "EC Management Plan"
  - Step 3. "EC Constitution" - the foundational document for the COE CST entering its self-sustaining phase.
- Current Membership:
  - Nat Villaire (FIT)
  - Norm Fitz-Coy (UF)

Self-Governance - Next Steps

- Sample documents provided by Pat Hynes.
- Discussion of Next Steps

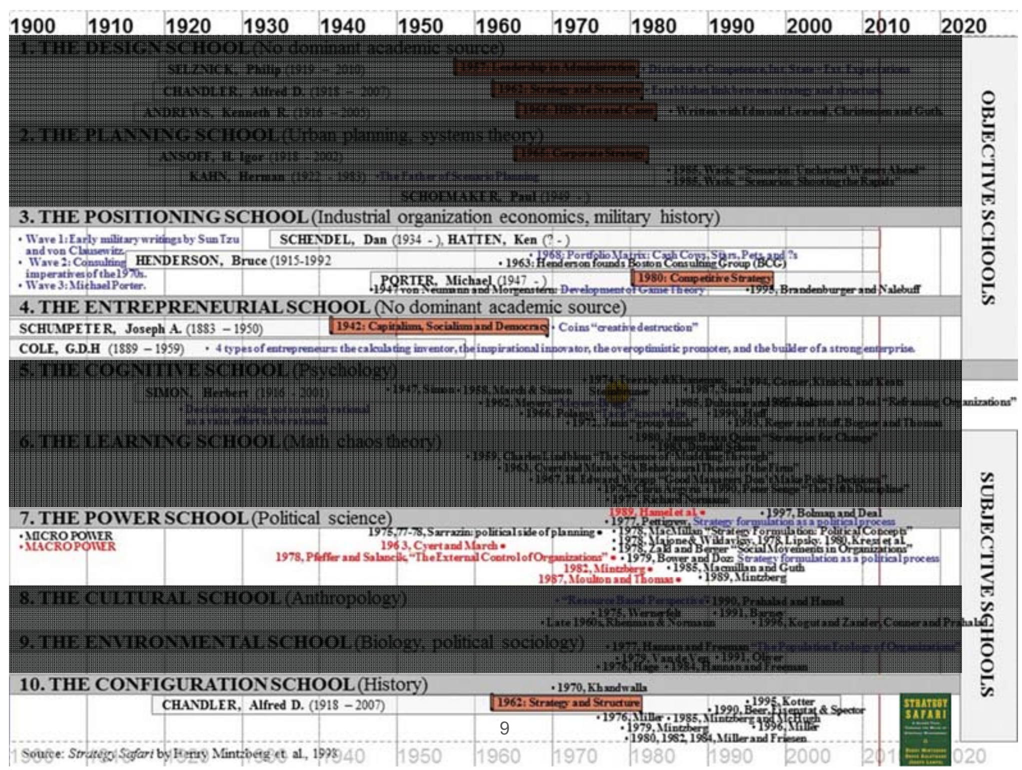


Strategic Planning Subcommittee

- Goal: To provide the basis for sustained, meaningful activities among the participating members.
- Current Membership:
  - Dave Klaus (CU)
  - Dan Kirk (FIT)
  - Billie Oates (FSU)
  - Scott Hubbard (SU)
  - Sigrid Close (SU)
  - Juan Alonso (SU)
  - Andrei Zagrei (NMT)

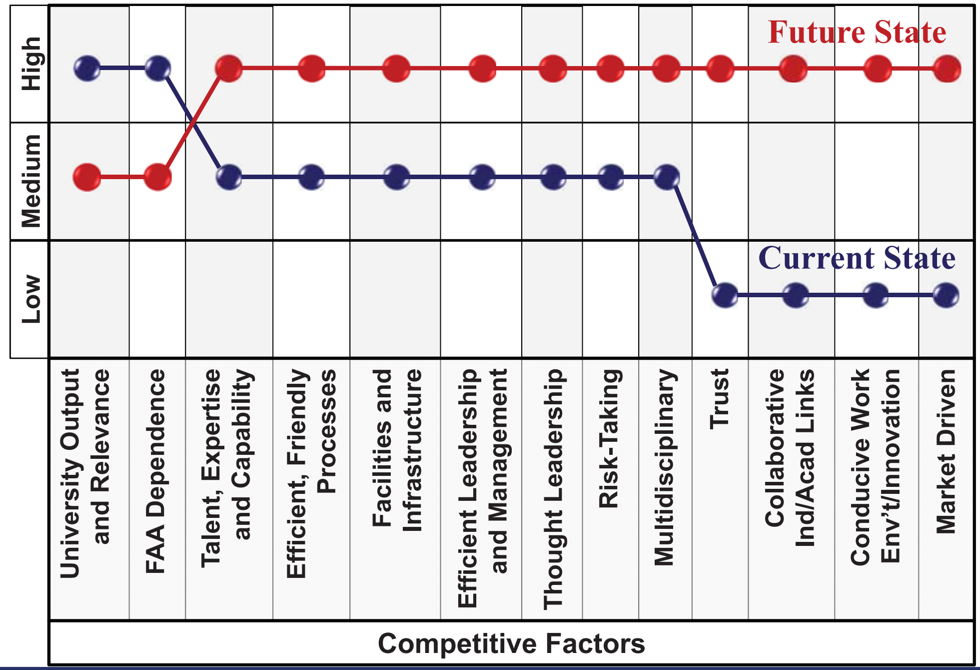
Strategic Planning Background

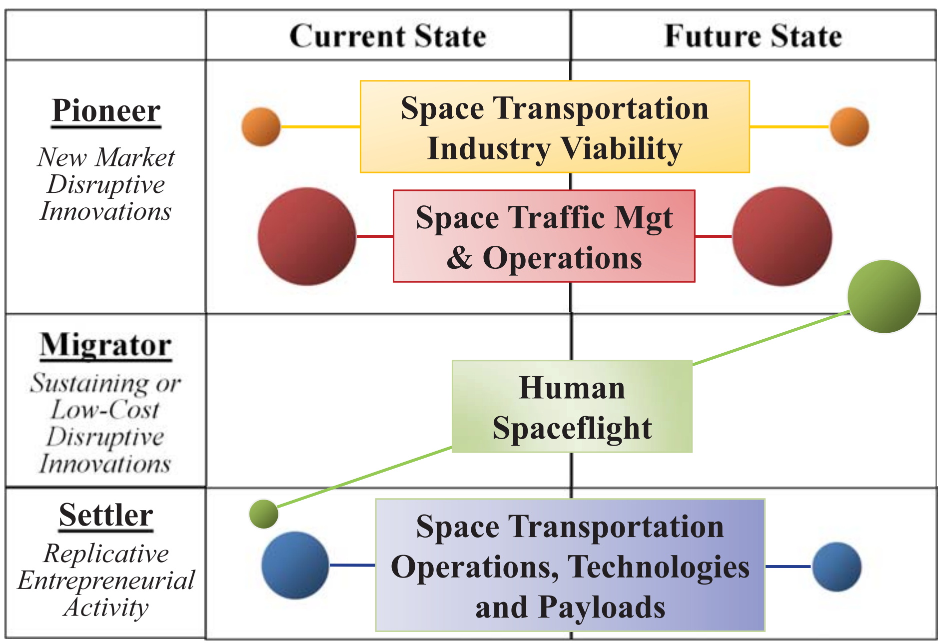
- Membership
  - Good start with 7 volunteers.
  - Dave Klaus has offered to lead group
- Approach
  - "Go With What You Know" is common
  - Complement to AST activities
  - Other options: academic perspectives…



AST's COE CST Strategic Planning

- Based on Kim & Mauborgne's "Blue Ocean Strategy"
- Initial Results
  - COE CST Form, Function, Purpose
  - Identification of Substitutes, Alternatives
- External (i.e. "your") Inputs Needed
  - Competitive Factors - Strategy Canvas
  - Portfolio Evolution Map
  - BOS Survey in Survey Monkey

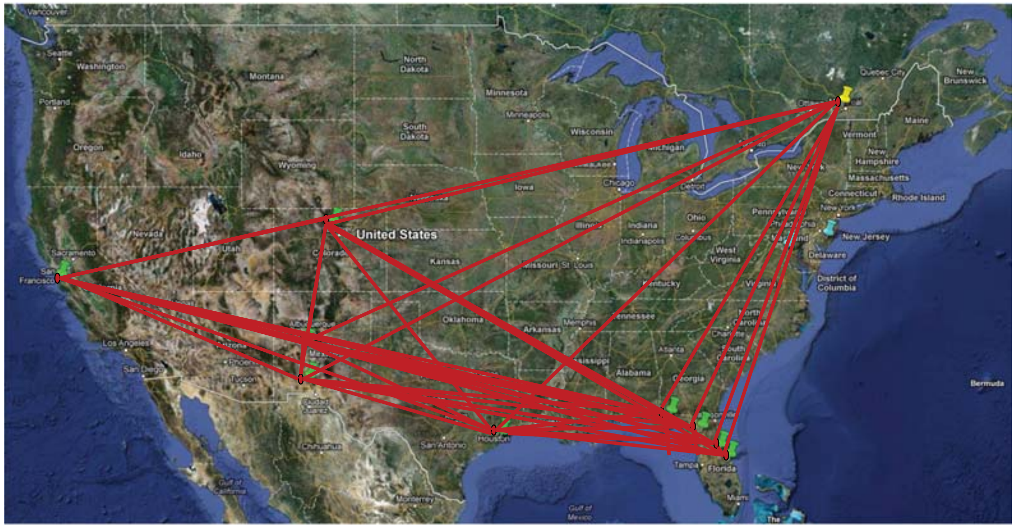




COE CST BOS Industry Survey

- On the web at https://www.surveymonkey.com/s/2BZL8DQ
- Paper copies available

Collaboration Subcommittee



Collaboration Subcommittee

- Goal: To foster cooperative efforts among internal and external COE CST entities.
  - Also… To respond to FAA and external funding solicitations.
- Current Membership:
  - Mark Sheplak (UF)
  - Penny Axelrad (CU)
  - Warren Ostergren (NMT)
  - Dan Scheeres (CU)
  - ***Tristan Fiedler (FIT)***
  - Pat Hynes (NMSU)
  - Jim Vanderploeg (UTMB)

Collaboration Subcommittee

- Encourage, facilitate and promote collaborative activities.
  - Among member universities.
  - Of new Affiliate Members, Supporting Orgs.
- Current Plans
  - Incremental collaborative steps of increasing formality toward final status of consortium.

Incremental Collaborative Step #1

- Adoption of central research theme in support of which multiple research tasks would contribute.
  - Based on NASA ARC Virtual Institute Model
  - Example: Space Transportation Concept of Operations (integration into the NAS, NextGen)

1. Space Traffic Management & Operations (5 Tasks)	2. Space Transportation Operations, Technologies & Payloads (6 Tasks)
• 186(2x) - Space Environment Modeling • 247 - Air & Space Traffic Considerations • 220 - Space Operations Framework • 186 - Unified 4-D Trajectory	• 244 (4x) - Autonomous RDV & Docking • 257 - Launch & On-Orbit Ops Lab • 258 - Multidisciplinary Analysis of Safety Metrics
3. Human Spaceflight	**4. Space Transportation Industry Viability**
• None identified.	• 301 - Worldwide Spaceport Regs

Summary

- Self-Governance Subcommittee
- Strategic Planning Subcommittee
- Collaboration Subcommittee

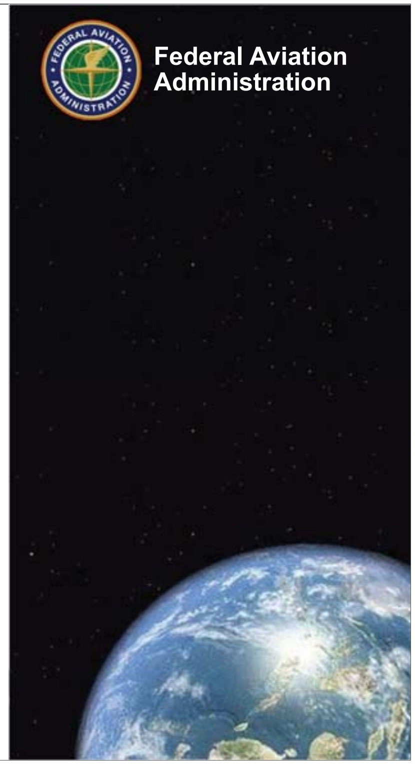
COE CST Second Annual Technical Meeting:

181: Physiologic Database Definition & Design

James Vanderploeg, MD

utmb Health
Aerospace Medicine

November 1, 2012



Overview

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

Team Members

- UTMB
  - PI: Jim Vanderploeg, MD (UTMB Aerospace Med.)
  - Co-I: Richard Jennings, MD (UTMB Aerospace Med)
  - Student: Jennifer Law, MD (UTMB Aerospace Med.)
  - Student: Charles Mathers, MD (UTMB Aerospace Med.)
  - Student: David Reyes, MD (UTMB Aerospace Med.)
- NASA Johnson Space Center
  - Mary Van Baalen, Dr. Kathy Johnson-Throop
  - Dr. Mike Barratt, Dr. Jeffrey Davis
- Wyle Integrated Science & Engineering
  - Christine Smith, Mary Wear, Robert Volpe, Jared McGrath
- FAA CAMI
  - Dr. Melchor Antunano

Purpose of Task

- Purpose:
  - Design a database to house medical & physiological data from commercial crew and spaceflight participants
- Objectives:
  - Identify the appropriate data elements
  - Recommend a scalable design for the database
  - Recommend security, approved access, appropriate uses of data
- Goals
  - Define the requirements and elements
  - Get “buy in” from commercial companies, NASA, and FAA

Understanding Human Complexity

Height
Weight
Mechanical Aptitude
Native Language
Susceptibility to SAS
Situational Awareness
Depth of Knowledge (Preparedness)
Verbal Clarity & Fluency
Strength
Visual Acuity

• HUMANS ARE THE MOST COMPLEX SUBSYSTEM OF YOUR SPACECRAFT

Underlying Medical Conditions
Arm Reach
G-Tolerance
Pain (Discomfort) Tolerance
Cultural Differences
Auditory Acuity
Gender
Reaction Time (Scan Pattern)
Operational Background
Endurance

Existing Data Sets

- Longitudinal Study of Astronaut Health (LSAH)
- Historical data in Integrated Medical Model (IMM)
- Individual NASA research experiments data
- Flight Surgeon post-flight astronaut debrief data
- Data from experiments performed on Life Science research Shuttle missions

Problems with Existing Data Sets

- Small numbers of astronauts or research subjects so de-identification is difficult
- Getting data out of the LSAH is difficult
- No integration among the data sets
- No standardization among the data sets

What We Have Accomplished

- Review of existing databases
- Discussions with NASA
- Workshop of ~30 interested parties (March 2012)
- Exploration of funding sources
- Agreement in principle for NASA hosting
- Exploration of commitment to participate by commercial companies

Results: Database Design

- Database should include:
  - Pre-flight Data
    - Medical screening data
    - Training data
  - In-Flight Data
    - Physiologic parameters
    - Vehicle parameters (G-profile, CO_2, cabin pressure, temperature, etc.)
    - Anomalies & in-flight events
  - Post-flight medical debrief
  - Correlation of discrete data with subjective data

Results – 2: Concept of Operations

"If you contribute data you have a say in how, when, and under what rules the data are used."

- Oversight Board made up of:
  - Commercial operators
  - FAA COE representative
  - NASA science representative
- Participation is voluntary, not FAA required
- NASA-hosted using existing LSAH infrastructure
- Independent from LSAH and other databases
- No or low cost to commercial operators

Conclusions

- General agreement a medical & physiologic database for commercial spaceflight would be very useful.
- Benefits:
  - Common archive of physiologic, medical, and flight data for medical assessment and future life sciences research
  - Validates / refines passenger acceptance criteria
    - Supports rationale for self-regulation
    - Potential time/cost savings for commercial operator
  - Demonstrates safety culture

Next Steps

- Continue to explore interest and commitment of commercial operators to participate
- Encourage operators who are approaching flight readiness to collect consistent and compatible data
- Prepare final report with recommendations
- Start flying so we have some data!

Summary

- Future of this task
  - Complete the report and recommendations by December 31, 2012
  - NASA wants to wait on further support until there is data on 500 flown spaceflight participants
  - Place this task in suspension pending acquisition of flight data by commercial operators
  - Re-visit future viability of consolidated database at that time

Contact Information

- Jim Vanderploeg, MD, MPH
  2.102 Ewing Hall, UTMB
  301 University Blvd.
  Galveston, Texas 77555-1110
  Phone: 1-409-747-6131
  Fax: 1-409-747-6129
  Email: jmvander@utmb.edu

COE CST Second Annual Technical Meeting (ATM2)
October 30 – November 1, 2012

COE CST Second Annual Technical Meeting:

182: Human System Risk Management Approach

James Vanderploeg, MD

utmb Health Aerospace Medicine

November 1, 2012

Overview – this task is completed

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

COE CST Second Annual Technical Meeting (ATM2)
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Team Members

- UTMB
  - Jim Vanderploeg, MD – PI
  - Richard Jennings, MD – Co-I
  - Jennifer Law, MD – Resident in Aerospace Med
  - Charles Mathers, MD – Resident in Aerosp Med
- Wyle Laboratories
  - Eric Kerstman, MD
- U.S. Army
  - Susan Fondy, MD

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Team Members - Students

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Purpose of Task

- Purpose
  - Investigate the feasibility of applying the JSC Human System Risk Management approach for long-duration spaceflight to commercial suborbital and short duration orbital spaceflight
- Objectives
  - Select subset of risks appropriate for commercial spaceflight
  - Quantify the health and performance risk
  - Define mitigation strategies

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Research Methodology

- Sources of Information:
  - NASA Human Research Roadmap (HRR)
  - Historical Human Spaceflight Data
  - Integrated Medical Model
- Thirty-one operationally focused risks defined in HRR Program Requirements Document
- Integrated Research Plan and Evidence Book (IRD) details activities to fill the knowledge and mitigation gaps

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Research Methodology - 2

- Assign level of concern for each risk applicable to commercial flight

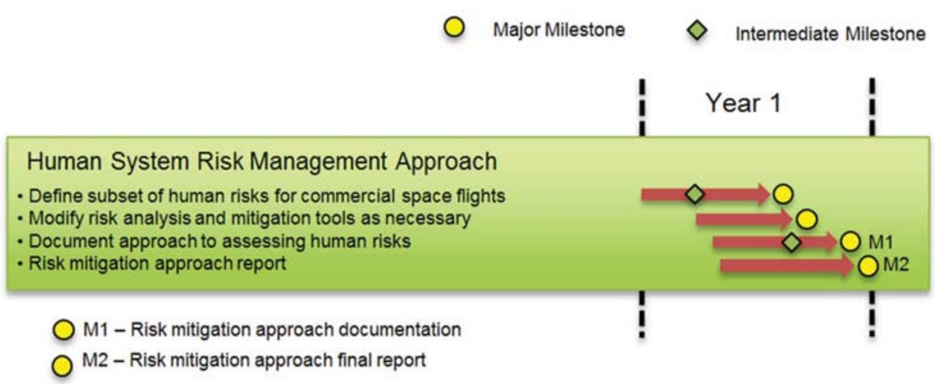
Concern Level	Crew	Passengers
Definite	3	4
Possible	21	21
Least	7	6

- Develop risk mitigation strategies for each definite and possible concern

Example

- Risk: Abnormal cardiac rhythm
- Rationale:
  - Passengers in poorer health with history of heart problems
  - Reduced cardiac function
  - Increased risk of cardiac arrest
- Mitigation:
  - Pre-screening to identify
  - Pre-treatment to eliminate or control arrhythmia
  - Pre-flight testing/training under simulated environment (centrifuge and/or Zero-G flight)

Schedule & Milestones



Results

- Thirty-one risks were identified and categorized
- Twenty-four risks for crew members and 25 for passengers were evaluated for mitigation strategies
- Final report was submitted to the FAA AST in December 2011.
- An article has been accepted for publication in *Aviation, Space, and Environmental Medicine*

Contact Information

- Jim Vanderploeg, MD, MPH
  2.102 Ewing Hall, UTMB
  301 University Blvd.
  Galveston, Texas 77555-1110
  Phone: 1-409-747-6131
  Fax: 1-409-747-6129
  Email: jmvander@utmb.edu

COE CST Second Annual Technical Meeting:

Flight Crew Medical Standards and Spaceflight Participant Medical Acceptance Guidelines

Richard T. Jennings, MD

November 1, 2012

Overview

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

Team Members

- Jim Vanderploeg, MD,UTMB (Co-PI)
- Melchor Antunano, MD, FAA CAMI
- Smith Johnston, MD, NASA-JSC
- Vernon McDonald, PhD, Wyle
- Jan Stepanek, MD, Mayo Clinic Scottsdale
- Mark Campbell, MD, Paris Surgical Associates
- Col Steve Nagel, University of Missouri
- Leigh Lewis, MD, UTMB/Mayo Jacksonville*
- Chuck Mathers, MD, UTMB/Mayo Scottsdale*

Purpose of Task

Objectives

- Develop recommendations for medical standards for suborbital and orbital space vehicle crew members
- Develop recommendations for spaceflight participant (SFP) acceptance criteria for suborbital and orbital flight
- Develop an 'Informed Consent' document to appropriately convey risks related to personal medical status

Research Methodology

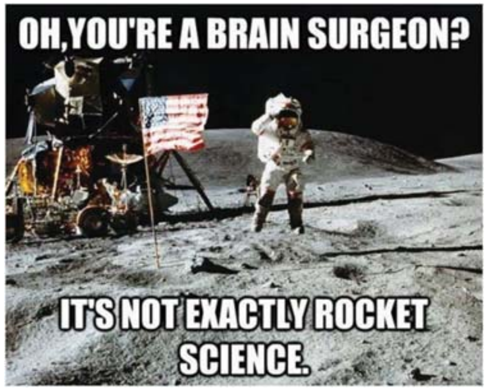
- Industry and expert review of existing documents (12) addressing flight crew member medical certification, SFP medical acceptance guidelines, and testing and training recommendations for crew members and SFPs (Phase I).
- Prepare a draft document incorporating standards/guidelines and recommendations identified in Phase I and distribute for review/input to individuals, agencies, organizations, and companies involved in commercial space flight.

Research Methodology

- Convene a working group of industry representatives and experts in aerospace medicine and physiology, operations, training, safety, and commercial space flight to consider Phase I input and prepare final recommendations for the medical certification of crew members, medical acceptance guidelines of SFPs, and recommended training procedures
- Conduct a preliminary study of the information that is required for spaceflight participants to receive appropriate risk-based "Informed Consent."

Phase I Review and Input

- SpaceX
- Wyle
- Environmental Tectonics Corp
- XCOR
- Blue Origin
- NASA
- FAA
- Owen K. Garriott



Phase II Review and Input March 2012

- 25 Total Participants
- NASA-JSC (7)
- Wyle
- Sierra Nevada
- SpaceX
- XCOR
- Space Adventures
- NASTAR (2)
- FAA CAMI
- Mayo Clinic, Scottsdale
- University of Missouri
- UT Health Sciences Center
- UTMB (5)
  - 3 residents

What We Have To Date


Flight Crew Medical Standards and Spaceflight Participant Medical Acceptance Guidelines for Commercial Space Flight

June 30, 2012

Informed Consent

- ASM Grand Rounds to Introduce Subject 9/2012

  Medical Standards for Spaceflight Participants and Crew: FAA Regulations and Informed Consent-Carminati
- Slide Set Available at http://www.dsls.usra.edu/education/grandrounds/archive/2012/20120925/092512.pdf
- Medical data collection starts December 2012 (another task) which will help define parameters for medical informed consent discussion

Law School Gym

Results or Schedule/Milestones

- Phase I document completed and distributed for review
- Updated document distributed
- Phase II Review March 2012
- Final Document Delivered to FAA July 2012 (Based on expected expiration of "Human Space Flight Requirements for Crew and SFPs")
- Informed Consent TBD

Conclusions and Future Work

- This task is essentially completed, and there is no FY13 Funding
- Informed Consent
- Document value increased by including industry, academia, NASA and governmental regulatory agencies in the document creation process

Contact Information

- Richard Jennings

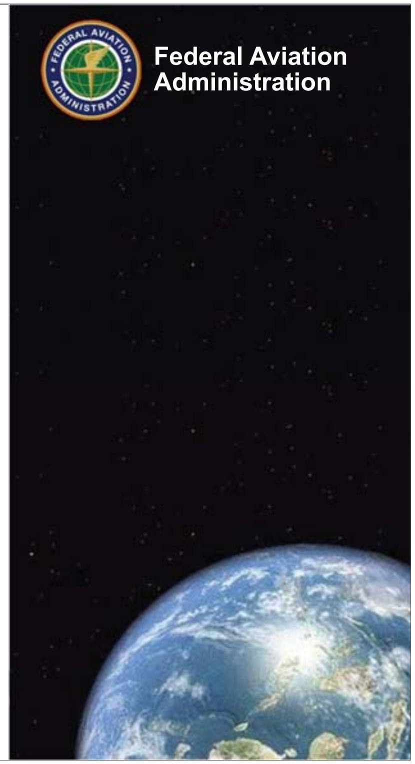
University of Texas Medical Branch
301 University Blvd
Galveston, TX 77555-1110
409-747-6131
rjenning@utmb.edu

COE CST Second Annual Technical Meeting

Task 184
Human-Rating of Commercial Spacecraft

Prof. David Klaus
University of Colorado Boulder

November 1, 2012



Overview

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

- *Related PhD Research*

Team Members & Affiliates

- **David Klaus**, PI, University of Colorado
- **Christine Fanchiang**, PhD student, CU Aerospace (funded by COE)
- **Pam Melroy, Jeff Sugar, Rene Rey**, FAA
- **Robert Ocampo**, PhD student, CU Aerospace (funded by SNC)
- **Mark Weyland**, NASA JSC
- **Kenneth Stroud**, **Merri Sanchez,** Sierra Nevada Corp.
- **Scott Norris, Todd Sullivan**, Lockheed Martin
- **Sheryl Kelley,** Boeing
- **Tim Bulk**, Special Aerospace Services
- **Jeffrey Forrest**, Metropolitan State College of Denver

- Plus Working Group members (being formed)

Purpose of Task

- Purpose
  - Assess criteria for Human-Rating of commercial spacecraft to assist the FAA with informed decision making regarding regulatory aspects affecting safety from a technical perspective
- Objectives - *year 2* (6/1/12 to 5/31/13)
  - Identify and define pertinent Human-Rating Terms and Definitions
  - Assess existing FAA aviation design, production and operation certification processes to identify best practices that anticipate and guide the structure of future commercial spaceflight regulatory needs
  - Contribute to FAA 'Human-Rating Ground Rules and Assumptions'
- Goals
  - Develop baseline 'Human-Rating (Certification?) Guidelines and Considerations' for Commercial Space Transportation addressing requirements, validation & verification, and regulatory practices

Research Methodology

- Fundamental tenets underlying Human Rating are to:
  - **accommodate** physiological needs of the crew
  - **protect** the crew and passengers from harm, including ground crew and uninvolved public
  - **utilize** the crew's capabilities to safely and effectively achieve the goals of the mission
  - Drives Life Support Requirements, Risk Mitigation Strategies, and Vehicle Functionality Design Goals, respectively
  - Task focus is primarily on regulatory aspects related to safety

Human-Rating Considerations…

- **What does 'human-rated' mean?**
  - Usually LOC-based, how safe is 'safe enough'?
  - What else besides 'safety' is considered?
- **How do we achieve / regulate it?**
  - Design functionality
  - Validation & Verification
  - Risk Analysis
  - Requirements-driven or Outcome-assessed?
  - Licensing? Certification?

Human-Rating Perspectives…

Research Methodology

Σ S/C = *f* (physics) + *f* (physiology)

Non-negotiable Design Parameters

→ required to effectively accomplish mission objectives

Task 184 ← *PhD thesis*

+ *f* (safety) + *f* (operability)

Design Trade Space 'Figures of Merit'

→ incorporated to reduce risk and improve crew utilization

Research Methodology

1) Conduct literature review including NASA and FAA documentation
- summarize current human-rating guidelines and prior outcome
- evaluate existing FAA aviation design, production and operation certification processes

2) Examine related applications such as Building Certificate of Occupancy
- bring analogous industry insight into the mix
- help to anticipate the need for and guide the structure of future commercial spaceflight regulatory processes

3) Form Working Group of industry, government and academic partners who have vested interest in contributing to the effort
- identify where consensus is attained and note where additional research is needed to resolve remaining philosophical and/or pragmatic differences on approaching human-rating
- expect to address both legal and technical aspects.

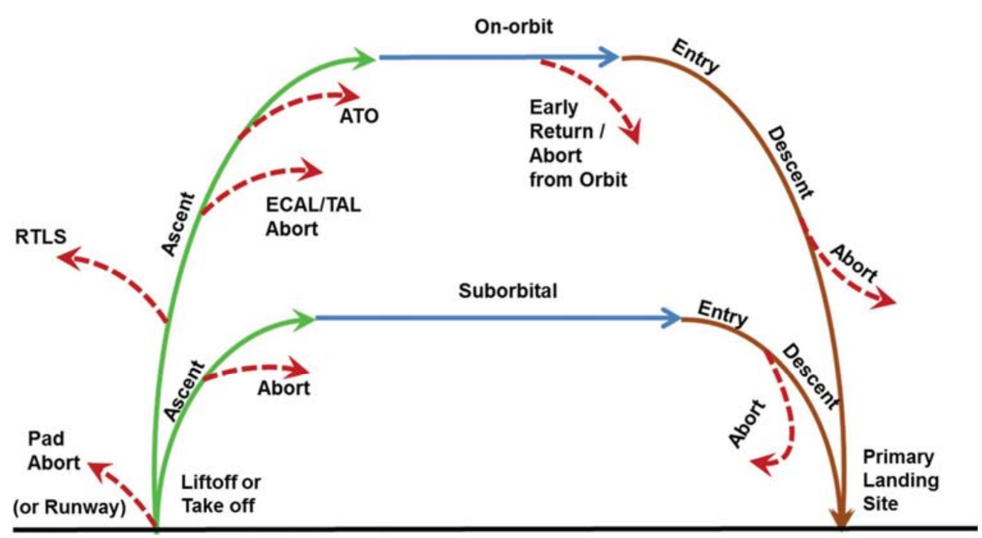
Key Participants in 'Terms and Definitions' Working Group to date

- Armadillo Aerospace
- Boeing
- Sierra Nevada Corporation
- SpaceX
- United Launch Alliance (ULA)
- Draper Laboratory
- Environmental Tectonics Corporation (ETC)-NASTAR Center
- Metropolitan State College of Denver
- Space Adventures
- University of Texas Medical Branch (UTMB)
- Wyle
- Baylor
- University of Colorado (Law)
- University of Nebraska (Law)

Results or Schedule/Milestones

- Task 184 was recently refocused to help support a related effort now underway by the FAA toward developing a Human-Rating Ground Rules and Assumptions (GR&A) document.
- Per our plans for the third calendar quarter of 2012
  - Completed a baseline version of a human-rating terminology and definitions with over 300 terms relevant to commercial human spaceflight with one or more definitions cited from 20 sources
  - Incorporated feedback from 18 interested participants across industry, academia and government (*in work*)
  - *Discussion of this effort being planned as a topic for an upcoming COMSTAC teleconference to gather feedback on process and key critical definitions, with emphasis on 'safe return to Earth'.*

'Safe Return to Earth' by Phase of Flight



Results

- Resultant publications and presentations this quarter include:
  - Klaus, D.M., Fanchiang, C. and Ocampo, R.P. (2012) Perspectives on Spacecraft Human-Rating, AIAA-2012-3419, 43rd AIAA ICES, San Diego, CA, July 2012 (paper and presentation)
  - Fanchiang, C., Defining an Operability Index for Human Spacecraft Design (student poster), 43rd AIAA ICES, San Diego, CA, July 2012

Next Steps

- ‘Terms and Definitions’ under review – upcoming COMSTAC topic
- Assess existing FAA aviation design, production and operation certification processes to facilitate open discussion aimed at identifying best practices to anticipate and guide the structure of future commercial spaceflight regulatory needs – **baseline target of December 31, 2012**
- Contribute to definition of FAA Human-Rating *Ground Rules and Assumptions* document intended to scope applicability of requirements as a function of mission phase, risk acceptance, etc., to be validated through thoughtful, systematic discussion with critical feedback from industry and public – **ongoing**

COE CST Second Annual Technical Meeting

Task 184 Human-Rating of Commercial Spacecraft

Christine Fanchiang
PhD Student
University of Colorado Boulder

November 1, 2012

Human-Rating of Spacecraft

- Human spacecraft operate in an extreme and unique environment
- Internal spacecraft environment creates major challenges for space operations
  - Induced Spacecraft Environment
  - Demanding Spacecraft Operations
  - Degraded Human Performance

Image credit: nasa.gov

Research Motivation

- As human spaceflight increases in complexity and capability, need better understanding of design impacts on human performance
- Poor human performance increases risk to ***mission success*** and ***safety***.
- Currently, no clear indicator or criteria for determining how well spacecraft optimizes human performance
  - →What is considered optimal human performance?
  - →How does spacecraft design influence crew performance?

GOAL: Identify spacecraft design influences on crew performance and create an index for assessing spacecraft design

Factors Affecting Crew Performance

VEHICLE ENVIRONMENT	VEHICLE ARCHITECTURE	HABITABILITY
The natural and induced environment factors.	Factors that create the physical environment surrounding the crew.	Human needs of the system including aspects that affect crew's psychological well-being.
Internal Atmosphere	Décor	Food and Nutrition
Water	Anthropometric Accommodations	Personal Hygiene
Contamination	Habitable Volume	Waste Management
Acceleration	Location and Orientation Aids	Countermeasures
Acoustics	Translation Paths	Medical
Vibration	Hatches and Doors	Stowage and Inventory Management
Radiation	Windows	Sleep
	Lighting	Clothing
		Housekeeping
		Recreation
		Private/personal space

Human Performance Modeling

INPUTS:

Vehicle Accommodations:
Vehicle Environment

Vehicle Architecture

Habitability

Usability Factors:
Workspace Layout

Human/Machine Interface

Task-Specific Design

Integrated Factors (future):
-Work/task allocation
-Crew Interaction
...

HUMAN

Internal characteristics:
-Physiological adaptability
-Cognitive adaptability
-Psychological adaptability

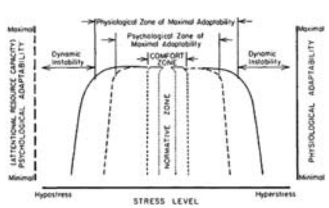


Image credit: *Hancock, 1989.*

OUTPUTS:

Physiological Metrics:
-HR
-Respiration
-Sensory Sensitivity Level
…

Cognitive Metrics:
-Processing Speed
-Workload Capability
…

Psychological Metrics:
-Irritability Level
-Emotional Stability
-Level of Happiness
…

Plan Forward

- Build descriptive model for human error
  - Model dynamics of human response
  - Identify more influential factors
- Test model components
- Verify model with historical spacecraft data

Contact Information

Professor David Klaus
Aerospace Engineering Sciences Dept.
University of Colorado / 429 UCB
Boulder, CO 80309-0429
303-492-3525
klaus@colorado.edu

Christine Fanchiang, PhD student
CU Aerospace Engineering Sciences
christine.fanchiang@colorado.edu

COE CST Second Annual Technical Meeting:

Task 185: Unified 4D Trajectory Approach for Integrated Traffic Management

Tom Colvin & Juan J. Alonso
October 31 2012

October 31 2012

Overview

- Team Members
- Brief overview of the aviation/space transportation conflict
- Research Methodology
- Results
- Next Steps
- Conclusions

Outline

- Brief overview of the aviation/space transportation conflict
- Research: Propose architectures for aircraft safety during launch/re-entry and analyze them using compact 4D envelopes
- Results
  - Propagate Uncertain Trajectories and Debris
  - Generate compact 4D envelopes
  - Counting SUA "piercings" with FACET
  - Rerouting aircraft with FACET
- Concluding thoughts and directions

Team Members

- Principal Investigator
  - Juan Alonso - Stanford University
- Graduate Student
  - Thomas Colvin - Stanford University
    - Ph.D Candidate in Aeronautics and Astronautics
- Special Thanks
  - Dan Murray - FAA AST

What's The Problem?

- Safely and fairly sharing the NAS
  - Need launch architectures to ensure all NAS users are safe
  - Current method uses SUAs
  - No formal quantitative framework for creating SUAs, thus they tend to be overly conservative
  - Commercial space traffic in rising volume and launching from new ranges will require new ATM architectures
  - Can advancements in NextGen be leveraged?

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Federal Aviation Administration

What's Needed?

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

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Federal Aviation Administration

Purpose of Task

- Development of requirements, architecture and prototype implementations of simultaneous air/space traffic management procedures for commercial space transportation. Leverage projected improvements derived from NextGen.
- Develop and analyze plausible architectures for an Integrated Airspace Management System (IAMS)
- Research and develop the foundation of IAMS based on 4D, time-space probabilistic trajectories and safety assessments

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Federal Aviation Administration

Research Methodology

- Develop mathematics and software environment to propagate trajectories under uncertainties in 4D (timing, location, "unscheduled" events, weather, system uncertainties, ...)
- Develop a way to bound the trajectories, to a "dialed-in" level of safety, within compact 4D envelopes
- Use these tools to construct potential architectures, then evaluate and compare their impact on the NAS with FACET
- Key metric: shared costs to airlines and launch providers, public at large

Calculating Trajectories

- **Long-term:**
  - Given a nominal trajectory or envelope, along with vehicle and mission parameters, create a PDF of the possible rocket and debris locations using advanced Uncertainty Quantification techniques
  - Use this PDF to generate a physical (x,y,z,t) boundary, corresponding to a given level of safety, that can be analyzed with ATM software
  - Investigate optimization of probabilistic trajectory envelopes to minimize NAS impact
- **Near-term:**
  - Use Monte Carlo simulation to approximate the rocket location PDF, sampled at many points
  - Bound the trajectories into 4D compact envelopes and quantify their impact on the NAS

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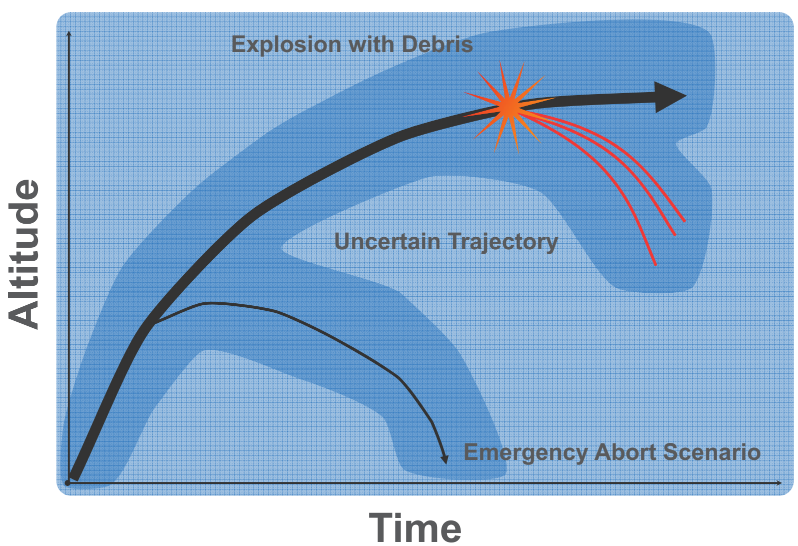
Compact Envelope Concept



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Federal Aviation Administration

How To Measure NAS Impact?

- Further develop existing ATM simulation software: NASA FACET.
- NASA Ames has provided Tom Colvin with access to the FACET source code (on site) to make necessary modifications
- Currently can measure impact by counting how many aircraft pierce the compact envelope
- Working on rerouting aircraft trajectories to measure
  - increased flight time / passenger hours
  - increased fuel burn and cost
  - impact on airline flight schedules due to these diversions

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Federal Aviation Administration

Results

- **We have an environment ready to begin analyzing ATM architectures for launching commercial space missions**
  - **Propagate Uncertain Trajectories and Debris**
  - **Generate compact 4D envelopes**
  - **Automated interface with FACET**
  - **Counting aircraft / launch vehicle conflicts with FACET**

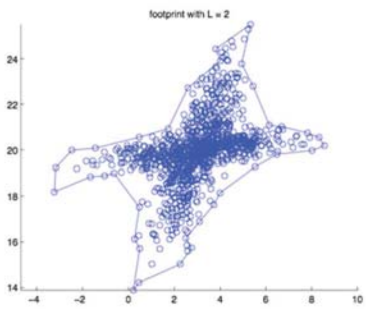
Results: Propagation Code

- **Monte Carlo software framework that accepts arbitrary:**
  - **Thrust profiles (TVC, etc)**
  - **Weather profiles for wind and temperature, with uncertainty parameters for each**
  - **Failure parameters and distributions**
  - **Debris model**
  - **Leverages work in Project 258**
- **Outputs:**
  - **Collection of (x,y,z,t) points which represent all places a vehicle or its debris may be found from a MC simulation**

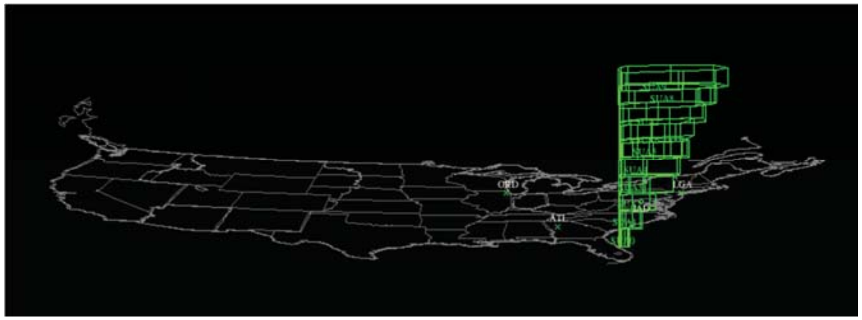
Results: Characterize Trajectories

- **Trajectories as points in space and time**
- **How do we turn this set of trajectories into something useful?**

Difficult Test Shape: No Physical Meaning



Results: Compact 4D Envelopes



- **With reasonably realistic mission plans and probabilistic trajectories, can create dynamic 4D compact envelopes**
- **Analyze with existing ATM software: FACET**

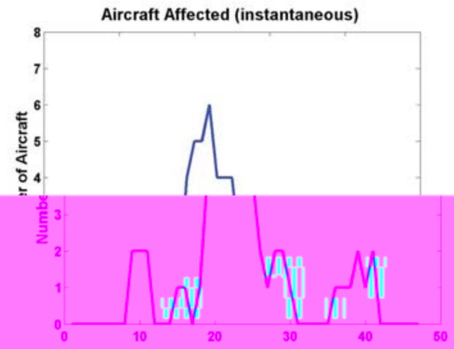
FACET: Intro to the environment

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

Results: Developing FACET For Our Task

- Nominal Capabilities
  - Specify reasonably complex time-evolving SUAs
    - But they were invisible in the GUI, could not turn on/off, etc.
  - Count piercings of SUA by aircraft using historical data
    - Bugs in determining when multiple are active, overlap, etc.
  - Simulate rerouting flights around SUA and compute cost to airlines from this diversion
- Issues: SUA aspects less mature than rest of code
  - MANY key functionalities for SUAs, including rerouting around them, are only partially developed or buggy
  - API exists but does not expose everything needed

Sample Results: Plot Of Aircraft Conflicts

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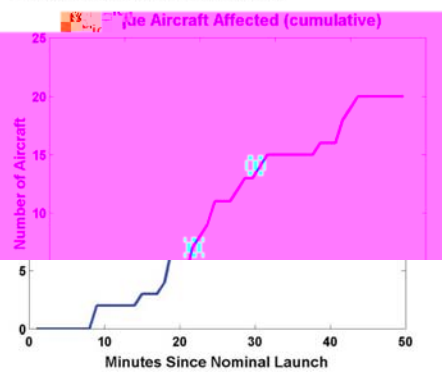


Ongoing Work

- Further develop FACET capabilities to reroute aircraft around compact envelopes to calculate added time, fuel burn, and cost to airlines
- Collaborate with FAA and launch providers to construct realistic mission profiles
- Design ATM architectures based on these mission profiles for use in trade studies
- Research techniques to optimization the integrated air-space system given uncertainties inherent to space launch
- Eventually will make suggestions to FAA on how to safely and equitably integrate airline and commercial space traffic

Conclusions

- In most proposed spaceports (not necessary all), significant conflicts will arise between airlines and launch providers. What is a fair way of utilizing a shared resource: the NAS?
- Developing mathematics and software implementations to propagate uncertainties in launch trajectories to construct compact 4D envelopes. Based on STOP (Stanford Trajectory OPtimization) tool and Monte Carlo
- Gathering information to construct realistic mission profiles and three separate scenarios (low, medium, high frequencies with varying numbers of launch locations) as a basis to assess potential ATM approaches
- Planning to use NASA's FACET to quantitatively analyze impact on NAS
  - Working with NASA to ensure FACET has needed capabilities implemented

COE CST Second Annual Technical Meeting:

Federal Aviation Administration

Mitigating threats through space environment modeling/prediction

PI: Tim Fuller-Rowell

University of Colorado Boulder

October 31st, 2012

Overview

University of Colorado Boulder

- Team Members
- Purpose of Task
- Overview of Research Methodology
- Research: Recent highlight
- Next Steps
- Contact Information

Team Members

University of Colorado Boulder

Timothy Fuller-Rowell, Tomoko Matsuo, Houjun Wang, Fei Wu

Cooperative Institute for Research in Environmental Sciences (CIRES)

University of Colorado, Boulder

NOAA Space Weather Prediction Center

Mihail Codrescu, Rodney Viereck

NOAA Space Weather Prediction Center, Boulder, CO

Jeffrey Forbes

Aerospace Engineer Sciences, University of Colorado, Boulder

Purpose of Task

University of Colorado Boulder

Purpose: *An integrated air and space traffic management system requires seamless and real-time access to density predictions for on-orbit collision avoidance and atmospheric re-entry, and near-surface weather prediction*

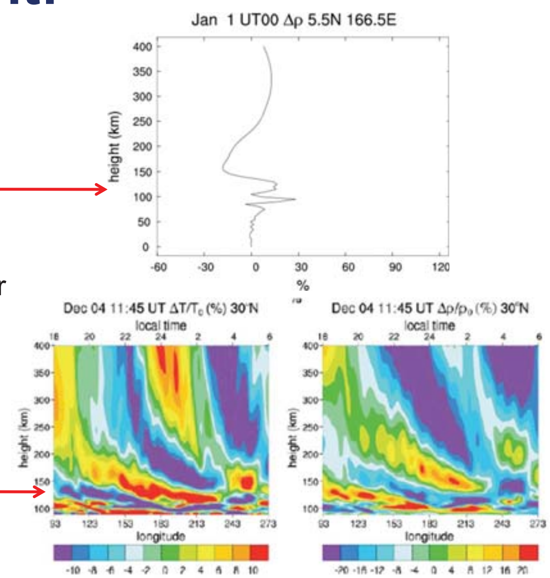
Objectives: *Develop a "weather" (terrestrial weather and space weather) prediction model extending from Earth's surface to the edge of space*

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

Recent highlight:

University of Colorado Boulder

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



Next Steps

University of Colorado Boulder

Short term

- Continue to **validate WAM structure** with LIDAR and radar observations
- Determine **WAM spectrum of variability** and explore impact on density, drag, and ionosphere structure

Medium term

- **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 structure

Longer term

- **Couple to the ionosphere** to determine balance between lower atmosphere and solar/magnetospheric forcing
- Explore **assimilation of ionospheric data** for density prediction
- Whole atmosphere/ionosphere data assimilation at high resolution

Contact Information

University of Colorado Boulder

- **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
- **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
- **Professor Jeffrey M. Forbes**, Department Chair, Aerospace Engineering Sciences, University of Colorado, Forbes@Colorado.edu

Stanford University

Federal Aviation Administration

COE CST Second Annual Technical Meeting:

Space Environment MOD Modeling and Prediction

Sigrid Close

October 31, 2012

Overview

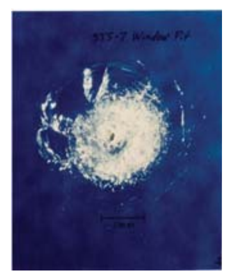
- Team Members
- Purpose of Task
- Research Methodology
- Results
- Next Steps
- Contact Information

Team Members

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

Purpose of Task

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

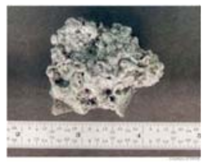


- Goal: Characterize impactor population and provide predictive threat assessment

Impactors

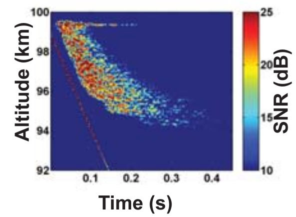
- **Meteoroids**
  - **Speeds**
    - 11 to 72.8 km/s (interplanetary)
    - 30-60 km/s (average)
  - **Densities**
    - ≤1 g/cm^3 (icy) or > 1 g/cm^3 (rocky/stony)
  - **Sizes**
    - < 0.3 m (meteoroid)
    - < 62 μm (dust)

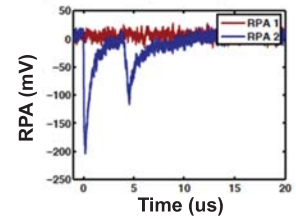
- **Space Debris**
  - **Speeds in LEO**
    - < 12 km/s
    - 7-10 km/s (average)
  - **Densities**
    - > 2 g/cm^3
  - **Sizes**
    - < 10 cm (small)



Methodology: Meteoroids

- **Atmospheric Plasmas**
  - Data: ground-based radar
  - Models: Particle-In-Cell (PIC) for plasma formation, 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: PIC for plasma formation and RF emission
  - Deliverables: plasma composition, temperature, RF spectra



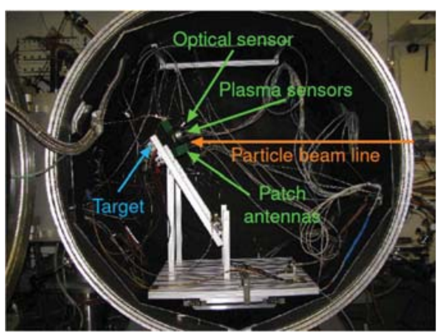


Meteoroid Data

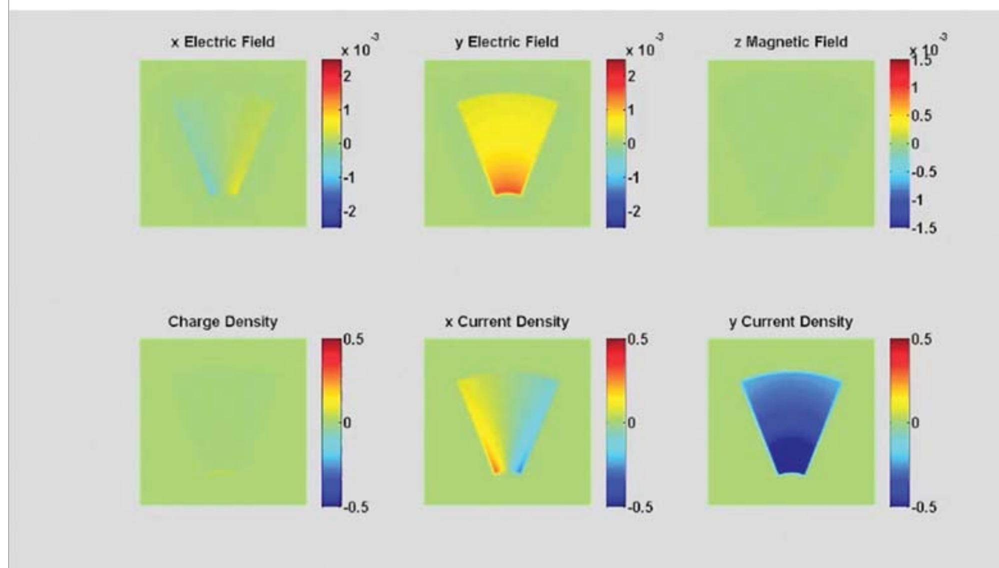
- **Radars**
  - ALTAIR
  - Arecibo Observatory
  - MIT Millstone
  - MU




- **Accelerator**
  - Van de Graaff at Max Planck Institute

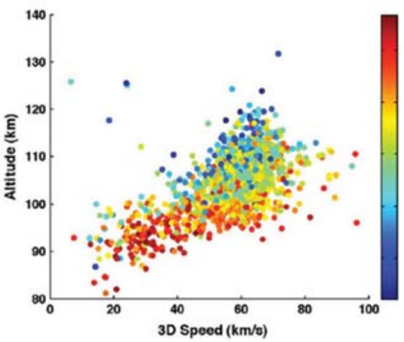


Plasma Modeling Results: PIC

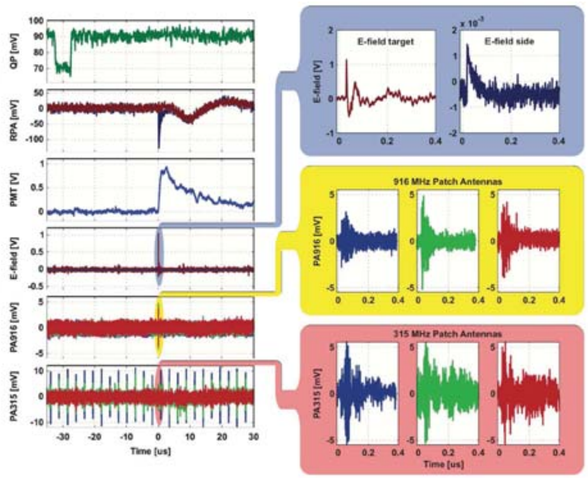


Meteoroid Results

Atmospheric Plasmas

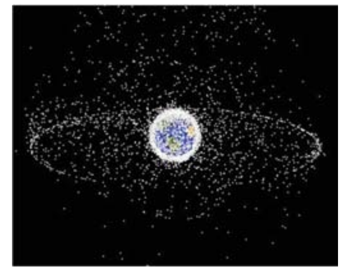


Impact Plasmas



Methodology: Debris

- **Orbital Debris**
  - Models: force models for source (collisions), propagation in space/time, atmospheric models
  - Data: ground-based radar, in situ
  - Deliverables: flux, mass, orbit, source, prediction



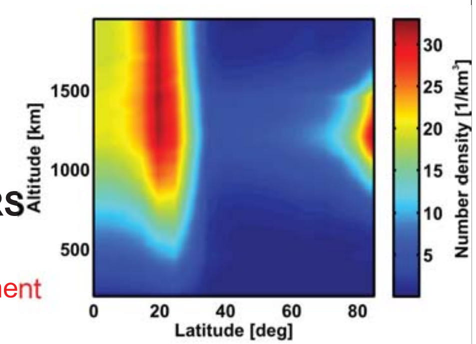
Debris Data

- **EISCAT Svalbard radar**
  - 78.1° N, 16.0° E
  - 500 MHz, 32 m dish, 0.8 MW peak power
  - Az 182.1° , El 81.6°
- **Data collection**
  - Primarily during IPY (International Polar Year) from January 2007 to February 2008

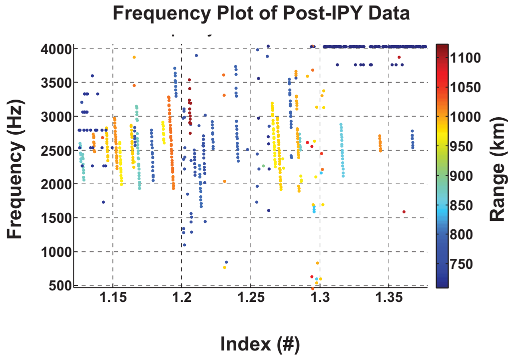
Debris Modeling Results

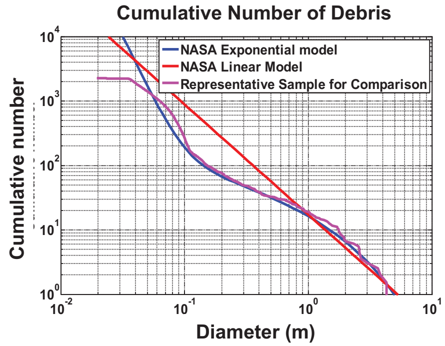
- **ORDEM (NASA)**
  - Environment
  - Data: SSN, HAX, Goldstone, LDEF, returned arrays from HST
  - Model: EVOLVE (used to extrapolate where data is scarce
- **LEGEND (NASA) and MASTERS (ESA)**
  - Collision and propagation (environment evolution)
  - Includes drag modeling
  - MASTERS predicts lower amount of small debris

ORDEM 2000 for debris > 0.01 mm



Debris Results





Next Steps

- **Meteoroids**
  - Energy flux model
  - Spectra of RF emission
  - Effect of charging on electrical failure mechanism
- **Debris**
  - Continue EISCAT analysis
  - Comparison of EISCAT data with MASTERS/ORDEM
  - Light-gas gun experiments

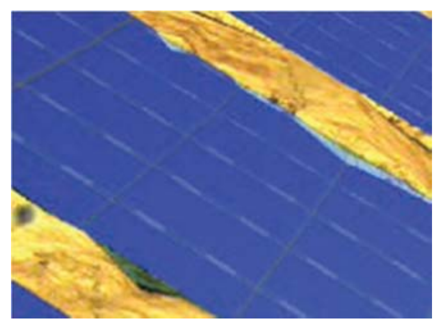
Initial Threat Assessment Model

Publications

- Volz, R. and S. Close (2012), Inverse filtering of radar signals using compressed sensing with application to meteors, *Radio Sci.*, *47*, RS0N05, doi:10.1029/2011RS004889.
- Close, S., R. Volz, R. Loveland, A. Macdonell, P. Colestock, I. Linscott, M. Oppenheim (2012), Determining meteoroid bulk densities using a plasma scattering model with high-power large-aperture radar data, *Icarus*, doi:10.1016/j.icarus.2012.07.033.
- Kelley, M., S. Pancoast, S. Close, Z. Wang (2012), Analysis of electromagnetic and electrostatic effects of particle impacts on spacecraft, *Adv. Space. Res.*, *49*, doi: 10.1016/j.asr.2011.12.023.
- Pifko, S., D. Janches, S. Close, J. J. Sparks, T. Nakamura, and D. Nesvorny (2012), Modeling the meteoroid input function at mid-lattitude using meteor observations by the MU radar, *Icarus*, in review.
- Li, A., S. Close and J. Markannen (2012), EISCAT space debris after the international polar year (IPY), IAC, 12.A6.1.8.

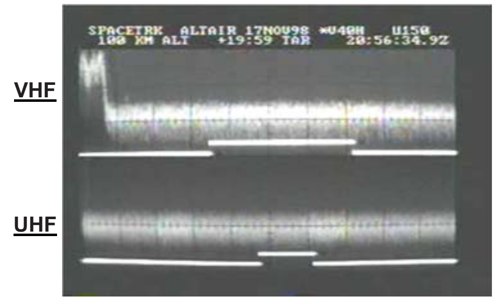
Thank You!

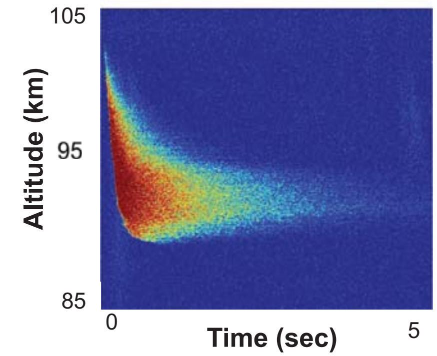
- **Sigrid Close (sigridc@stanford.edu)**
- **Alan Li (alanli@stanford.edu)**



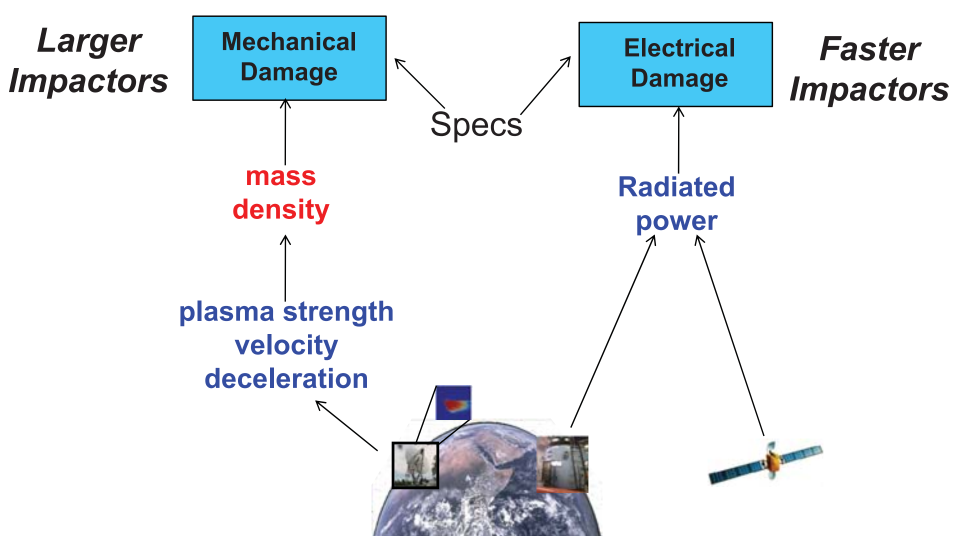
Backup

ALTAIR Radar Data





Mechanical and Electrical Damage



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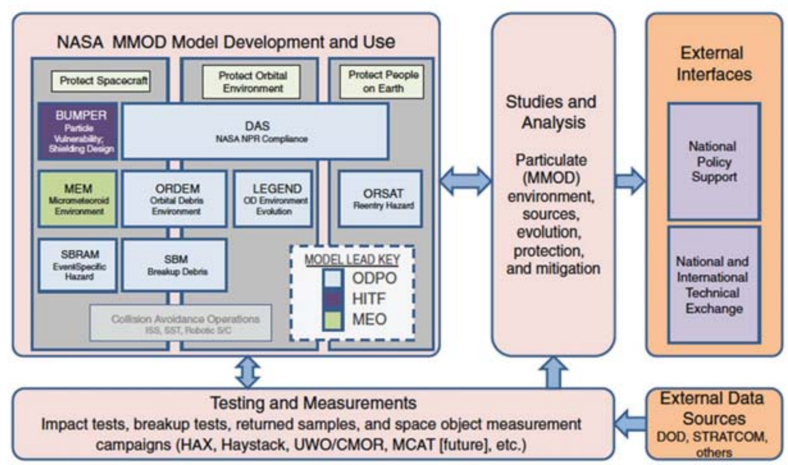
NASA Approach

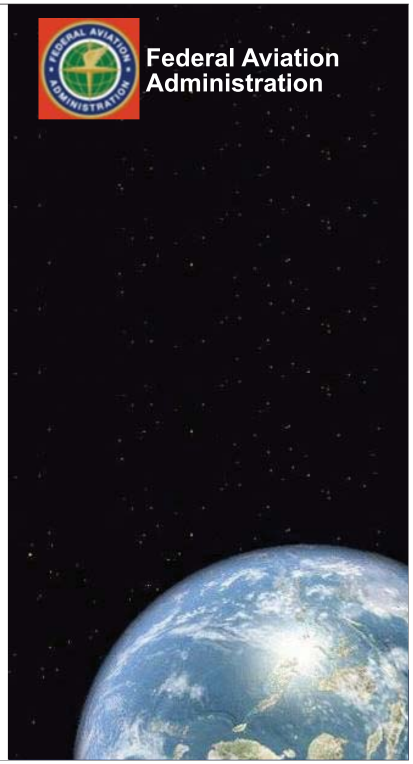


COE CST Second Annual Technical Meeting:

Space Situational Awareness

D.J. Scheeres

October 31, 2012



Overview

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

SSA 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 Research Scientist
- •Kohei Fujimoto, CU PhD Candidate

Related Research from Fellowship Students

- •Aaron Rosengren, CU Graduate Student, NSF Fellow
- •Antonella Albuja, CU Graduate Student, NSF Fellow
- •Ddard Ko, CU Graduate Student, Korean Government grant

Government and Industry Partners

- •AFRL Kirtland and Maui
- •NASA Orbit Debris Program Office
- •Analytical Graphics, Incorporated
- •Orbital Sciences Corporation

Purpose of Task

- ***Space Situational Awareness***

  SSA = Cognizance of Resident Space Objects (RSO) and activities in orbital regions of interest, both now and in the short and long-range future.

- **Objectives**: 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 orbit propagation, non-gravitational model prediction and estimation, orbit estimation techniques.

Schedule/Milestones

- Past:
  - Presented 12 papers at 8 international conferences
  - Published 2 papers in peer-reviewed journals
- Future:
  - Will present 2 papers in February 2013 at AAS/AIAA conference
    - Debris rotation
    - Maneuver reconstruction
  - Total of 7 journal papers in development, for submission by May 2013

Results since commencement of funding

- Journal Papers:
  - K. Fujimoto and D.J. Scheeres. 2012. "Correlation of Optical Observations of Earth-Orbiting Objects and Initial Orbit Determination," Journal of Guidance, Control and Dynamics 35(1): 208-221.
  - K. Fujimoto, D.J. Scheeres and K.T. Alfriend. 2012. "Analytical Non-Linear Propagation of Uncertainty in the Two-Body Problem," Journal of Guidance, Control and Dynamics 35(2): 497-509.
- Conference Papers:
  - K. Fujimoto, D.J. Scheeres , and K.T. Alfriend. "Analytical Non-Linear Propagation of Uncertainty in the Two-Body Problem," paper presented at the 2011 **AAS/AIAA Spaceflight Mechanics Meeting**, New Orleans, February 2011. Paper AAS 11-202.
  - A. Rosengren and D.J. Scheeres. "Averaged Dynamics of HAMR Objects: Effects of Attitude and Earth Oblateness," paper presented at the 2011 **AAS/AIAA Astrodynamics Specialist Meeting**, Girdwood, Alaska, August 2011. Paper AAS 11-594.
  - D.J. Scheeres and A. Rosengren. "Closed Form Solutions for the Averaged Dynamics of HAMR Objects," paper presented at the **62nd International Astronautical Congress**, Cape Town, South Africa, October 2011.
  - K. Fujimoto and D.J. Scheeres. "Non-Linear Propagation of Uncertainty With Non-Conservative Effects," paper presented at the 2012 **AAS/AIAA Spaceflight Mechanics Meeting**, Charleston, SC, Jan/Feb 2012.
  - S. Gehly, B. A. Jones, P. Axelrad, G. H. Born, "Minimum L1 Norm Orbit Determination Using a Sequential Processing Algorithm", paper presented at the 2012 **AAS/AIAA Spaceflight Mechanics Meeting**, Charleston, SC, Jan/Feb 2012.
  - K. Fujimoto and D.J. Scheeres. "Non-Linear Bayesian Orbit Determination Based on the Generalized Admissible Region," paper presented at Fusion 2012, the 15th International Conference on Information Fusion, Singapore, July 2012.
  - D.J. Scheeres, M.A. de Gosson, and J. Maruskin. "Fundamental Limits on Orbit Uncertainty," paper presented at Fusion 2012, the 15th International Conference on Information Fusion, Singapore, July 2012.
  - A.J. Rosengren and D.J. Scheeres. "Long-term Dynamics of HAMR Objects in HEO," paper presented at the AIAA/AAS Astrodynamics Specialist Meeting, Minneapolis, August 2012.
  - A.J. Rosengren and D.J. Scheeres. "Prediction of HAMR Debris Population Distribution Released from GEO Space," paper presented at the 2012 AMOS Meeting, Maui, September 2012.
  - K. Fujimoto and D.J. Scheeres. "Rapid Non-Linear Uncertainty Propagation via Analytical Techniques," paper presented at the 2012 AMOS Meeting, Maui, September 2012.
  - A.J. Rosengren and D.J. Scheeres. "Long-Term Dynamics of High Area-to-Mass Ration Space Debris in GEO," paper presented at the 63rd International Astronautical Congress, Naples, Italy, October 2012. Paper IAC-12, A6.2.5.
  - K. Fujimoto and D.J. Scheeres. "Non-Linear Bayesian Orbit Determination: Angle Measurements," paper presented at the 63rd International Astronautical Congress, Naples, Italy, October 2012. Paper IAC-12-C1.6.11.
- Industry Interactions:
  - Exchanges of simulated data with AFRL Maui research personnel.
  - Interactions with NASA Orbit Debris Program Office and the Center for Space Standards & Innovation (AGI).
  - Dissemination of orbit determination tools to Aerospace Corp. researchers for analysis and testing.
  - Visiting positions and collaborations at IHI Corporation (Japan) and the University of Bern (Switzerland), applying orbit determination research to real data and observations.

COE CST Second Annual Technical Meeting (ATM2)
October 30 – November 1, 2012

Results since commencement of funding

- Journal Papers:
  - K. Fujimoto and D.J. Scheeres. 2012. "Correlation of Optical Observations of Earth-Orbiting Objects and Initial Orbit Determination," Journal of Guidance, Control and Dynamics 35(1): 208-221.
  - K. Fujimoto, D.J. Scheeres and K.T. Alfriend. 2012. "Analytical Non-Linear Propagation of Uncertainty in the Two-Body Problem," Journal of Guidance, Control and Dynamics 35(2): 497-509.
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  - K. Fujimoto, D.J. Scheeres , and K.T. Alfriend. "Analytical Non-Linear Propagation of Uncertainty in the Two-Body Problem," paper presented at the 2011 **AAS/AIAA Spaceflight Mechanics Meeting**, New Orleans, February 2011. Paper AAS 11-202.
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  - D.J. Scheeres, M.A. de Gosson, and J. Maruskin. "Fundamental Limits on Orbit Uncertainty," paper presented at Fusion 2012, the 15th International Conference on Information Fusion, Singapore,

Visiting positions and collaborations at IHI Corporation (Japan) and the University of Bern (Switzerland), applying orbit determination research to real data and observations.

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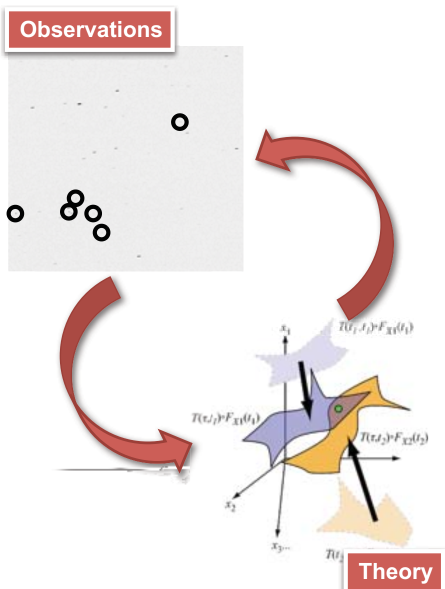
COE CST Second Annual Technical Meeting (ATM2)
October 30 – November 1, 2012

Research in SSA

- Current and future areas of research identified:
  - Rapid uncertainty propagation and conjunction analysis (Fujimoto)
  - Hypothesis-free optical observation correlation and initial orbit determination (Fujimoto)
  - Long-term dynamics of objects in GEO and identification of safe graveyard orbits (Rosengren)
  - Rotational dynamics of debris objects (Albuja)
  - Representation of unobserved maneuvers (Ko)

COE CST Second Annual Technical Meeting (ATM2)
October 30 – November 1, 2012

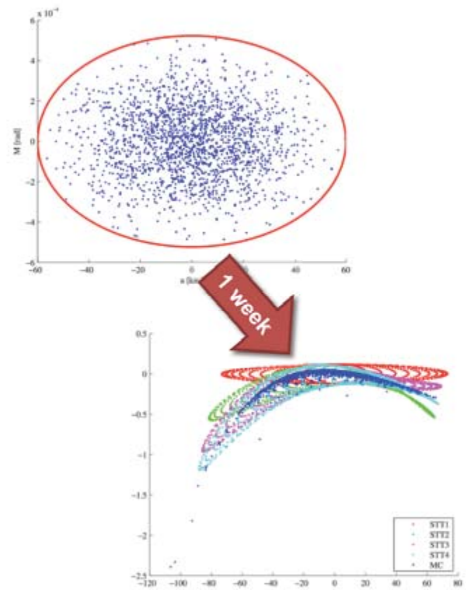
Association of Optical Observations



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
  - To be submitted to ISTS 2013
- “Closing the loop” on the too-short-arc problem

Analytic Propagation of Uncertainty



- 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
  - Up to 10^6X faster but comparable results to numerical simulation with realistic drag model
- “Consistent” representation of uncertainty key to SSA
  - Conjunction assessment, track correlation, etc.

Averaged Model for GEO Objects

- Perturbations in vector form (Milankovitch elements):

$$\boldsymbol{h} = \sqrt{1-e^2}\hat{\boldsymbol{h}}, \quad \boldsymbol{e} = e\hat{\boldsymbol{e}}$$

$$\boldsymbol{h}\cdot\boldsymbol{e} = 0, \qquad \boldsymbol{h}\cdot\boldsymbol{h} + \boldsymbol{e}\cdot\boldsymbol{e} = 1$$

$$\dot{\boldsymbol{h}} = \tilde{\boldsymbol{h}}\cdot\left(\frac{\partial\mathcal{R}^*}{\partial\boldsymbol{h}}\right)^T + \tilde{\boldsymbol{e}}\cdot\left(\frac{\partial\mathcal{R}^*}{\partial\boldsymbol{e}}\right)^T$$

$$\dot{\boldsymbol{e}} = \tilde{\boldsymbol{e}}\cdot\left(\frac{\partial\mathcal{R}^*}{\partial\boldsymbol{h}}\right)^T + \tilde{\boldsymbol{h}}\cdot\left(\frac{\partial\mathcal{R}^*}{\partial\boldsymbol{e}}\right)^T$$

	SRP	J_2	Third-body
$\bar{\dot{\boldsymbol{h}}}$	$-\frac{3}{2}\sqrt{\frac{a}{\mu}}\frac{\beta}{d_s^2}\tilde{\hat{\boldsymbol{d}}}_s\cdot\boldsymbol{e}$	$\frac{3nC_{20}}{2a^2h^5}(\boldsymbol{h}\cdot\hat{\boldsymbol{p}})\tilde{\hat{\boldsymbol{p}}}\cdot\boldsymbol{h}$	$\frac{3\mu_p}{2nd_p^3}\hat{\boldsymbol{d}}_p\cdot[5\boldsymbol{ee}-\boldsymbol{hh}]\cdot\tilde{\hat{\boldsymbol{d}}}_p$
$\bar{\dot{\boldsymbol{e}}}$	$-\frac{3}{2}\sqrt{\frac{a}{\mu}}\frac{\beta}{d_s^2}\tilde{\hat{\boldsymbol{d}}}_s\cdot\boldsymbol{h}$	$\frac{3nC_{20}}{4a^2h^5}\left[\left(1-\frac{5}{h^2}(\boldsymbol{h}\cdot\hat{\boldsymbol{p}})^2\right)\tilde{\boldsymbol{h}}+2(\boldsymbol{h}\cdot\hat{\boldsymbol{p}})\tilde{\hat{\boldsymbol{p}}}\right]\cdot\boldsymbol{e}$	$\frac{3\mu_p}{2nd_p^3}\left\{4(\boldsymbol{e}\cdot\hat{\boldsymbol{d}}_p)\tilde{\boldsymbol{h}}\cdot\hat{\boldsymbol{d}}_p-\tilde{\boldsymbol{h}}\cdot\boldsymbol{e}-\hat{\boldsymbol{d}}_p\hat{\boldsymbol{d}}_p\cdot\tilde{\boldsymbol{h}}\cdot\boldsymbol{e}\right\}$

$\mathcal{R}^* = \mathcal{R}/\sqrt{\mu a}, \mathcal{R} =$ force potential, $a =$ semi-major axis
$n = \sqrt{\mu}/a^{3/2} =$ mean motion
$\beta = (1+\rho)(A/m)P_\Phi$
$\rho =$ reflectivity, $A/m =$ area-to-mass, $P_\Phi =$ SRP constant
$C_{20} =$ oblateness gravity field coefficient
$\hat{\boldsymbol{p}} =$ unit vector aligned with Earth’s rotation pole
$\boldsymbol{d}_p = d_p\hat{\boldsymbol{d}}_p =$ position vector of disturbing body

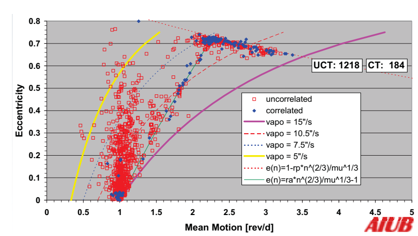
Assumptions and approximations:

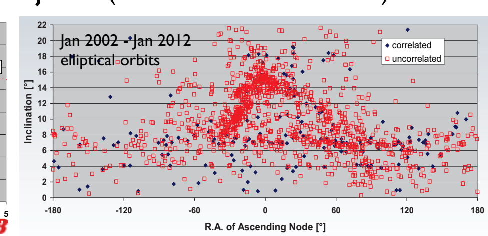
- perturbations come from force potential (semi-major axis = constant of motion)
- SRP modeled using cannonball model
- Hill’s approximation for lunisolar third-body perturbations

HAMRs: A New Class of Debris

- Discovery (Schildknecht et al. 2004)
  - mean motion suggest release near GEO
  - orbital evolution indicates they are HAMRs
- Recent studies focusing on long-term orbit dynamics:
  - analytical, semi-analytical, and numerical investigations

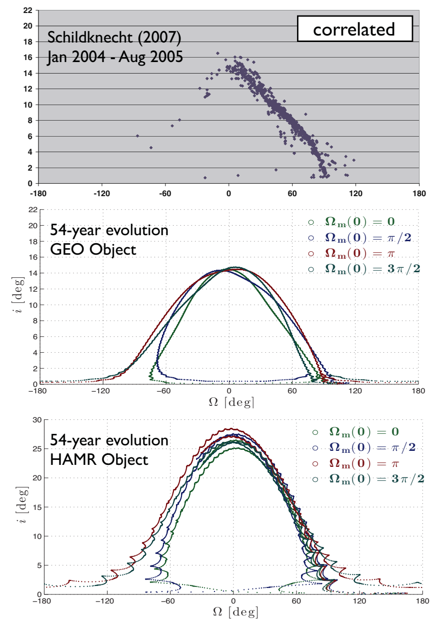
    Liou & Weaver (2004, 2005), Anselmo & Pardini (2005-2010), Chao (2006), Valk et al. (2007-2009), Rosengren & Scheeres (2010-2012)
- Distribution of observed objects (Schildknecht et al. 2012)





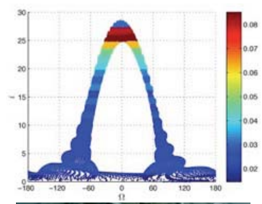
Long-term Behavior of GEO Orbits

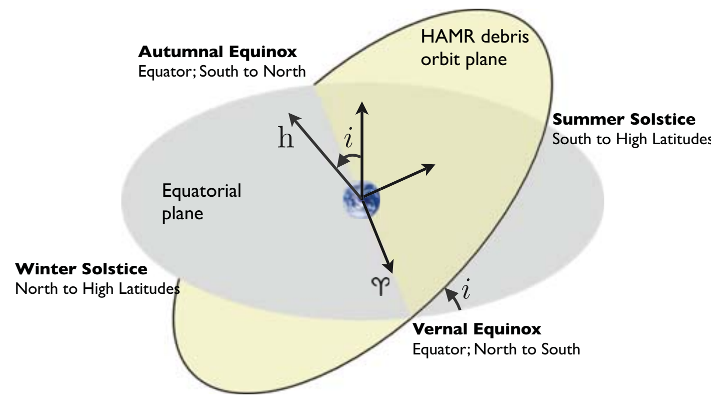
- Almost fifty years have elapsed since satellites were first launched into GEO
- The motion of uncontrolled GEO satellite:
  - precession about the Earth's rotational axis (J2 effect)
  - precession about pole of the ecliptic (solar third-body)
  - precession about pole of the Moon's orbit (lunar third-body)
- Structure in (i, Ω) phase space
- What about HAMRs?



Implications for Space Surveillance

- Inclination and ascending node of HAMRs evolve in predictable ways
- Where should observers point their telescopes?
  - Spring, Fall: anti-solar survey, concentrate near equator
  - Summer, Winter: look at high latitudes





Conclusions

- Progress being made on the following fronts:
  - Object correlation and initial orbit determination
  - Rapid and accurate propagation of uncertainty
  - Long-term dynamics of objects in Earth orbit
- Future work will focus on:
  - Continuing above achievements
  - Identification of robust, long-term GEO disposal orbits
  - Modeling of debris rotational motion
  - Modeling of unobserved maneuvers

Contact Information

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

COE CST Second Annual Technical Meeting (ATM2)
October 30 – November 1, 2012

COE CST First Annual Technical Meeting:

Defining the Future by Engaging Emerging Leaders

Task 193:Role of COE CST in EFP
PI: George H. Born
Bradley Cheetham

10.31.2012

Overview

- Team Members
- Task Purpose/Objectives
- Theory Based Analysis
- ESIL-02 Workshop
- ESIL-03 Workshop
- Next Steps
- Contact Information

Team Members

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

Purpose of Task

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

FAA COE CST Objectives

- **Research**
  - Industry Structural Analysis – Commercial Crew to Orbit Industry Segment
- **Training**
  - Emerging Space Industry Leaders Workshop Series
- **Outreach**
  - Disseminating activity results, promoting a broader understanding of commercial space

Theory Based Analysis

Theory Based Analysis of the Commercial Crew to Orbit Transportation Industry Structure and Evolution

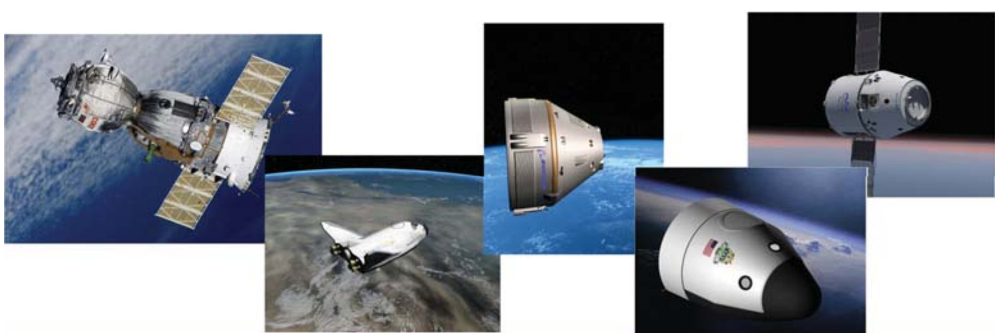
Presented at 2012 International Astronautical Congress

- IAC-12-E6.1.6
- Third iteration on analysis
- Based on Michael Porter Competitive Strategy Theory

Theory Based Analysis

Scope: Commercial delivery of humans to Earth orbit

- Considering the transport vehicle only
- Launch vehicle is a supplier



Theory Based Analysis

Forces	2010	2011	2012
Threat of Entry	L	L	L
Rivalry	H	M	M-H
Substitute	L	L	M
Buyers – NASA	H	M-H	H
Buyers - Other			L
Suppliers	H	M	L

ESIL Workshop Series

- Bring together emerging industry leaders
- Objectives
  - Inform – perspective, background, context
  - Perform – group analysis on identified market
  - Network – internal and external to industry
- Output
  - Product of attendees and newly strengthened network

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Federal Aviation Administration
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ESIL-01 Workshop

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ESIL-02 Workshop

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ESIL-02 Workshop

- "Emerging Leader" Defined:
  - Early- to Mid-Career Young Professionals and Graduate Students
- Broad industry backgrounds/experience
- Total Attendees: 11
  - Male: 5
  - Female: 6
- Total Guest Speakers: 8
- Location: Capitol Hill, Washington D.C.

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ESIL-02 Workshop: Objectives

Assemble a knowledgeable group representing emerging leaders within the U.S. space sector to:

Objective 1: Identify the current role of the U.S. Government in the commercial space sector

Objective 2: Identify how this role should evolve in the future from the perspective of the assembled group

Connect emerging leaders throughout the industry with peers and current industry leaders

ESIL-02 Workshop: Schedule

	Monday, March 26, 2012 *Longworth HOB 1540-A*		Tuesday, March 27, 2012 *Cannon HOB 5C (adjacent to room 509)*
8:30	**Welcoming and Introductions**	8:30	**Working Group**
9:00	**Overview of FAA AST & COE CST** *Ken Davidian, AST*	9:00	
9:30	**Overview of Workshop Objectives**	9:30	
10:00	**Other Transactional Authorities** *Richard Dunn*	10:00	
10:30	**Break**	10:30	**Break**
11:00	**Government Representatives (45min):** *Chris Shank - Deputy CoS, Congressman Lamar Smith* **Discussion (45min)**	11:00	**Industry and Regulators (45min):** *Jim Van Laak - Deputy Associate Administrator, FAA AST* *Clay Mowry - President, Arianespace Inc.* **Discussion (45min)**
11:30		11:30	
12:00		12:00	
12:30	**Lunch**	12:30	**Lunch**
13:00		13:00	
13:30	**Working Group**	13:30	**Working Group**
14:00		14:00	
14:30	**Break**	14:30	
15:00	**Civil and Defense (45min):** *Alan Ladwig, NASA HQ* *James Finch - Director, Policy and Strategy Development, OSD/Space Policy* **Discussion (45min)**	15:00	
15:30		15:30	**Break**
16:00		16:00	**FAA AST - Dr. George Nield**
16:30	**Evening Reception** Tortilla Coast	16:30	**Workshop Outbrief** *Committee on Science, Space, and Technology Room Rayburn 2325*
17:00		17:00	

ESIL-02

ESIL-03

- Where: Buffalo-Niagara Convention Center Buffalo, NY, USA
- When: November 7-8, 2012
- In conjunction with SpaceVision 2012
- Topic: Game Theory Applied to Commercial Space – Participant Training Sector

Next Steps

- Further dissemination of ISA activities
- ESIL-03
  - Expected paper and presentation
- ESIL-##
  - Future workshops hosted around the country in collaboration with other industries
  - Looking for host for ESIL-04
    - West Coast? Financial Sector?

Contact Information

George H. Born
George.Born@Colorado.edu

Bradley Cheetham
Bradley.Cheetham@Colorado.edu

Stanford Propulsion and Space Exploration

Secondary & Hosted Payloads Market Characterization

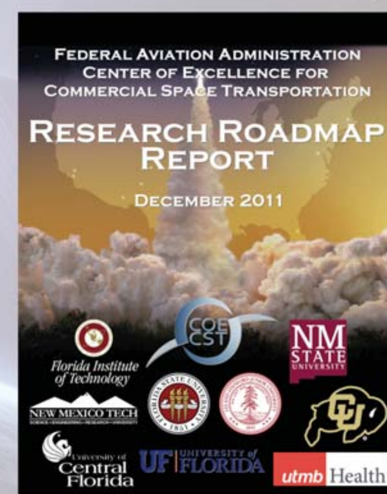
Prof. Scott Hubbard
Jonah Zimmerman

Motivation

- Results of research roadmapping work for Theme 4:

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

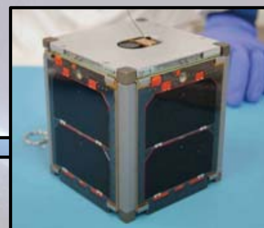
- Focusing on secondary and hosted orbital payloads represents a tractable portion of this task
  - Topic was strongly suggested by several industry partners during roadmap workshop



Secondary & Hosted Payloads

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

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



ZACUBE-01 (CPUT, South Africa)

The Opportunity

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

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

(Office of Space Commercialization)

The Problem

- An opportunity that hasn't been extensively utilized
  - No real technical issues
    - Aerospace Corp.: 43 nanosatellites launched by 1975
    - The first US intelligence satellite (GRAB-1) was a SP for the launch of a navigation satellite (Transit-2A) in 1960
  - Programmatic issues are abundant

Currently, 13 operational hosted payloads (Spaceworks)

↓

Approximately 1% of all operational satellites

Since 2000, 23 launches with secondary payloads [Atlas, Delta, Minotaur, Pegasus, Taurus] (Various Sources)

↓

Approximately 10% of all launches

How to Solve the Problem

1. Reach out to industry partners to gain an understanding of the landscape
2. With their help, identify specific areas that our analyses and studies can address
3. Perform specific analyses and studies – especially in expanding the opportunity
4. Disseminate results

An Important Distinction

	Commercial Primary	Government Primary
Commercial SHP	Commercial on Commercial	Commercial on Government
Government SHP	Government on Commercial	Government on Government

The Hot Topic (Government on Commercial)

Tauri Group: 4% of satellites <15kg on the books are commercial
Spaceworks: 23% of operational HP's are commercial

Secondary Payloads (1/2)

Hardware Costs → Owner of SP
- Universities
- Civil Gov't
- Defense
- Commercial

Integration Costs → Varies:
- Owner of SP
- Owner of Primary
- Other

Launch Costs → Owner of the Primary
- Civil Gov't
- Defense
- Commercial

- Government Programs
  - STP, ELaNa
- Brokers
  - ISIS, Spaceflight Services, Cal Poly, UTIAS
  - Can deliver many secondaries as a single integrated payload to the LSP (e.g. ESPA, P-POD)

Secondary Payloads (2/2)

Technical Feasibility → Launch Service Provider
- ULA/Boeing/LM
- Orbital
- SpaceX
- Foreign

Ultimate Decision → Owner of the Primary
- Civil Gov't
- Defense
- Commercial

- Note that typically LSP does not make the decision to put SP's on because they don't own the manifest
- Exceptions:
  - SpaceX reserves the right to add SP whenever 20% excess vehicle capability
  - Supply missions to ISS: SpaceX and Orbital are selling a service

Hosted Payloads

Hardware Costs → Owner of HP
- Civil Gov't
- Defense
- Commercial

Everything Else → Owner of the Primary
- Civil Gov't
- Defense
- Commercial

- For some missions HP's are the only possible architecture:
  - Small payloads and high orbits do not comply with 25 year rule for orbital debris
- Much more variability amongst satellites than launch vehicles
  - Few standardized systems or infrastructure

Programmatic Issues

Manufacturing a commercial satellite: approx. 2 years

+

Developing new hardware for SP or HP: approx. 4 years

+

Low revenue (commercial) or Low importance mission (gov't) from SP or HP

=

Primary will not wait around for the SP or HP

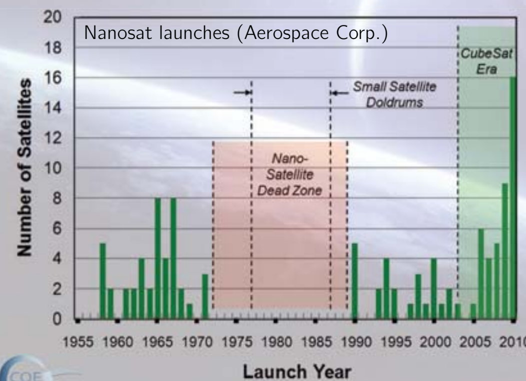
But…

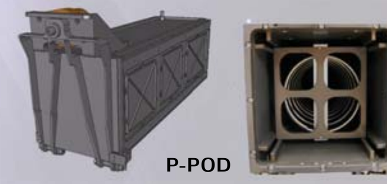
Satellite constellations: GPS, Iridium, RapidEye, Globalstar, Galileo, etc. → Many launches to same orbit with same hardware → Perfect opportunity for secondary or hosted payloads

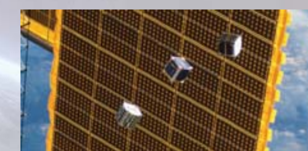
EG: Iridium NEXT, 72 satellites going to LEO in 2015-2017 on Falcon 9's

CubeSats

- Standard developed in 2000 by Stanford University and Cal Poly
- Satellites constructed from 10x10x10 cm cubes, each having mass of 1 kg
- Poly Picosatellite Orbital Deployers (P-POD's) have deployed approx. 90% of all CubeSats







Cubesats Deployed from a P-POD on ISS

Future Work

- Continue work with industry partners to identify the best focus area for our work
  - How to monetize, assess growth areas
  - Consider a different paradigm, such as an "Airline Model"
- Perform analyses and studies
- Coming Soon:
  - Stanford Institute for Economic Policy Research and Stanford COE CST *Forum on Space Entrepreneurship*, Feb 7-8, 2013
  - *New Space*: a new quarterly peer-reviewed journal published Spring 2013. Hubbard Editor-in-Chief.

Acronyms

EELV	Evolved Expendable Launch Vehicle
ELaNa	Educational Launch of Nanosatellites
ESPA	EELV Secondary Payload Adapter
HP	Hosted Payload
ISIS	Innovative Solutions In Space
LSP	Launch Service Provider
P-POD	Poly-Picosatellite Orbital Deployer
SHP	Secondary and Hosted Payloads
SP	Secondary Payload
STP	Space Test Program
UTIAS	University of Toronto Institute for Aerospace Studies

COE CST 2012

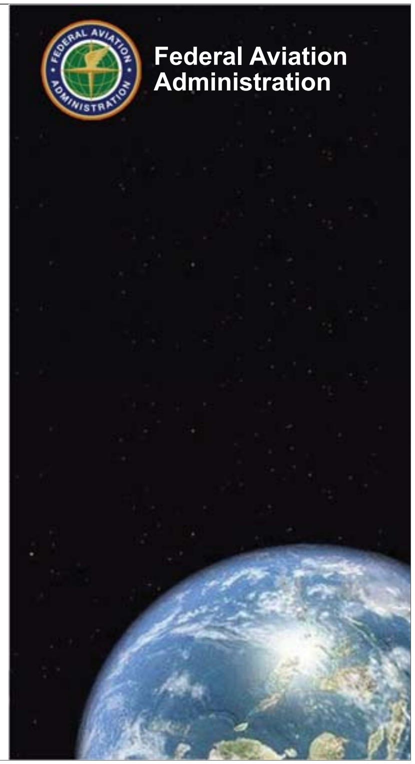
ANNUAL TECHNICAL MEETING:

Task 220:

Integrate into the Spaceport Operations Framework Applicable Documents & Relevant Materials; Enable Documents to Be Found by Title, Subject, Or Keyword; Assure Copyright Protections.

PI: Patricia C. Hynes, Ph.D.

October 31, 2012



Overview

- Team Members
- Purpose of Task 1 & Survey Results
- Purpose of Current Task 2 – Integrate into the Spaceport Operations Framework Applicable Documents & Relevant Materials; Enable Documents to Be Found by Title, Subject, Or Keyword; Assure Copyright Protections.
  - Implementation of a Document Management System including Development & Implementation of DMS Parameters & Data Fields
  - Documents added to the Body of Knowledge DMS Database
- Access the Body of Knowledge Database & Beta Test
- Next Step Task 3 – Gap Analysis
- COE CST Study Team Web Site

Team Members

- **Pat Hynes,** Principal Investigator, New Mexico State University
- **Herb Bachner,** HBachner & Associates
- **Jim Hayhoe,** Spaceport America Consultants
- **Paul Arthur,** Rear Admiral (Retired), Former Technical Director/Deputy Commander, White Sands Missile Range
- **Craig Day,** Director, Business Development, AIAA
- **Robert Reuter,** Project Manager, The Boeing Company
- **Bill Gutman,** Chief Technical Officer, Spaceport America
- **Lou Gomez,** Program Manager, Spaceport America
- **David Headley,** Program Strategic Planning, The Boeing Company
- **Sandy Saunders,** Vice President Operations, Locked On, Inc.
- **Norice Lee,** Associate Dean, Library, NMSU
- **Ingrid Schneider,** Metadata & Authority Control Librarian, Library, NMSU
- **Hank Strevel,** Graduate Intern, Dept. of Government, NMSU
- **Jacob Deaven,** Former Graduate Intern, Dept. of Government, NMSU

Purpose of Task 1

Task 1: Develop a Framework - Completed

Prepare the framework in collaboration with spaceport directors

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

Survey Results – Sample

5	GROUND & FLIGHT SAFETY	Include	Do Not Include	Not in This Topic
5.1	Safety Policy	100%	0%	0%
5.2	Safety Management System	75%	25%	0%
5.2.1	Safety Risk Management	78%	22%	0%
5.2.2	Safety Promotion	67%	33%	0%
5.2.3	Safety Assurance	78%	22%	0%
5.3	Ground Safety	100%	0%	0%
5.3.1	Runway Safety	78%	22%	0%
5.3.2	Safety of the General Public	78%	22%	0%
5.3.3	Motor Vehicle Safety	56%	33%	11%
5.3.4	Fuel Safety	67%	22%	11%
5.3.6	FAA Launch Site License Requirements	89%	11%	0%
5.4	Flight Safety	78%	22%	0%
5.4.1	Mission Planning & Flight Analysis	63%	37%	0%
5.4.1.1	Development & Coordination of the Mission Plan	67%	33%	0%
5.4.1.2	Air Traffic Coordination	56%	33%	11%

Purpose of Current Task

Task 2: Integrate into the Spaceport Operations Framework Applicable Documents & Relevant Materials; Enable Documents to Be Found by Title, Subject, Or Keyword; Assure Copyright Protections.

- In progress

- Began work January 2012
- The FAA determined that Section 5 (Ground & Flight Safety) should be our first priority

Research Methodology—Document Management

- Problem:
  - Initial document estimate on Section 5 of the Framework: >1,000 documents
    - Government & Commercial Documents

Research Methodology—Document Management Cont'd

- Proposed Solution:
  - Analyze an initial target sample of 45 documents:
    - Review for applicability
    - Map into Framework established in Task 1

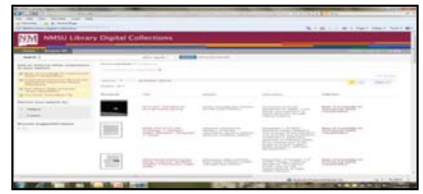
Research Methodology—Document Management Cont'd

- Labs/Facilities:
  - NMSU Library Digital Library selected to develop the DMS
    - NMSU Library licenses/utilizes CONTENTdm system that facilitates storage, management, & delivery of digitized documents & collections to users across the web.
    - Body of Knowledge (BoK) Database has secure access & easily updated.
    - Working Group determined parameters & data fields for DMS.
    - Procedure for document data extraction defined & implemented

Results

Current Status:

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



Results Cont'd

- Reviewed copyright requirements & developed letters requesting the use of on-line documents by the Spaceport working group in the establishment of the Body of Knowledge (BoK).
  - Currently 45 documents have been inserted into the DMS
  - Multiple document sources reviewed (NASA, AF, FAA, WSMR, NFPA)

- DMS has been Beta Tested by peers

Results Cont'd: Sample of Documents Added to Body of Knowledge (BoK)

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

Results Cont'd: Access the Body of Knowledge (BoK) Database

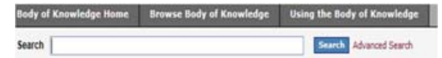
- **ACCESS** the URL: http://contentdm.nmsu.edu
- **LOGIN**:
  - USERNAME: libguest
  - PASSWORD: libguest23
- **REFRESH** the page (or it won't load the BoK information)
- **CLICK** on the link:

  Body of Knowledge for Commercial Space Transportation

Beta Test—Next Step

One you have logged in, please complete the following five (5) tasks:

1. Please scroll through & read "Using the Body of Knowledge," the link for which found at the top left, third tab from the left. This document provides an overview of how the collection works. Some users may find it helpful to print the document & keep a copy on hand as they work through the beta.



2. Briefly describe how to remove a term or keyword from a search parameter.
3. Please find the 2nd chapter of NPR 8715.3C NASA General Safety Program Requirements, & determine the document's date of expiration.
4. Please search for all documents that contain the keyword "fire" & are in Framework Category 5.3 Ground Safety. How many are there?
5. Please search for all the documents that originate from the United States Air Force. How many are there?

Summary

- Integrated Spaceport Operations Framework, applicable documents, & relevant material
- Enabled documents to be found by title, subject, or keyword
- Assured copyright protections
- Evaluated 45 documents
- Established a process
- University Library perfect for:
  - Size of this task
  - Management of updates
  - Copyright protection
  - Searchable user-friendly database in common use across most university libraries
  - Workforce development will be required
  - Easily accessed user-friendly database is essential

Next Steps

Next 3 Sections to Be Parsed into the Body of Knowledge (BoK):

- Section 1.0 – **Airfield & Launch Operations**
  - There will be plenty of source documents across sub-sections 1.1, 1.2, & 1.3
    - NASA, FAA, Military, & Commercial
  - This is the main area that Spaceport America is working on developing procedures for through a contractor

Next Steps Cont'd

- Section 8.0 – **ITAR Requirements**
  - "Low hanging fruit" for small list of source documents
  - Having the Virgin Galactic Export Control resident here in Southern New Mexico should expedite filling out this section
  - Recent panel at ISPCS 2012 provided insight

Next Steps Cont'd

- Section 9.0 – **International Coordination among Spaceports**
  - New Mexico Space Grant Consortium has an excellent relationship among the Swedish & French launch sites
  - Sub-sections 9.1 & 9.2 are very specific & narrow topics

NEW MEXICO TECH
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Federal Aviation Administration

Task 228: Magneto-Elastic Sensing for Structural Health Monitoring

Andrei Zagrai and Warren Ostergren

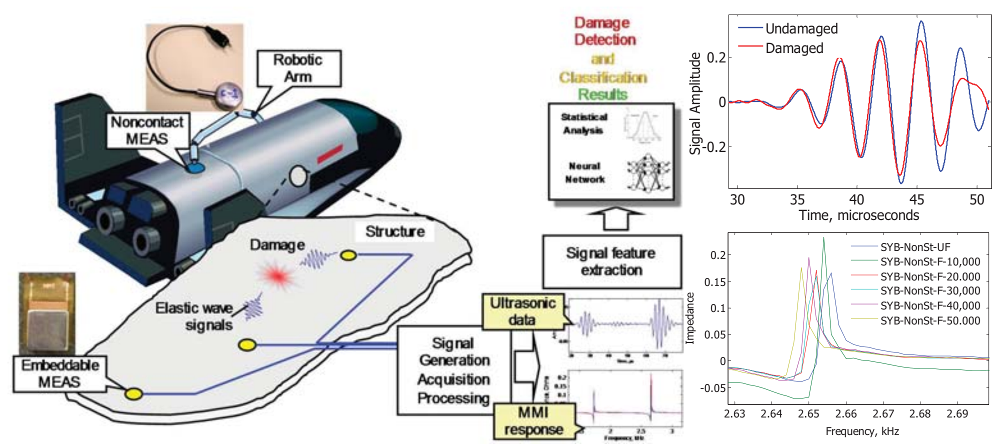
October 31, 2012

Overview

- Structural Health Monitoring (SHM) of Space Vehicles
- Motivation, needs and objectives
- Research team
- Tasks progress
- Schedule & Milestones
- Next Steps
- Contact Information

Spacecraft Structural Health Monitoring

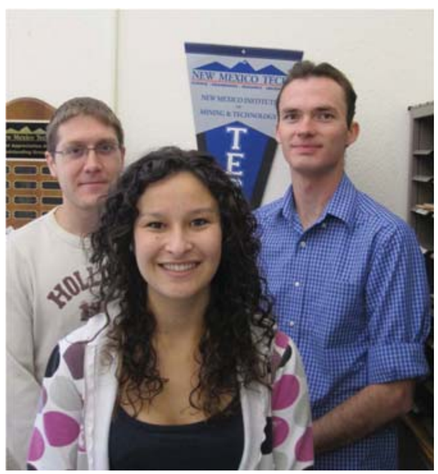
SHM System Engineering



Team Members

Task 228 NMT Team

- Jaclene Gutierrez (UG ME)
- Daniel Meisner (GR ME)
- David Conrad (Graduated)
- Andrei Zagrai
- Warren Ostergren



Collaborators

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

Purpose and Objectives

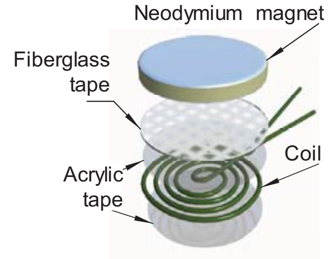
- The objective of the proposed project is to develop magneto-elastic sensing technologies for structural diagnosis of space vehicles.
- In achieving this objective, the investigation team conducts both theoretical and experimental research on the physical mechanism of sensing, its practical realization in the engineering system, information inference from the magneto-elastic response and automatic data classification / decision support.
- A separate objective of this research is educating young aerospace professionals at the undergraduate and graduate levels as well as broadening participation of minority groups such as students with disabilities and Hispanics.

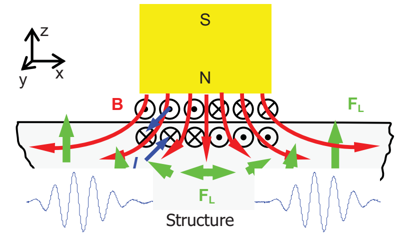
Schedule/Milestones

Tasks	Milestones (Year 1 – Year 2, Months 2–24)
1. Analytical and numerical magneto-elastic modeling.	1-D models for magneto-elastic sensing
2. Magneto-elastic characterization of interfaces and fatigue damage.	Experimental data on magneto-elastic sensing of interfaces in structures of simple geometry; Experimental data on magneto-elastic sensing of fatigue damage in available laboratory specimens.
3. Damage manifestation in magneto-elastic sensing	Experimental data on manifestation of electromagnetic and elastic structural characteristics in MMI signature. Selection of suitable feature extraction algorithms.
4. Damage classification algorithms for magneto-elastic sensing	Analysis of data classification algorithms for magneto-elastic sensing. A preliminary example of damage detection and classification.

Magneto-elastic Active Sensors (MEAS)

Capable of NON-CONTACT excitation INSIDE material - NO COUPLING MEDIUM NEEDED

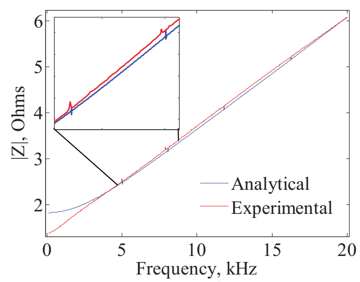


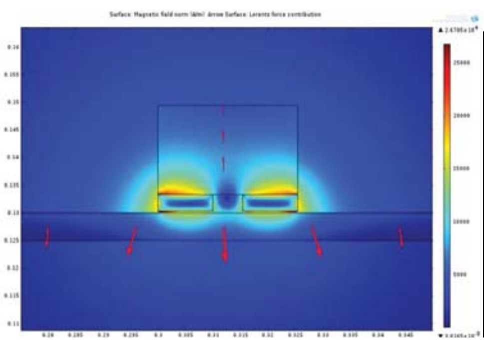


Electric current passing through the coil induces eddy currents in the structure. The eddy currents interact with the applied static magnetic field, resulting in Lorentz forces, responsible for generating elastic waves.

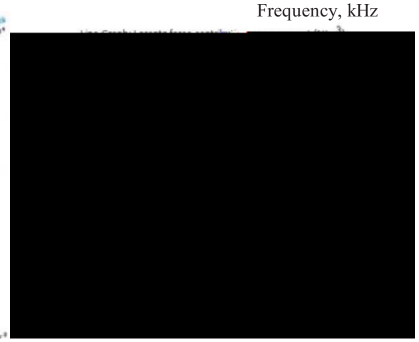
Analytical and Numerical Models

- Analytical models for 1D structures
- Numerical models using multi-physics finite element analysis



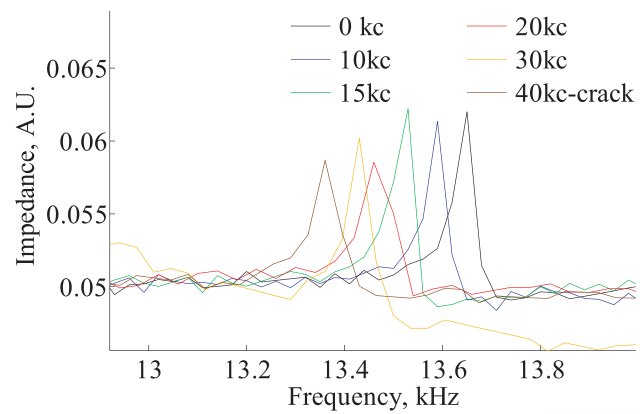


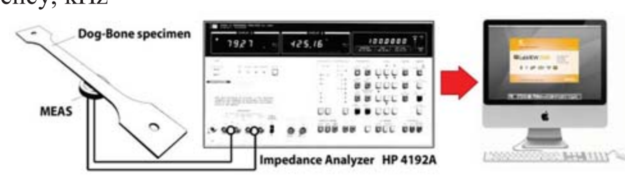
MEAS, magnetic field (shown in color), and Lorentz force (shown in arrows).



Spatial distribution of the Lorentz force on the surface of the specimen underneath MEAS.

Preliminary Fatigue Tests

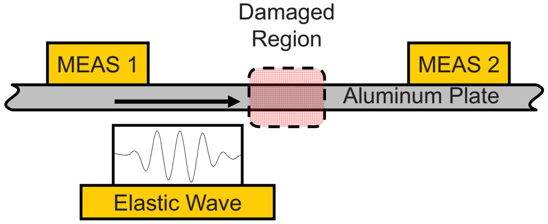


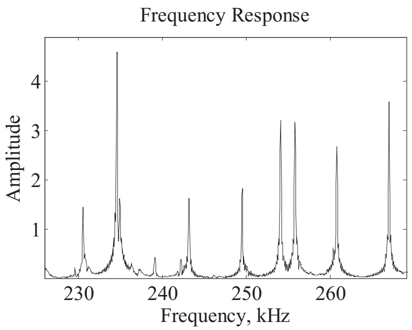


Damage Detection Methods

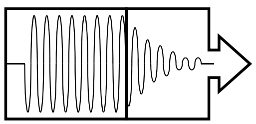
Wave Propagation

- Amplitude, Phase, and nonlinear characteristics





Received Signal



Frequency Response

- Amplitude and frequency of resonance peaks

Received Signal

$$x(t) = A(t)\sin(\omega t + \phi)$$

Analog Integration

$$I_1(t) = r\int_{t_1}^{t_2} D_1(t)dt$$

$$I_2(t) = \int_{t_1}^{t_2} D_2(t)dt$$

Quadrature Phase Detection

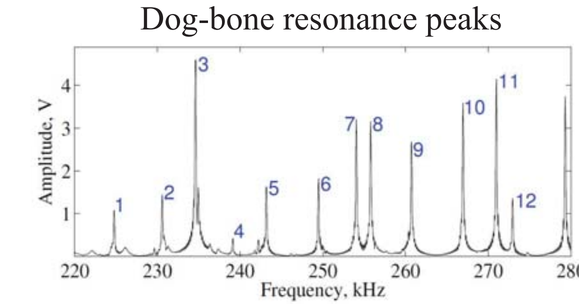
$$D_1(t) = g \cdot A(t)\sin(\phi)$$

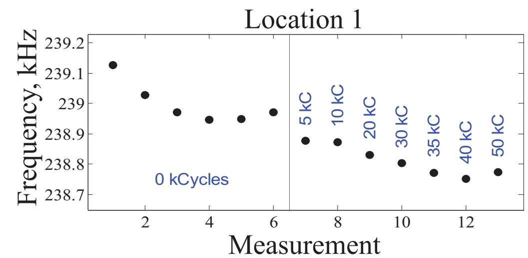
$$D_2(t) = g \cdot A(t)\cos(\phi)$$

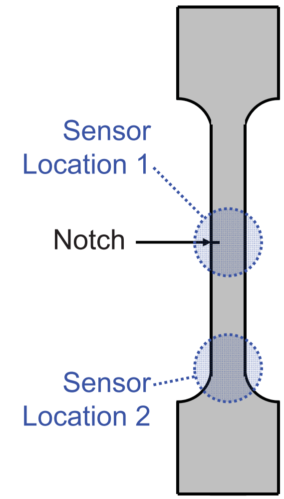
Magnitude Response

$$A = \sqrt{I_1^2 + I_2^2}$$

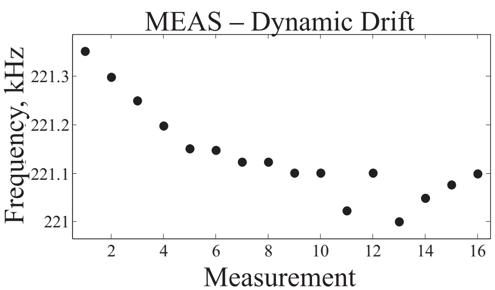
Dog-Bone Experimental Layout

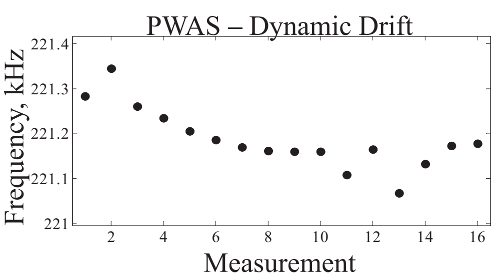






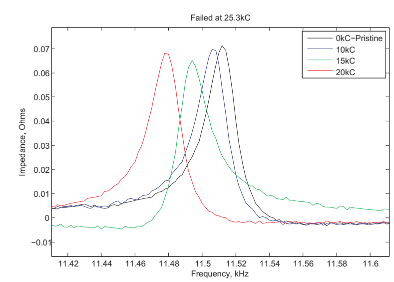
Fatigue Samples Frequency Analysis



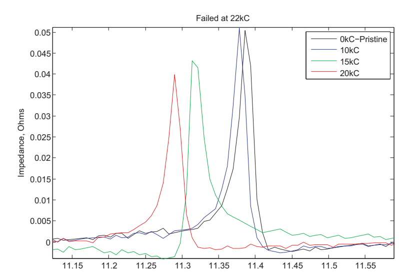


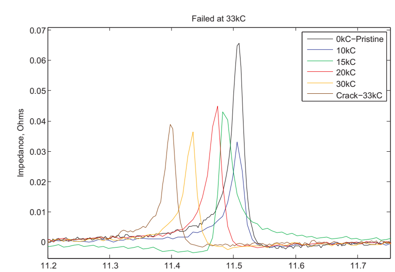
- Measured frequency drift appears consistent with sensor heating.
- Drift is observable in both PWAS and MEAS data indicating independence from equipment.

Fatigue Results for Multiple Specimens

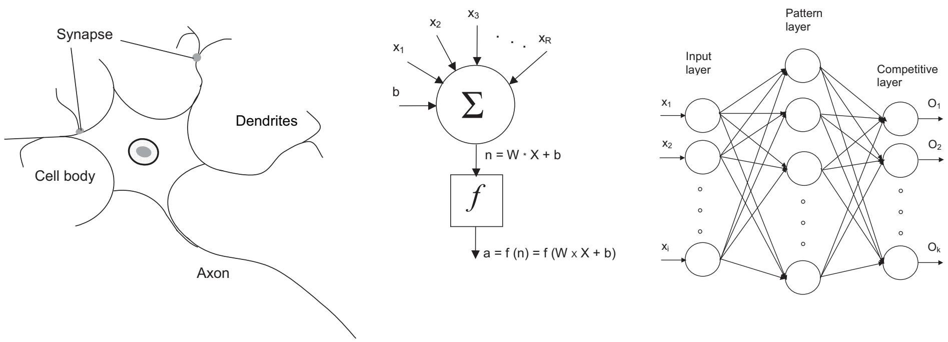


- Detection of fatigue damage was consistent in multiple specimens
- Sensitivity depends on frequency considered
- Magnitude of frequency shift may deviate from sample to sample.





Artificial Intelligence Decision Support



Neural networks (NN) are biologically-inspired artificial intelligence representations that attempt to mimic the functionality of the nervous system

For practical applications, artificial neural networks are organized in layers and are implemented as software algorithms and/or hardwired electronic devices.

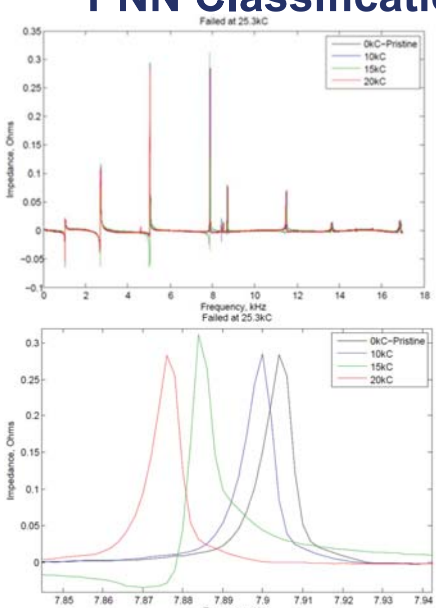
Probabilistic Neural Network

- While a substantial number of NN configurations are available to tackle the classification problem, we employ the probabilistic neural network (PNN).
- The reason for selecting the PNN is that this network reflects an association with classical statistic classification methods as it implements the Bayesian decision analysis with Parzan windows.
- PNN includes input layer, patter layer and competitive layer.

$$p_A(x) = \frac{1}{n \cdot (2\pi)^{d/2} \sigma^d} \sum_{i=1}^{n} \exp\left(-\frac{(x - x_{Ai})^T (x - x_{Ai})}{2\sigma^2} \right)$$

where *i* is a pattern number, x_{Ai} is i^{th} training pattern from *A* category, *n* is total number of training patterns, *d* is dimensionality of measurement space, and *σ* is a spread parameter.

PNN Classification of Fatigue Damage



Class	1	2	3	4
Ra, f kHz	7.894	7.89	7.874	7.866
Rb, f kHz	7.81	7.802	7.746	7.73
Rc, f kHz	7.914	7.906	7.898	7.89
Norm freq.				
Ra, f kHz	0	-0.004	-0.02	-0.028
Rb, f kHz	0	-0.008	-0.064	-0.08
Rc, f kHz	0	-0.008	-0.016	-0.024

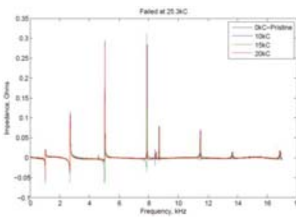
Train

Test

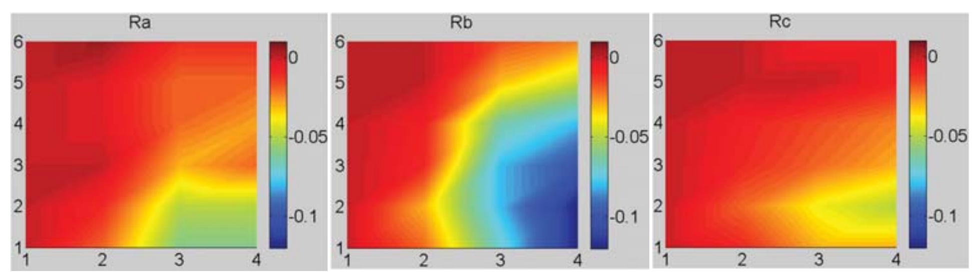
- PNN assigns neuron's weights based on values in the input *Train* vector.
- Spread constant controls distance between classes
- PNN freezes weight and spread constant
- When a *Test* vector is assigned to PNN, it compares *Test* vector values to *Train* vectors values based on neuron function
- Competitive layer outputs resulted classes.

PNN Classification of Fatigue Damage

Six sets of frequencies are considered for classification tests



	Train	Test	Test	Train	Test	Test	Train	Test	Test
Sample	Ra	Rb	Rc	Rb	Ra	Rc	Rc	Ra	Rb
Class **1** 0kc	1	1	1	1	1	1	1	1	1
Class **2** 10kc	2	2	2	2	1	2	2	2	2
Class **3** 15 kc	3	3	3	3	2	2	3	4	4
Class **4** 20 kc	4	3	3	4	2	2	4	4	4



SHM During H-A Balloon and Suborbital Flights

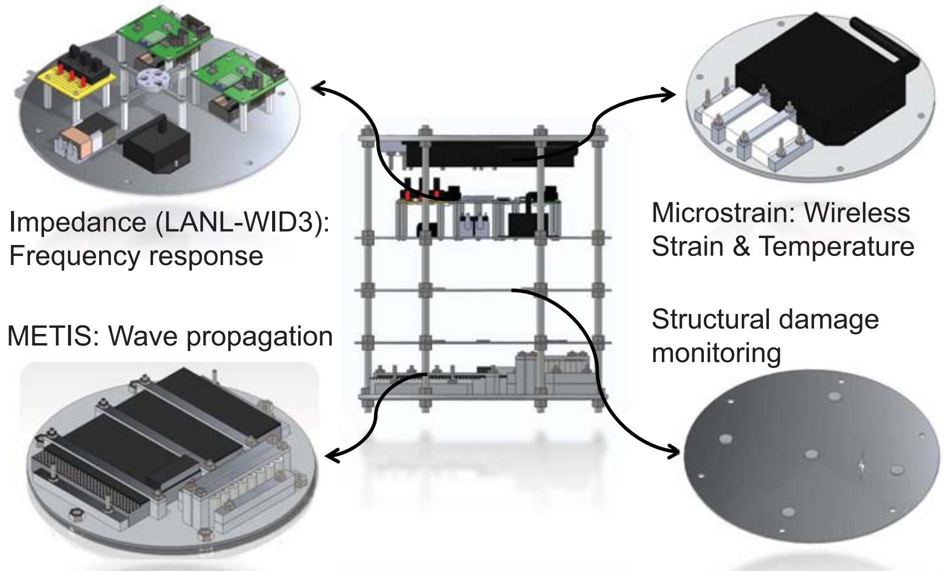
Objectives:

- Test majors concepts of spacecraft SHM systems during high altitude balloon and suborbital flights
- Collect SHM data from an experiment designed, built, and tested by the a student team.

Sponsors: NASA FOP NMT, FAA COE

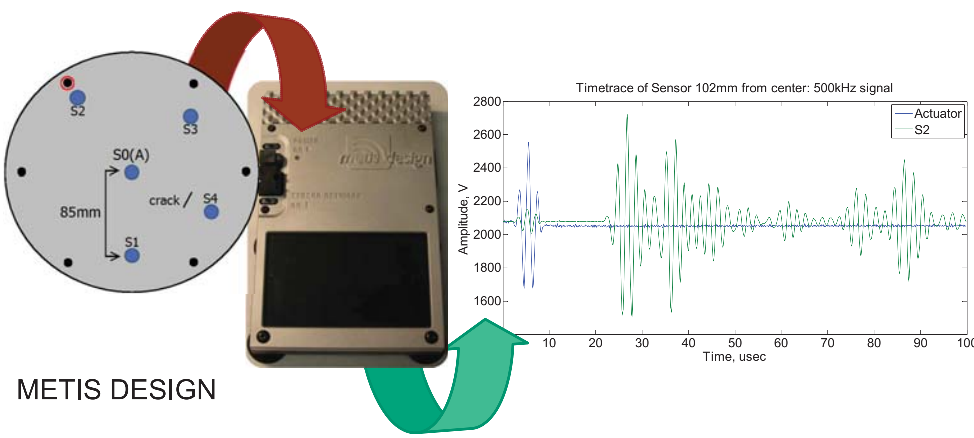
The Spaceloft XL rocket lifting off (left) and a large high altitude balloon (right).

Payload Design



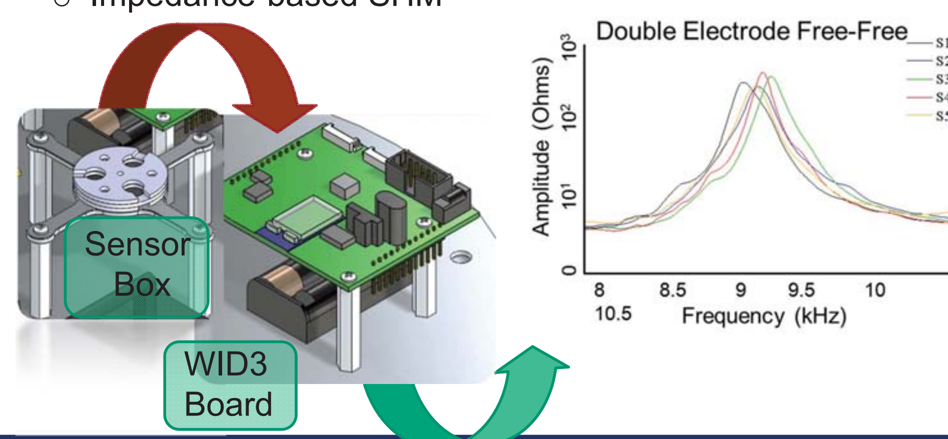
Elastic Wave Propagation Experiment

- Structural sound speed measurement
- Active ultrasonic SHM (mode 1)
- Acoustic emission (mode 2)



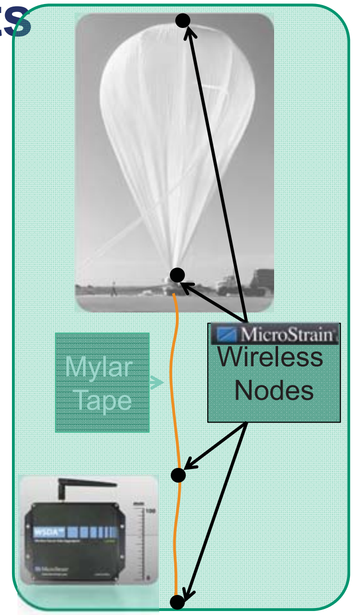
Electro-mechanical Impedance

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



Wireless Measurements

- Experiment Components:
  - Goals is to conduct wireless measurement in space/near-space environment and explore associated technical/regulatory issues with launch providers
  - WSDA-1000 wireless data aggregator
  - Four wireless strain and temperature sensors
  - 8 full-bridge strain gauges and 4 internal temperature sensors
  - Approximately 234 ft span (70 ft balloon and (164 ft – Mylar tape)



Publications/Presentations

- Conrad, D and Zagrai, A, (2011) "Active Detection of Structural Damage in Aluminum Alloy Using Magneto-Elastic Active Sensors (MEAS)," *Proceedings of SMASIS-11, ASME Conference on Smart Materials, Adaptive Structures and Intelligent Systems*, September 18 – 21, 2011, Scottsdale, AZ, paper: SMASIS2011-5219.
- Meisner, D and Zagrai, A (2012) "Magneto-elastic Active Sensors for Detection Of Incipient Fatigue Damage in Aerospace Structures," International Youth Competition of Scientific Research Works "Student and Science & Technology Progress," Taganrog, Russia, June 20, 2012.
- Conrad, D., Zagrai, A., Meisner, D, (2012) "Influence of Sensor Statistics on Piezoelectric and Magneto-elastic Damage Detection," *Proceedings of SMASIS-12, ASME Conference on Smart Materials, Adaptive Structures and Intelligent Systems*, September 19 – 21, 2012, Stone Mountain, GA, paper: SMASIS2012-8255.
- Conrad, D., Zagrai, A., Meisner, D, (2012) "Design, Development, and Assembly of Space Flight Structural Health Monitoring Experiment," *Presentation at ASME Conference on Smart Materials, Adaptive Structures and Intelligent Systems*, September 19 – 21, 2012, Stone

Contact Information

- Andrei Zagrai
- Department of Mechanical Engineering
- New Mexico Institute of Mining and Technology
- 801 Leroy Pl., Weir Hall, Room 124, Socorro, NM
- Ph: 575-835-5636;
- Fax: 575-835-5209;
- E-mail: azagrai@nmt.edu

COE CST Second Annual Technical Meeting: Fracture Mechanics of Sapphire for High Temperature Pressure Transducers

Justin Collins
Advisor: William Oates

10/31/2012

Team Members

- Mark Sheplak (UF)
- David Mills(UF)
- Daniel Blood(UF)

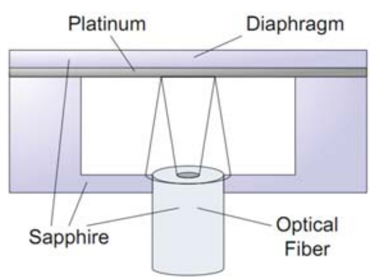
Overview

- Motivation
- Background
  - Structure property relations
- Experimental work
  - TEM Characterization
- Theoretical calculations
  - Anisotropic fracture mechanics
- Summary and future work

Motivation

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

Kulite Pressure Transducer



Structure-Property Relations

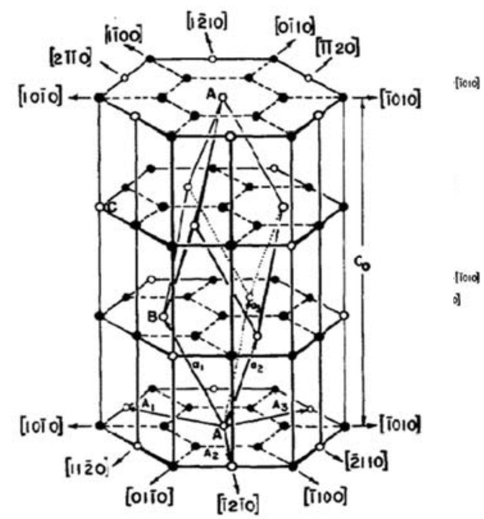
- Sapphire crystallographic structure
  - Complicated by hexagonal cage & internal rhombohedral structure
- *Anisotropic elastic behavior
  - Rhombohedral—not hexagonal

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

- Melting temperature 2030 ℃

Basal half loop dislocation

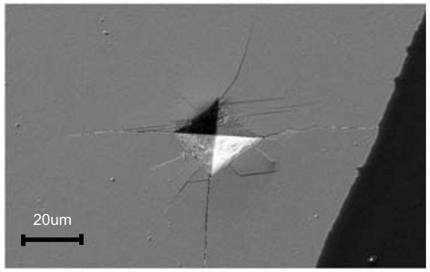
Hockey, Journal of the American Ceramic Society, May 1971, Vol. 54, No. 5

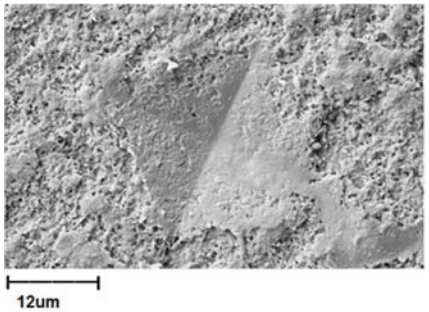


*Ohno, *Phys. Chem. Solids Vol. 47, No. 12. pp.* I ION 108. *1986*

Toughness Induced Laser Machining

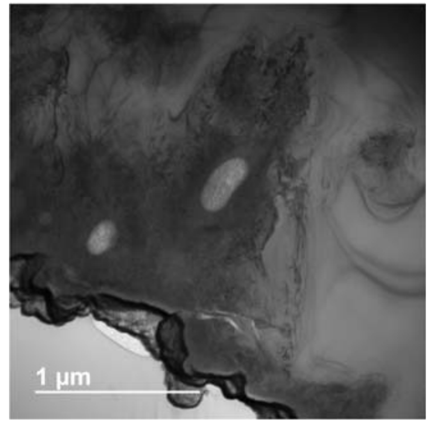
- Vicker's indentation characterization
- No visible cracks in laser machined specimens
- Laser machining parameters
  - 10 kHz rep rate, 10 mm/s scanning speed, 3.8 J/cm^2 fluence, 3um stepover

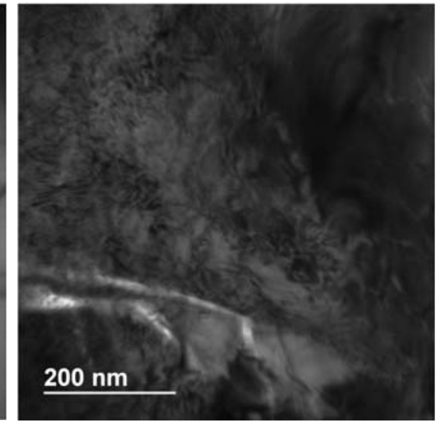




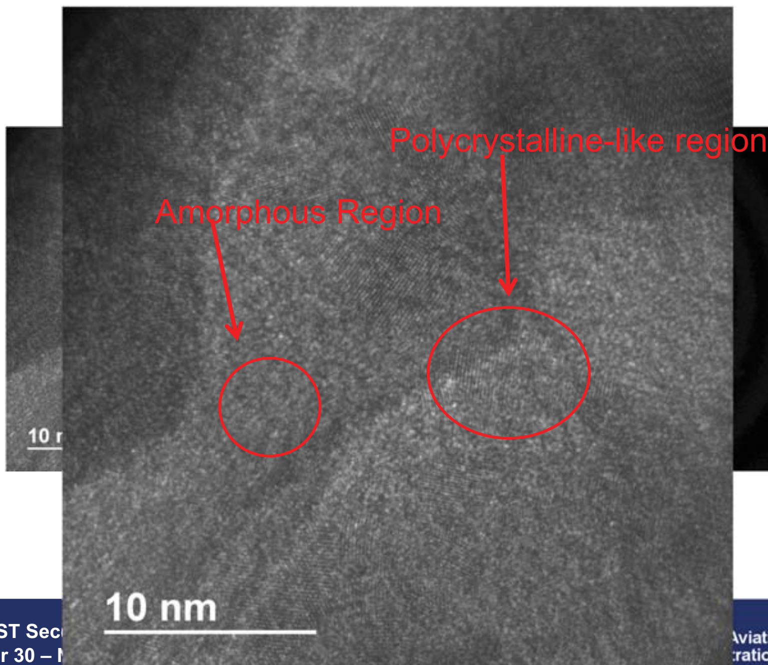
TEM Characterization

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





TEM Characterization-2



Theoretical Fracture Analysis

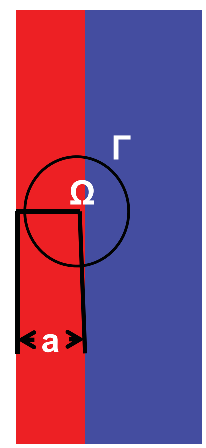
Eshelby stress tensor

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

J-Integral

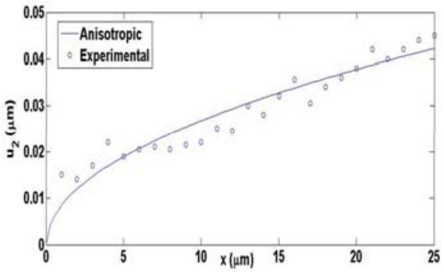
$$J_i^* = \int_\Gamma \; b_{ji}n_j dS - \int_\Omega \frac{1}{2} c_{prst,i}u_{p,r}u_{s,t}dA$$

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



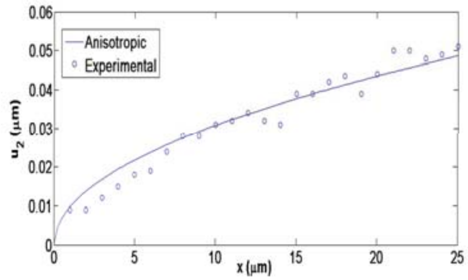
Fracture Toughness

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



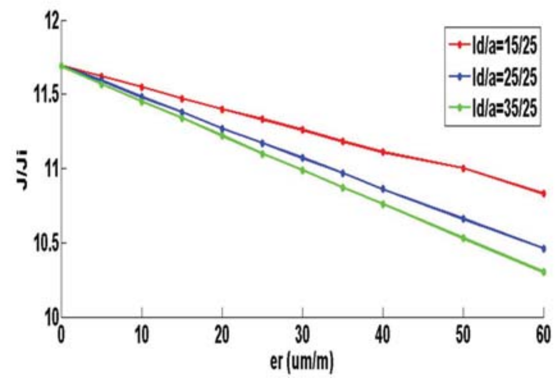
Indentation at ~0

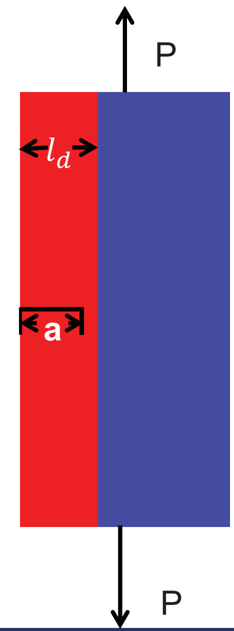
- $K_{1c} \cong 2.50\ MPa * m^{\frac{1}{2}}$
- $J_c \cong 15.25\ \frac{N}{m}$



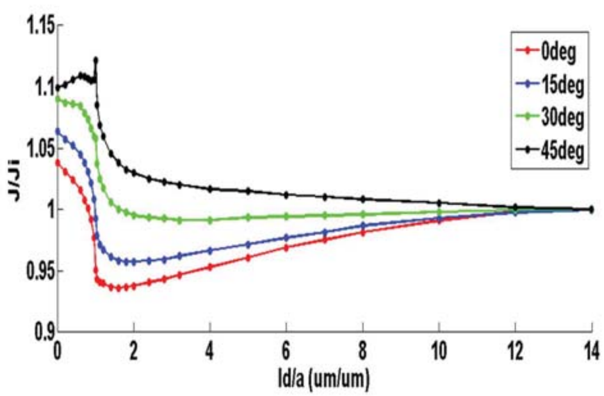
Indentation at ~45°

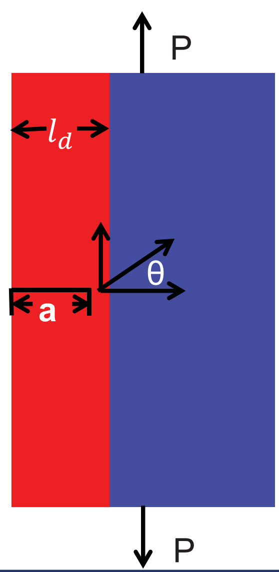
Theoretical Work-Residual Strain





Theoretical Work-Isotropic to Anisotropic





Summary

- Laser machining subsurface damage quantified
  - TEM characterization identified dislocations
  - Amorphous and polycrystalline-like behavior also observed
- Anisotropic fracture toughness
  - Significant dependence on crystal anisotropy
- Future work
  - Thermal annealing & laser parameter studies
  - Transition to pressure sensing characterization

Acknowledgements

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

Contact Information

- Justin Collins
  - Research Assistant
  - Email: justin.collins.eng@gmail.com
- William Oates
  - Associate Professor
  - Email: woates@eng.fsu.edu
  - Phone: (850) 645-0139
  - Fax: (850) 410-6337

Backup Slides

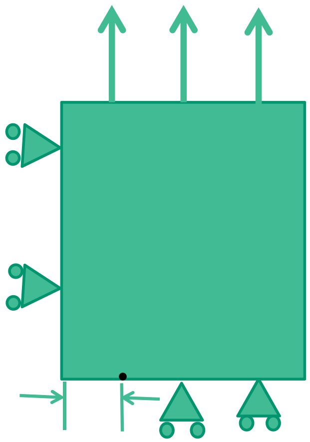
Table 4. Determined elastic constants of corundum and their standard deviations in GPa. Previous data are also shown

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]

Dislocation Mechanics

- Basal dislocations associated with a 100-g indentation on a (0001) basal plane section
- Specimen polished with abrasive paper.
- How does laser machining affect the properties of sapphire? Are dislocations induced during the process?

FEM Analysis



COE CST 2nd Annual Technical Meeting:

High Temperature Pressure Sensors for Hypersonic Vehicles

David Mills

October 31 – November 1, 2012

Overview

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

Team Members

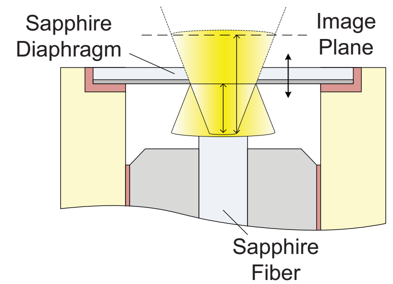
- **University of Florida**
  - **Mark Sheplak** - Professor, Dept. of Mechanical and Aerospace Engineering
  - **David Mills** - Graduate Research Assistant
  - **Daniel Blood** - Graduate Research Assistant
- **Florida State University**
  - **William Oates** - Asst. Professor, Dept. of Mechanical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

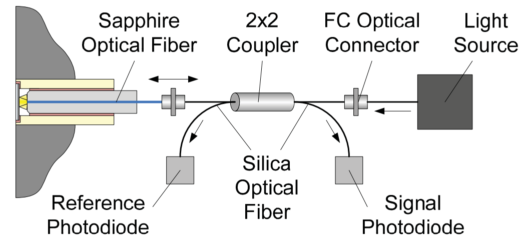
Purpose of Task

- Design, fabricate, and characterize a robust, high-bandwidth micromachined pressure sensor for harsh environments
  - Applications
    - High speed reentry vehicles
    - Hypersonic transports
    - Gas turbines
    - Scramjets
  - Performance Metrics
    - Temperature: >1000°C
    - Bandwidth: >10 kHz
- Develop novel processing techniques for the fabrication of high temperature sensors
  - Laser micromachining processes for patterning of structures in sapphire and alumina
  - Bonding process to for fabrication of multi-wafer sensors enabling three-dimensional structures

Research Methodology

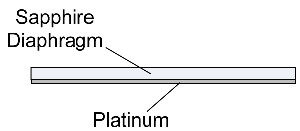
- Fiber optic lever
  - Intensity modulation
  - Single fiber in/fiber out
- Optical configuration
  - Multimode silica fibers
    - More efficient coupling to sapphire fiber
  - Incoherent LED light source
  - Reference photodiode to monitor source drift

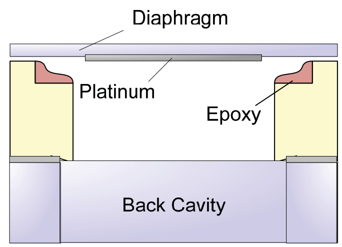




Device Fabrication

- 3mm tube sensor
  - 50 μm sapphire diaphragm
  - Deposit platinum reflective layer w/ titanium adhesion layer
  - Laser machine 4.5 mm recess in alumina tube
  - Epoxy diaphragm inside recess
- 7mm flat sensor
  - 50 μm sapphire diaphragm
  - Deposit platinum reflective layer w/ titanium adhesion layer in center
  - 1 mm thick sapphire substrate
  - Machine 7 mm diameter hole in 1 mm thick sapphire to form back cavity
  - Deposit 500 nm platinum bonding layer on 1 mm thick substrate
  - Align and bond diaphragm to cavity substrate



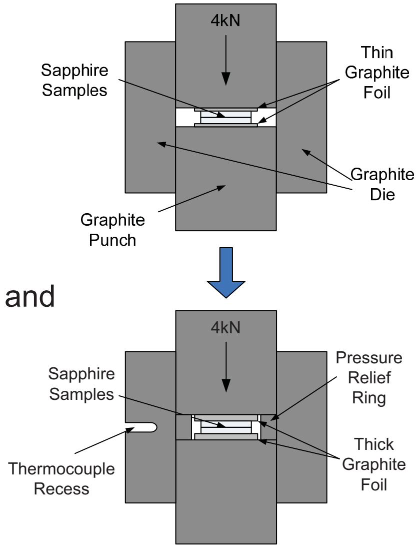


Fabrication Challenges

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

SPS Bonding Process

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



Bond Characterization

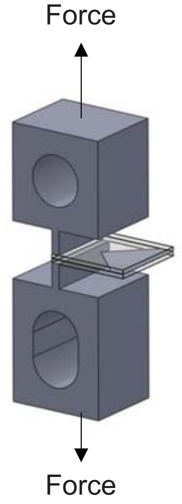
- Tensile test
  - Studs bonded to substrates using Hysol 9309.3NA adhesive
  - Original SPS sample tensile strength: ~350 kPa
  - Samples created using modified SPS process: >12 MPa
    - Adhesive joint failed before the bond interface
    - Need improved method for characterization

Bond Characterization

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

$$K_c \propto F_{max}$$

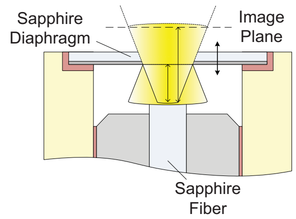
$$G_c \propto K_c^2$$



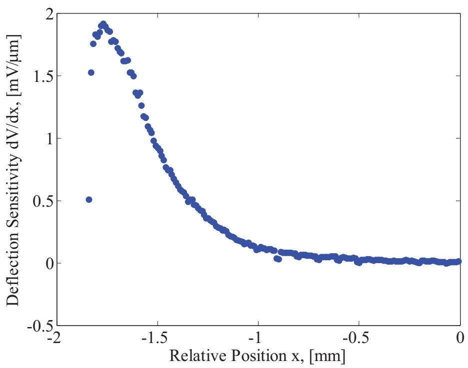
Sensor Fabrication

- High-temp prototype sensors
  - 3mm tube sensor
    - Ti/Pt-coated sapphire diaphragm epoxied to alumina housing
  - Sapphire fiber w/ zirconia optical ferrule
  - 7mm flat sensor
    - 50um sapphire diaphragm attached to 1mm thick back-cavity using SPS bond process
    - Reflective film degradation, buckling

Sensor Packaging



- Sensitivity Calibration
  - Experimentally determined optimal distance from fiber to diaphragm
  - Max deflection sensitivity of 1.92 mV/µm

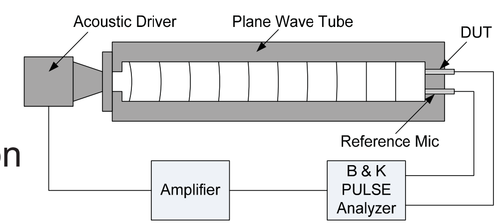


Sensor Packaging

- High-temp epoxy used on all connections
- Stainless steel braid and crimps
- Standard FC optical connector couples to traditional silica optical fiber components
- Package capable of operation up to 600°C

Next Steps

- Process development
  - Laser machining parameters for thinning sapphire diaphragms
  - Evaluate SPS bonding process using chevron test specimens
  - Improve metal film survivability during bonding
- Package 7mm flat sensor
- Static pressure calibration
- PWT calibration
  - Frequency response
  - Linearity
- High-temperature calibration
  - Temperature drift
  - Environmental chamber



Contact Information

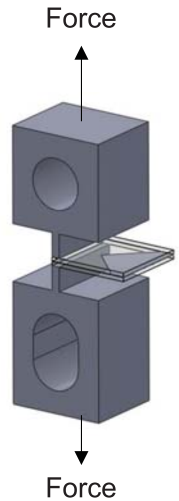
- David Mills – dm82@ufl.edu
- Mark Sheplak – sheplak@ufl.edu

Interdisciplinary Microsystems Group

FCAAP
FLORIDA CENTER FOR ADVANCED AERO-PROPULSION

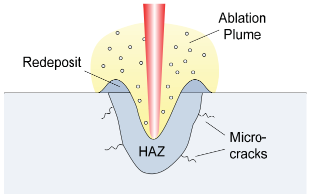
Bond Characterization

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



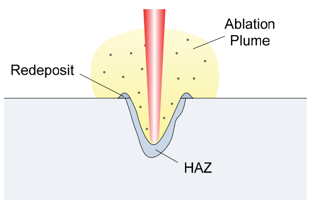
Laser Micromachining

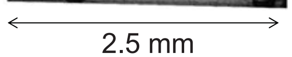
- "Long" Pulsewidths (>10 ps)
  - Industry standard
  - High reliability
  - Large heat affected zone (HAZ)
  - Micro-cracking and redeposit



Laser Micromachining

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



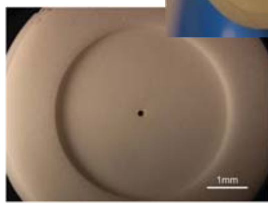


Thermocompression Bonding

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

Process Development Results

- Laser Machining
  - Cutting speed: 100 mm/s
  - Frequency: 100 kHz
  - Pulse overlap: ~86%
  - Laser fluence
    - Alumina: 2.45 J/cm²
    - Sapphire: 4.48 J/cm²
- Bonding
  - Bond parameters
    - Max temp: 800°C
    - Heating rate: 25°C/min
    - Hold time: 5 minutes
  - Tensile strength: ~350 kPa
  - Substrate cracking issues

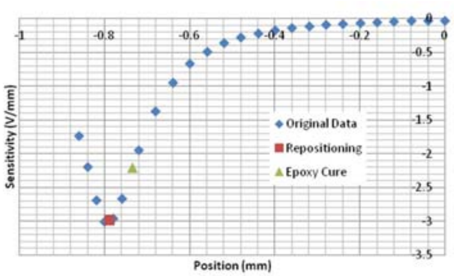


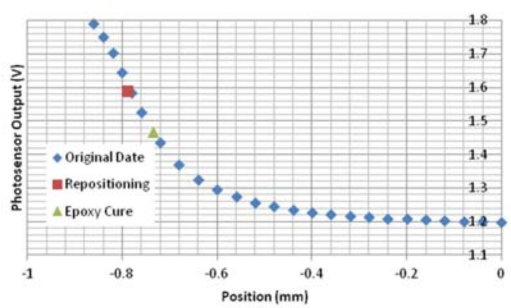
Fabrication Results

- Low Temperature Prototype
  - Silicon diaphragm
  - Silica fiber and low temp epoxy
- High Temperature Sensor
  - Pt-coated sapphire diaphragm
  - Sapphire fiber w/ zirconia optical ferrule

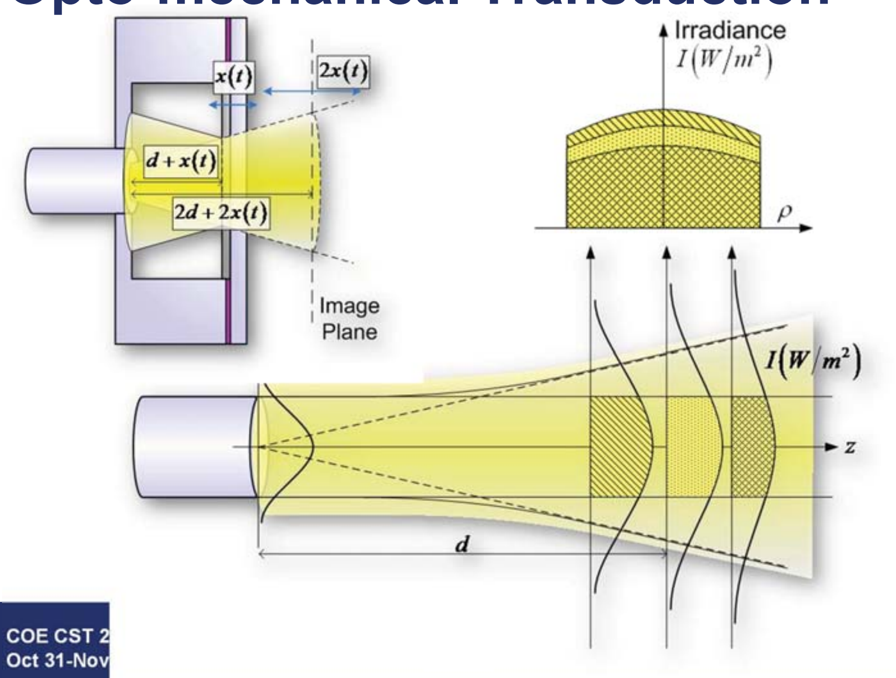
Backup Slides

- Prototype Sensor Static Calibration

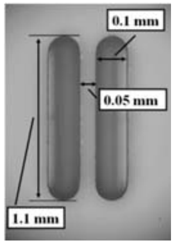


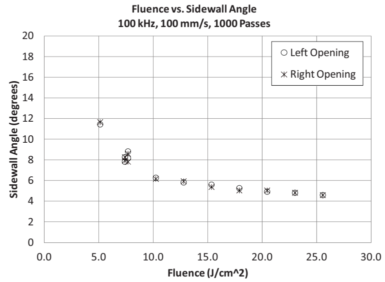


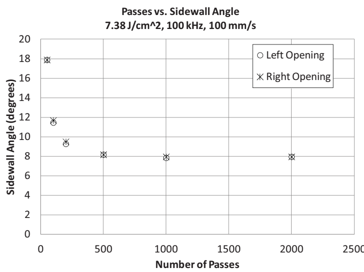
Opto-mechanical Transduction

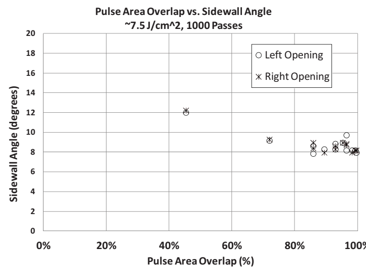


Laser Micromachining Trends

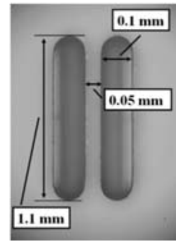


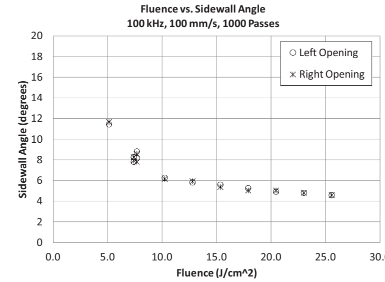


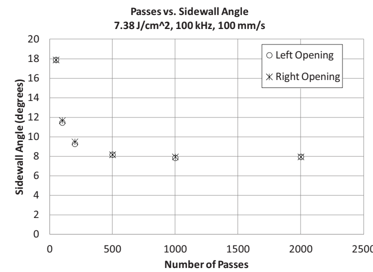


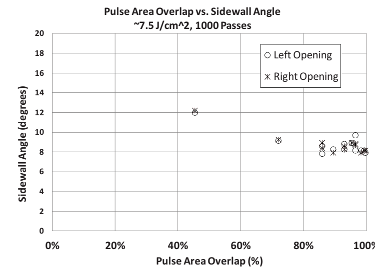


Laser Micromachining Trends







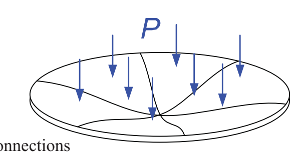


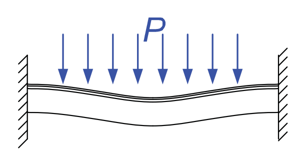
Oxsensis "Wavephire" Sensor

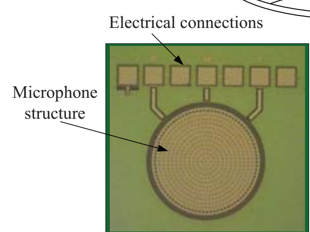
- Micro-machined sapphire pressure sensor with sapphire fiber-optic
  - Extrinsic Fabry Perot interferometer using at least two wavelengths
  - Diaphragm is micromachined using proprietary process
    - Limitations prevents further miniaturization to sub-millimeter size
- Specifications
  - Temperature range
    - -40 to 600°C (continuous)
    - -40 to 1000°C (research and development)
  - 100 dB dynamic range
  - Uncertainty <±10%

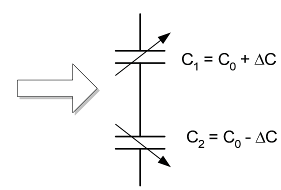
Dynamic Pressure Sensors

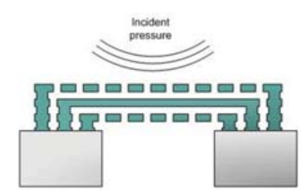
- **Diaphragm Sensors**
  - **Diaphragm deflects vertically due to incoming pressure**
  - **Displacement sensed via transduction method**
- **Transduction Schemes**
  - **Capacitive, optical, piezoresistive, piezoelectric, etc.**











Choosing a Transduction Scheme

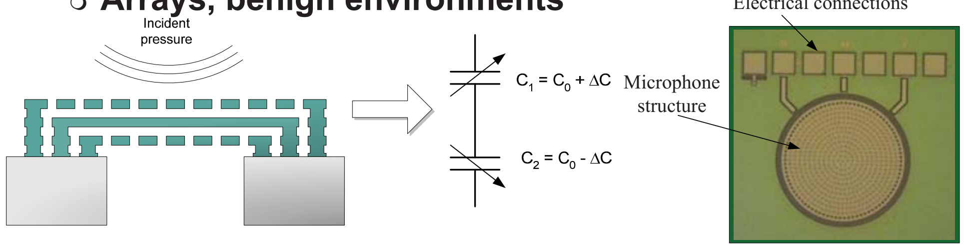
- Factors Influencing Choice of Transducer Concept
  - Specifications: "what do you want to measure?"
    - Physics related: dynamic range, bandwidth, spatial resolution, single sensor versus arrays, fundamental vs. control, etc.
  - Environment: "where do you want to measure it?"
    - Wind tunnel,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

Towards High-Temperature

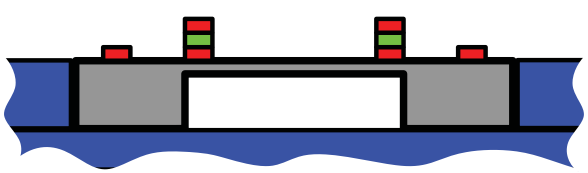
- Somewhat Unchartered Territory in MEMS
  - Silicon starts to plastically deform at 650 °C
  - Any circuit devices will be temperature limited (diodes, ICs, etc.)
- High-Temperature Limits Transducer Choices
  - Piezoresistive:
    - Leakage current and resistor noise increase with temperature
    -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

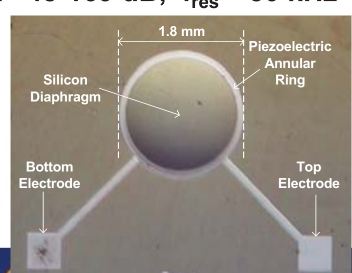
Microphones / Pressure Sensors

- **Capacitive: Sensitivity= 0.28 mV/Pa, DR= 22-160 dB, f_{res} = 158 kHz**
  - **Arrays, benign environments**



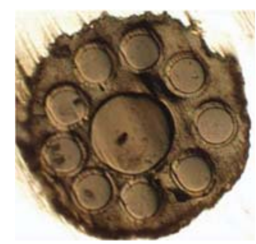
- **Piezoelectric: Sensitivity= 0.75 mV/Pa, DR= 48-169 dB, f_{res} = 50 kHz**
  - **Fuselage TBL studies**

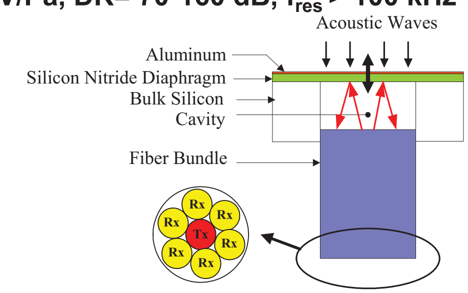




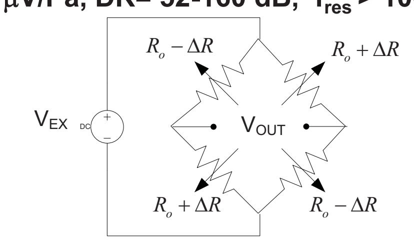
Microphones / Pressure Sensors

- **Fiber Optic: Sensitivity= 0.5 mV/Pa, DR= 70-160 dB, f_{res} > 100 kHz**
  - **Hostile environments**





- **Piezoresistive: Sensitivity= 1.8 μV/Pa, DR= 52-160 dB, f_{res} > 100 kHz**
  - **Directional acoustic arrays**



Material Properties

		Units	Silicon	Silica	Sapphire	Diamond	6H SiC
Material Properties	Melting Temp	°C	1412 [1]	1650	2040 [2]	3650 - sublimes	2830 - sublimes [1]
	Max Use Temp	°C	650 - strain point	1100 - no load [7]	1800 - no load [2]	650 - Si substrate	1650 - no load [5]
	Tensile Strength	GPa	7.0 [6]	8.4 [6]	15.4 [6]	53.0 [6]	21.0 [6]
	Poission's Ratio	-	0.28 - [100] plane, 0.26 - [110] plane [1]	0.14 - 0.17 [9]	0.25 - 0.3 [2]	0.1 [1]	0.14 [5]
	Young's Modulus	GPa	130 - [100] plane, 170 - [110] plane [1]	73 [6]	530 [6]	1035 [6]	700 [6]
	CTE, 20°C	µm/m-°C	2.6 [1]	0.55 [9]	5 - ⊥ to C-axis [2]	0.8 [1]	4.7 - ‖ to C-axis, 4.3 - ⊥ to C-axis [1]
	Thermal Conductivity, 20°C	W/m-°C	130 [1]	1.4 [9]	41.9 [2]	600-2000 [1]	490 [1]
	Thermal Shock Parameter [8]		1.52E+06	2.52E+05	1.83E+05	3.46E+07	2.94E+06
	Optical Transmission, UV-NIR	%	~0 - λ < 1.05µm, 50 - λ > 1.05µm [4]	86-93 [7]	80-90 [3]	60-70 [9]	70-80 [1]
	Refractive Index	-	3.42 (IR) [1]	1.45 @ 589 nm [7]	1.8 - 1.6, UV-IR [2]	2.4 (IR) [1]	2.59 - ‖ to C-axis, 2.55 - ⊥ to C-axis (IR) [1]
Transducer Issues	Optical Fiber Availability		no	yes	yes	no	no
	Substrate Availability		excellent	excellent	excellent	poor	limited
	Patternability / Process		Standard MEMS Processes		Laser Micromachining	Liftoff	SiC specific DRIE process, micromolding
	Transduction Mechanisms						

COE CST Second Annual Technical Meeting:

Autonomous Rendezvous and Docking for Space Debris Mitigation: Rapid Trajectory Generation

Emmanuel Collins, PI
Florida State University

November 1, 2012

Overview

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

Team Members

- Griffin Francis, PhD Student Mechanical Engineering

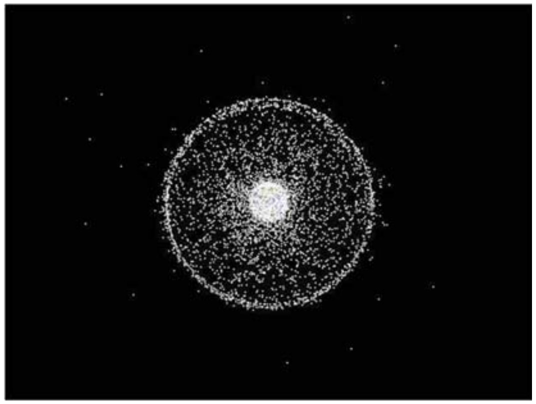
- Aneesh Sharma, PhD Student, Computer Science

- Oscar Chuy, Assistant Scholar Scientist

Purpose of Task

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

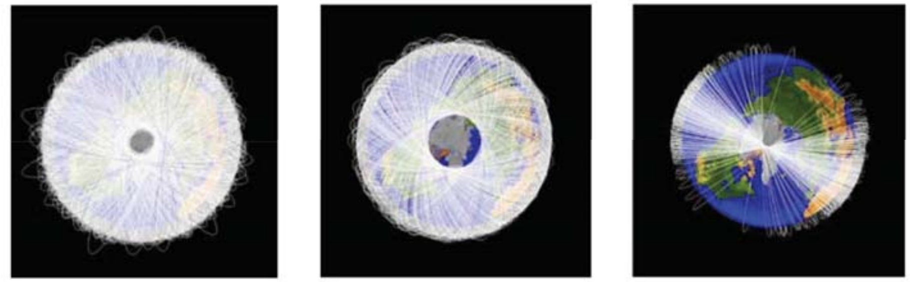
- A promising solution for direct debris removal is the development of a "Space Tow Truck."
- Requires automated guidance to approach targeted debris.



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

Purpose of Task

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



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

Purpose of Task

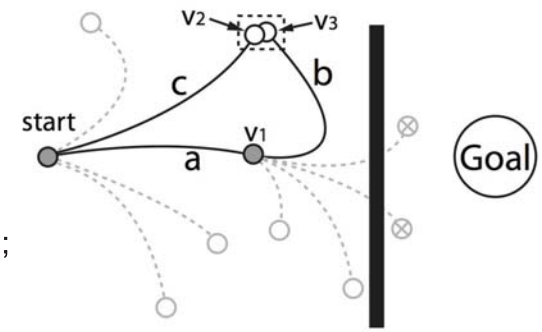
Goals:

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

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

Research Methodology

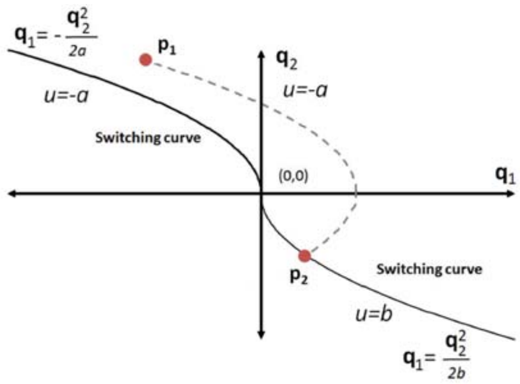
- The primary tool used is Sampling-Based Model Predictive Optimization (SBMPO).
- SBMPO is a graph search method characterized by:
  - Graph that is based on sampling of model inputs;
  - Optimization via A*;
  - Incorporation of dynamic model in planning;
  - Ability to rapidly replan;
  - Generation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



Graph formation: the process of node expansion, node rejection due to collision detection, and output space discretization via an imposed implicit grid encompassing nearby nodes V2 and V3.

Research Methodology

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



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

Research Methodology

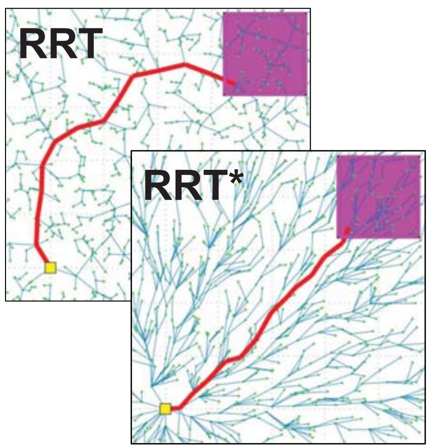
Facilities

- Dedicated in April 2012, research has moved into the new 60,000+ square foot AME (Aerospace, Mechatronics, and Energy) Building.
- The mechatronics laboratories will soon be equipped with a state-of-the-art motion capture system to be used for hardware testing of this research.

Results

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

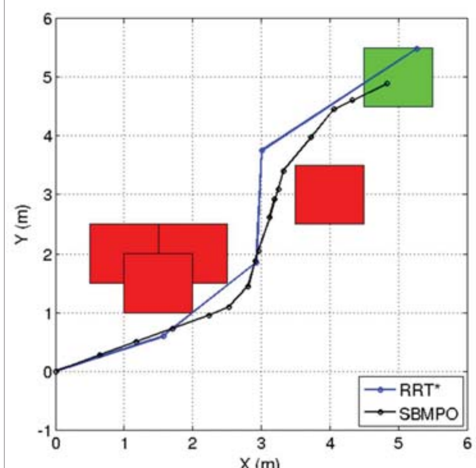
- Among the most popular motion planning methods, RRT* is an improvement of the RRT algorithm.
- Comparable to SBMPO, RRT* utilizes sampling, graph search, and cost-based optimization.
- However, RRT* does not employ prediction to speed up computations.



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

Results

Comparison of SBMPO with RRT* (Typical Result)



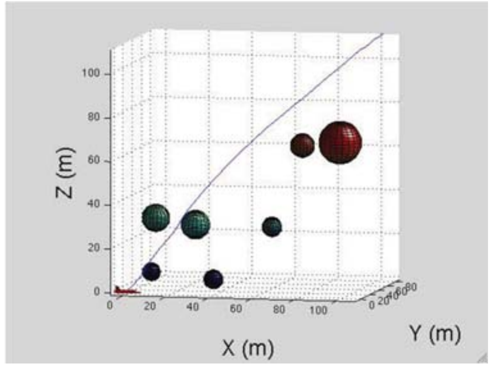
	SBMPO	RRT*
Distance (m)	7.39	8.28
Comp. Time (ms)	1.9	50.0

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

Results

3D Trajectory Generation in Cluttered Space

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



- Other approaches compute similar trajectories in 25+ seconds.

Scheduled Milestones

Hardware Integration

- Progress toward on-orbit implementation.
- Laboratory demonstration of planning for aerospace rendezvous.
- Utilize recently acquired quadrotor micro-air vehicles (MAV) as precursor to on-orbit deployment.
  - Complexity of trajectory generation problem is similar to spacecraft despite different dynamics.
- Employ VICON motion capture system for trajectory tracking.

Prominently featured as the standard platform of choice in authoritative autonomous MAV literature, a set of AscTec "Pelican" quadrotors will be used as a precursor for hardware implementation of this trajectory generation research. (AscTec, GmbH)

Next Steps

- Develop a better visualization tool using MATLAB's Virtual Reality Toolbox.
- Develop an "anytime" version of SBMPO that enables trajectory planning in a fixed time.
- Configure laboratory equipment for hardware implementation and real-world testing.
- Formulate a power consumption model and demonstrate planning of minimum energy trajectories.
- Apply trajectory constraints based on research of Penny Axelrad (U. Colorado).
- Use research of Steve Rock (Stanford) and Norm Fitz-Coy (U. Florida) to determine final pose constraints.

Contact Information

Emmanuel Collins
ecollins@eng.fsu.edu
850-410-6373

Griffin Francis
gfrancis@fsu.edu
850-410-6347

Aneesh Sharma
as10ac@my.fsu.edu
850-410-6347

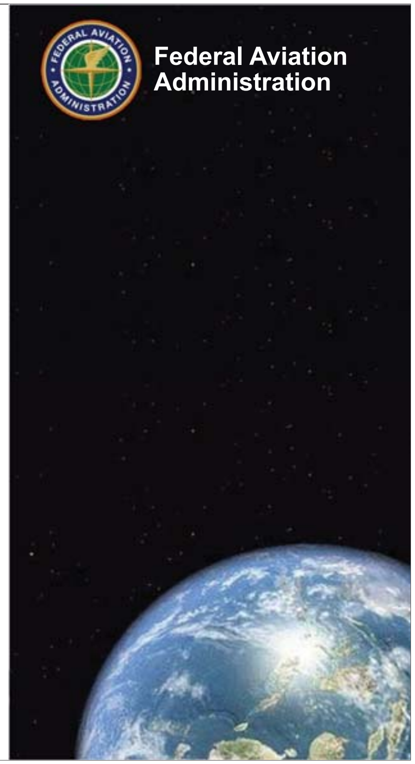
Oscar Chuy
chuy@eng.fsu.edu
850-410-6517

COE CST Second Annual Technical Meeting:

Task 244: AR&D for Space Debris Mitigation

Prof. Steve Rock (PI)
Stanford University

1 November 2012

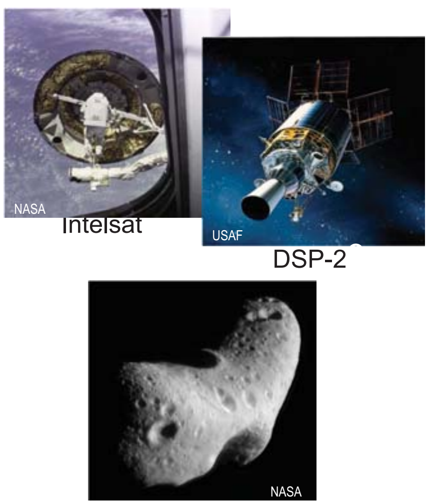


Team Members

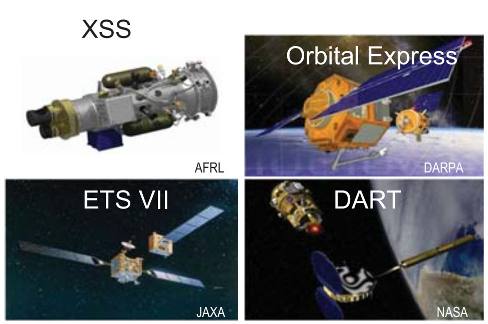
- Prof. Steve Rock (PI)
- Jose Padial
- Marcus Hammond
- Andrew Smith

The Aerospace Robotics Lab
Department of Aero and Astro
Stanford University

Motivation and Background



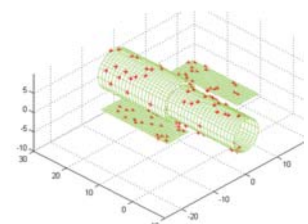
Related Missions



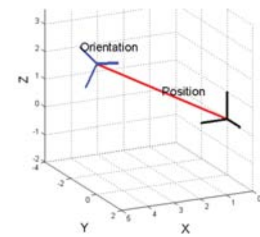
Statement of Purpose

- Target Reconstruction and Pose Estimation
- Unstructured rendezvous situations
  - Tumbling target motion
  - No a priori information
  - Uncommunicative target
- Enable this capability on a nano-satellite observer
  - Small satellites impose sensing constraints

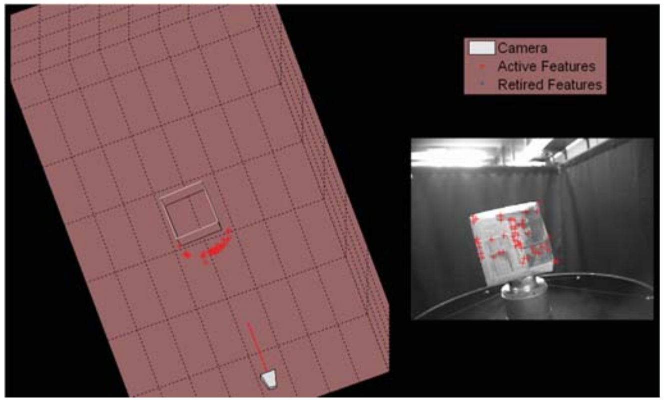
Target Reconstruction



Target Pose



Monocular Vision Tracking



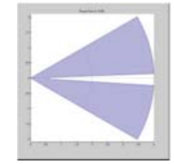
- Scale Ambiguity
- Sparse Reconstruction

→ **Add Range Sensing**

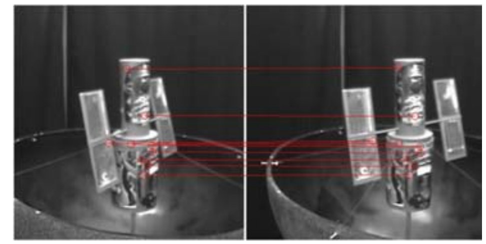
S. Augenstein and S.M. Rock. *Improved Frame-to-Frame Pose Tracking during Vision-Only SLAM/SfM with a Tumbling Target.* ICRA, 2011.

Fusion of Vision and Range Data

- Sparse-pattern Range Data
  - Line-scanning Laser
  - Low-resolution Flash LIDAR



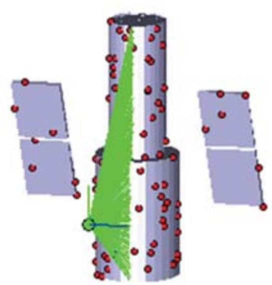
- Range data incapable of providing frame-to-frame correspondence
- Visual feature tracking (SIFT) used for frame-to-frame correspondence



COE CST Second Annual Technical Meeting (ATM2)
October 30 – November 1, 2012
Federal Aviation Administration

Fusion of Vision and Range Data

- **Monocular vision enables target reconstruction and pose estimation, but scale factor is unknown**
- **Scanning range data enables scale factor determination, but is subject to data smearing**
- **Challenge: alignment of disparate and sparse point clouds**



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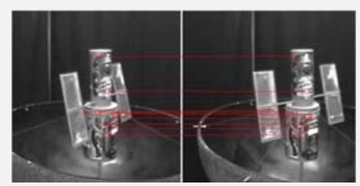
October 30 – November 1, 2012
Federal Aviation Administration

Algorithm Overview

Frame-to-Frame Vision Correspondence



Incorporate Range Returns

- Project range returns onto images
- Determine vision-range correspondence

Rao-Blackwellised Particle Filter Framework

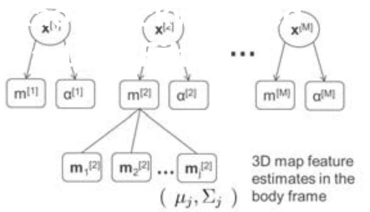
- Visual feature tracking drives particle weighting
- Vision-range correspondence for scale factor estimation

Pose Estimates

Target Map

COE CST Second Annual Technical Meeting (ATM2)
October 30 – November 1, 2012
Federal Aviation Administration

Algorithm Details



Details of the algorithm in:

J.Padial, M.Hammond, S.Augenstein, and S.M.Rock, "Tumbling Target Reconstruction and Pose Estimation through Fusion of Monocular Vision and Sparse-Pattern Range Data", *IEEE International Conference on Multisensor Fusion and Information Integration (MFI)*: IEEE Press, 2012.

And/or discuss with Jose by poster!

2D Vision Feature Measurements

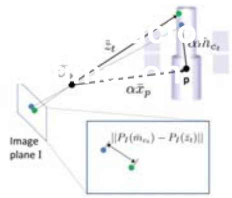
$$y_i^t = [u_i, v_i]_t^t$$

Expected Vision Measurements

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

Particle Weighting

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



Vision-range Correspondence

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

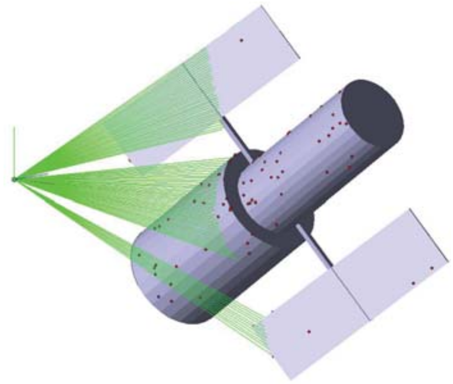
Scale Estimation System is *Linear*

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

Gaussian Measurement Distribution is *Linear* in Scale

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

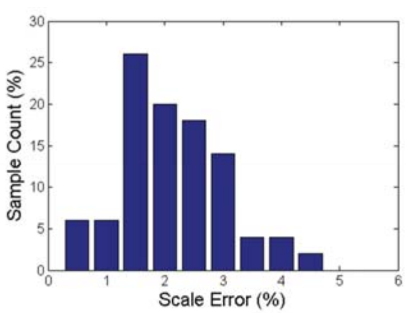
Simulation Environment

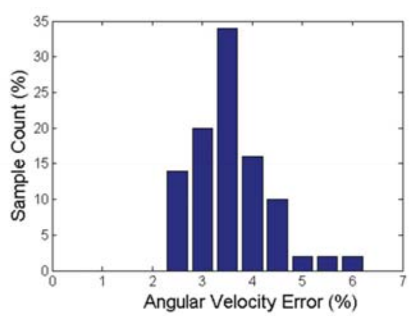


- **Target and observer (point-mass)**
- **Relative motion profile simulated**
- **Pixel measurement noise**
  - **sampled from zero-mean Gaussian with 1-pixel variances**
- **Range measurement noise**
  - **sampled from a zero-mean Gaussian with standard deviation 1% true DT**

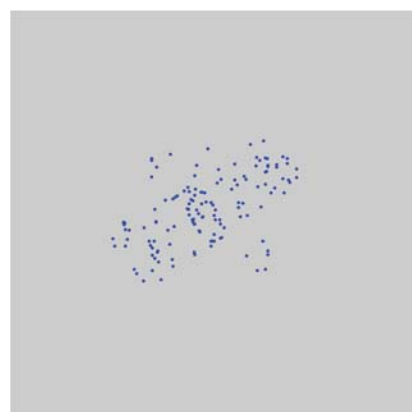
Simulation Results

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

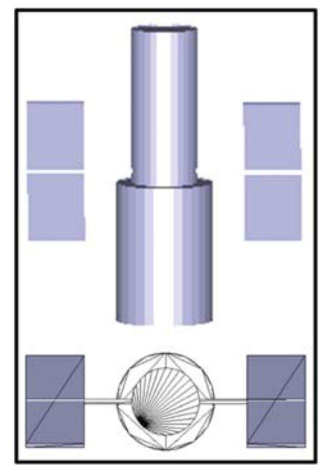




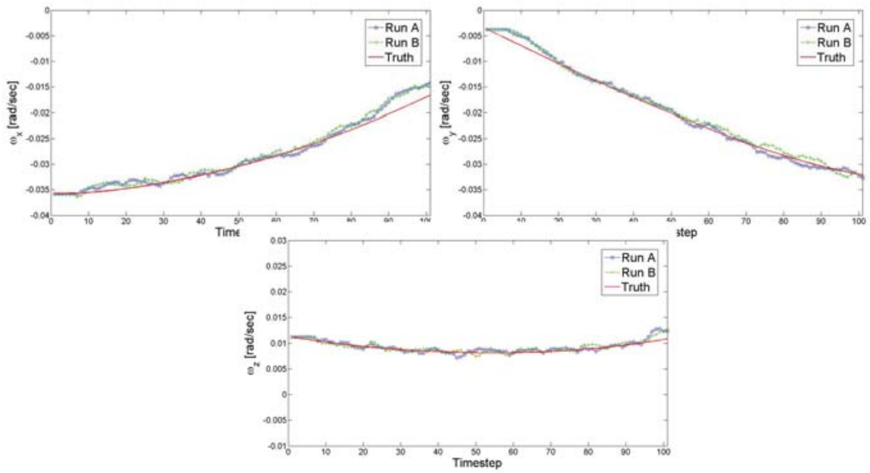
Simulation Results



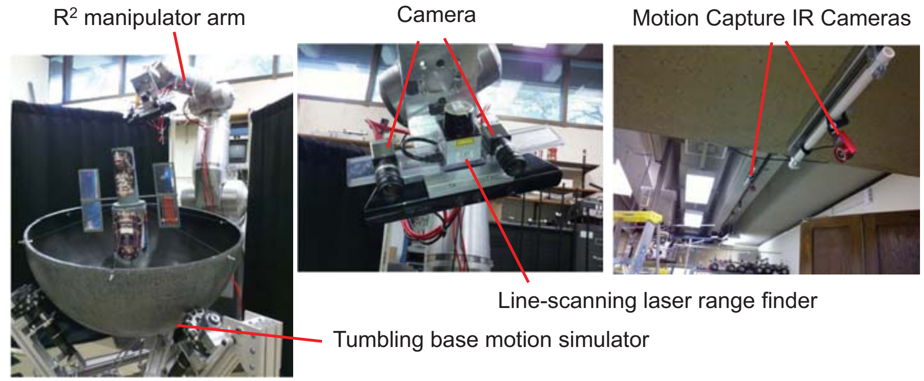
Run A: 0.42% scale error, 3.42% angular velocity error



Simulation Results - Angular Rate Tracking

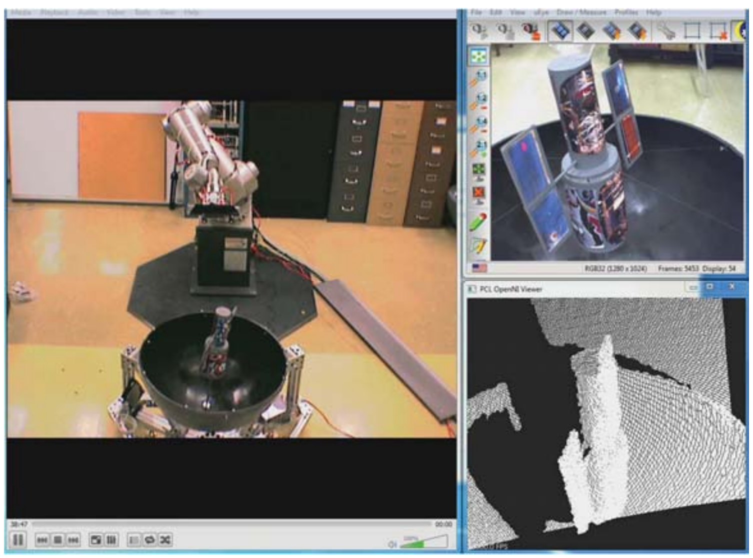


Hardware Test Platform



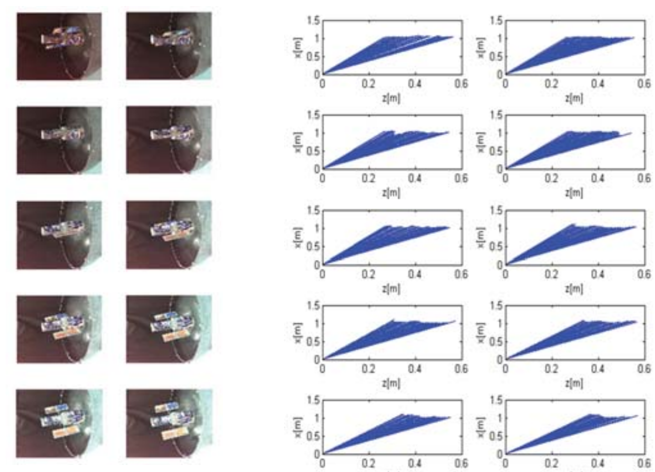
- **Simulink-based manipulator and tumbling base control with synchronized camera/ranging data collection and IR truth data collection**

Hardware Test Platform



Hardware Data Collected

10 sample images and laser range finder scans from dataset collected with ARL hardware test platform.



Moving Forward

In Progress:

- Initial hardware experimental data generated
- Dealing with truth data synchronization issues
- Dealing with algorithmic bugs in processing data

Priorities Moving Forward:

- Complete testing in ground-based hardware simulator
- Extend simulation studies and algorithmic analysis
  - Varying target geometries
  - Varying relative motion trajectories
- Modify algorithms to enable deployment on flight hardware (e.g. small sats)

Contact Information

- Prof. Steve Rock (PI)
- Jose Padial
- Marcus Hammond
- Andrew Smith

[rock,jpadial,mmh13,acsmith]@stanford.edu

COE CST 2nd Annual Technical Meeting: Task 244: Autonomous Rendezvous & Docking for Space Debris Mitigation

Norman Fitz-Coy

11-1-2012

Overview

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

Team Members

- Norman Fitz-Coy (PI, University of Florida)
  - Contact: nfc@ufl.edu / (352)-393-1029
- Takashi Hiramatsu (University of Florida)
  - Graduated (May 2012)
  - Contact: takashi@ufl.edu / (352) 846-3020
- Windroff Marseille (University of Florida)
  - Started Fall 2012
  - Contact: windfmars27@ufl.edu / (352) 846-3020

Purpose of Task - Motivation

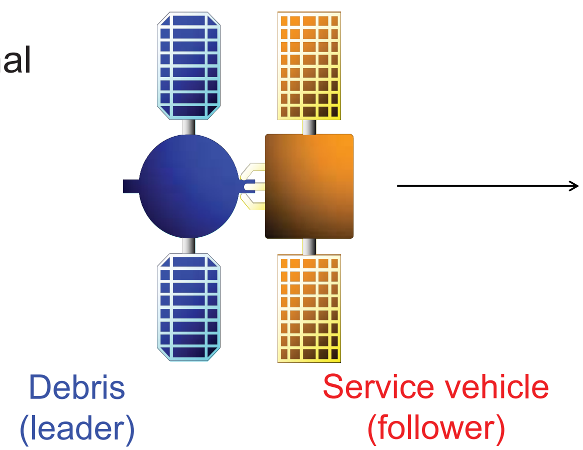
- Remediation requires active space debris removal
  - Removal of at least 5 pieces/year required to stabilize debris growth
- Proliferation of very small satellites (e.g., CubeSat form factor) results in more assets in space, thus the potential for more disabled satellites
  - Over 52 CubeSats launched since 2003 (only 23 active which suggest a success rate of ~44%)
  - Disabled spacecraft ⇨ debris
- Malfunction in actuator, communication, etc.
  - Non-cooperative behavior pre/post docking
- ARD requires safe path planning; we
  - Propose using an AFP-based guidance for collision avoidance

Purpose of Task

- Objective 1
  - Minimize interaction “forces” between vehicles when docked with a non-cooperative target
- Goals
  - Characterize the non-cooperative post-docking with “disabled spacecraft” (i.e., debris)
  - Develop necessary control strategy to counteract debris’s motion and maintain a safe docked state
- Objective 2
  - Facilitate autonomous rendezvous and docking (ARD)
- Goals
  - Develop collision free trajectories APF guidance
  - Augment APF using vision-based methods to identify/improve knowledge of obstacles

Towing Debris

- React to disturbances through rotational motion
  - None (cooperative)
  - Translational
  - Rotational



Methodology: Game Theory

- Game Theoretic Approach
  - Multiple players (debris, service vehicle)
  - Make an intelligent estimate of the debris's behavior to compute the reacting control strategy of the service vehicle
- Stackelberg Game
  - System with leader-follower hierarchy
  - Interaction with a non-cooperative spacecraft (leader)
- Completed (reported in Takashi Hiramatsu's PhD dissertation)

APF Background

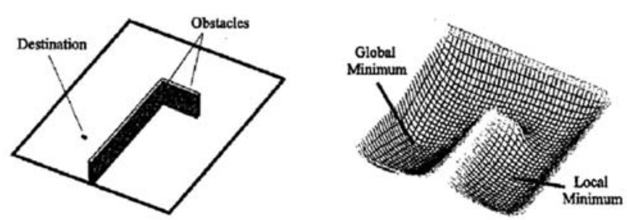
- Artificial potential function (APF) is used to construct an artificial potential field in the motion space. This function is used to avoid collisions with the obstacles in the environment (known a prior or determined en route to goal). That means APF has to attain its and.
- APF has two parts:
  - An attractive potential function which locates the goal (function has a minimum value)
  - Repulsive potential functions which locate the obstacles (function values is larger than surrounding)

APF Background

- APF commonly used in autonomous path planning
- Khosla and J. O. Kim – used APF mobile robots for obstacle avoidance (1986); incorporated harmonic function with APF to avoid local minimal (1992)
- Mabrouk and McInnes, M-G Park and J-H Jeon – developed other method to solve the local minimal
- S.S. GE and Y.J. CUI – applied APF to moving obstacles; developed the dynamic motion planning for mobile robots using potential field method

APF Background

- APF-based guidance may encounter local minimal problem



- Use harmonic functions as potentials solves this problem since they do no exhibit local minima when superimposed

APF Background

- The attractive potential function and attractive force:

$$U_{attr} = \frac{1}{2} k \rho^2 (X, X_g)$$

$$F_{attr} = -\nabla [U_{attr}(X)] = k \rho (X, X_g)$$

- The repulsive potential function and repulsive force:

$$U_{rep}(X) = \begin{cases} 0.5\eta \left(\frac{1}{\rho(X, X_0)} - \frac{1}{\rho_0}\right)^2, \rho(X, X_0) \le \rho_0 \\ 0, \rho(X, X_0) > \rho \end{cases}$$

$$F_{rep}(X) = -\nabla [U_{rep}(X)] = \begin{cases} \eta \left(\frac{1}{\rho(X, X_0)} - \frac{1}{\rho_0}\right) \frac{1}{\rho^2(X, X_0)}, \rho(X, X_0) \le \rho_0 \\ 0, \rho(X, X_0) > \rho \end{cases}$$

- The total force on robot:

$$F_{total} = F_{attr} + F_{rep}$$

APF Background

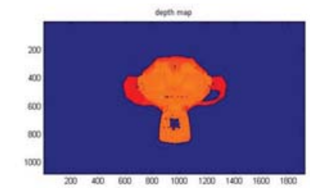
APF amenable to real time implementation and non-stationary obstacles

- APF in spacecraft rendezvous and docking, attitude manuevers: A. Tatsch, N. Martinson, J. Munoz, N. Fitz-Coy
- combined APF with different sensors (e.g., stereo vision system and TOF camera) used on mars rover: A. Eisenman and C. C. Liebe

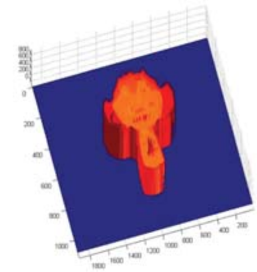
Methodology: APF Guidance

- Combine APF with a vision system to update the APF with near field information; i.e., provide more detailed definitions of obstacles along path
  - Initial path planning based on known obstacles modeled as point sources in the potential function but are updated to realistic shapes as they are within the FOV of the sensor
  - Unknown obstacles identified in the near-field as trajectory is traversed are incorporated into the potential function
- Vision system also used to provide information which regulates the vehicle's speed along the trajectory

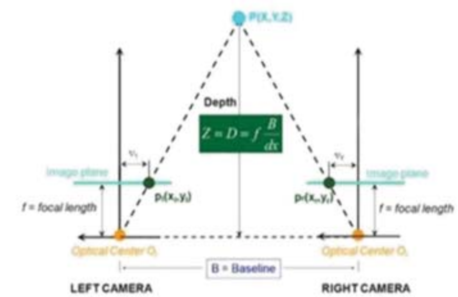
Vision-based Preliminaries



2D image (monocular vision)



3D image (from stereo vision)



<u>Simulation parameters</u>
Camera: Canon 60D
Camera focal length (mm): 35
Camera resolution:1920 (x), 1080 (y)
Camera sensor size (mm): 28.7 (w), 19 (h)
Pixel size: 28.7/1920 (w), 19/1080 (h)
Left camera location [x y z] (m): [-0.05 -6 0]
Right camera location [x y z] (m): [0.05 -6 0]
Object location [x y z] (m): [0 2 0]

Next Steps:

- Investigate APF-based guidance for collision free real-time trajectory development
- Augment APF guidance with vision-based system to improve perormance

	Year 1	Year 2	Year 3
Trajectory Planning	**Assessment of the state of the art for active debris removal**	Assessment of hardware implementation issues in APFG collision avoidance and SBMPC	Hardware assessment of all developed methodologies
Proximity operation		APFG collision avoidance strategies	Hardware implementation issues in APFG and SBMPC
Post-docking	**Initial assessment of post-dock scenarios**	Continued assessment of post-dock scenarios	Hardware assessment of all developed methodologies

Summary

- Demonstrated promise for removal of non-cooperative debris through game theoretic analysis
  - Stackelberg game strategy used to address post-dock interactions between service vehicle and debris
    - Demonstrated lower interactions between service vehicle and debris
    - Developed solution preserves nonlinearity of system dynamics (linearity in the error model)
    - However, concluded real-time implementation may be challenging (more analysis needed)
- Began analysis of APF-based guidance

COE CST Second Annual Technical Meeting:

Determine Baseline National Airspace System Impacts from Space Operations

Dr. Nathaniel E. Villaire
Dr. Daniel Robert Kirk
Dr. Samuel T Durrance
Mr. Sebastian Rainer

October 31, 2012

Overview

- Team Members
- Purpose of Task
- Research Methodology
- Schedule & Milestones
- What We Have To Date
- Future Work
- Next Steps
- Contact Information

Team Members

- Dr. Nathaniel E. Villaire
- Dr. Daniel Robert Kirk
- Dr. Samuel T. Durrance
- Mr. Sebastian Rainer

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Purpose of Task

- Purpose:
  - To provide a solution that safely and expediently reroutes aircraft around a space launch vehicle travelling in the national airspace based on added costs.
- Objectives:
  - Create a program that can display alternate flight paths for a given flight
  - Determine alternate flight paths based on monetary costs and time
- Goals
  - Have a working proof of concept
  - Simple to use design

Research Methodology

- Problem
  - Current NAS closures due to space vehicle launch is very expensive and costly for aircraft
  - Determine the most efficient and cost effective diversion of aircraft around closed airspace

Research Methodology (cont.)

- Proposed Solution
  - Investigators will use analysis of appropriate, existing, data supplied by the FAA to identify specific effects of CSV operations on the safe, expeditious flow of traffic in the NAS. (Proof of Concept)
  - Develop software that suggests alternate routes based on cost savings around closed airspace

Schedule & Milestones

The expected period of performance of this proposal is from 1 June, 2012 until 31 May, 2013.

***Phase 1 activity**

**** Phase 2 activity**

The expected major milestones of the proposed project are:

- *September 15, 2012 - Complete acquisition of data base expertise, applicable hardware and computer capabilities. Begin analysis of FAA LOAs from the affected ARTCCs.
- *September 30, 2012 – Complete categorization of data and selection of a processing program. (Data to be supplied by FAA. Program to be selected/developed by the FIT Research Team.)

Schedule & Milestones (cont.)

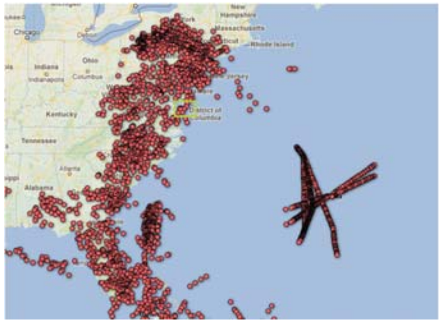
- *December 1, 2012 – Complete loading of the sample data bank and run test cases of CSV launch effects on separation of selected NAS operations.
- *December 31, 2012 – Select the data base processing system and computer requirements to be used to accomplish FAA/AST objectives.

Schedule & Milestones (cont.)

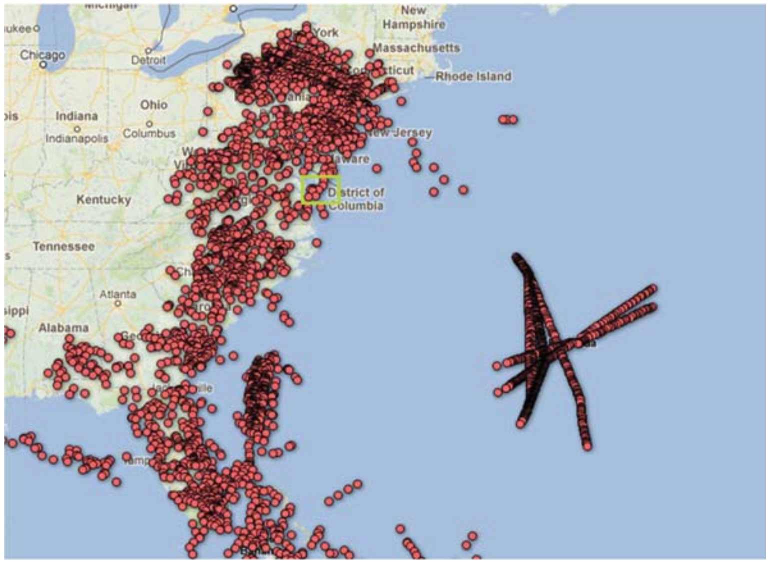
- **February 1, 2013 – Modify the data base program to adjust for any errors encountered to date and process cost analyses of selected airspace separation models involving CSV launches form sites designated by the FAA/AST.
- **March 31, 2013 – Develop the CSV Launch Effects Tool to satisfy the FAA/AST requirements listed in paragraph #9, “a” above.
- **May 31, 2013 – Deliver a CSV launch/recovery data management tool which will fulfill the requirements of #10 above.

What We Have To Date

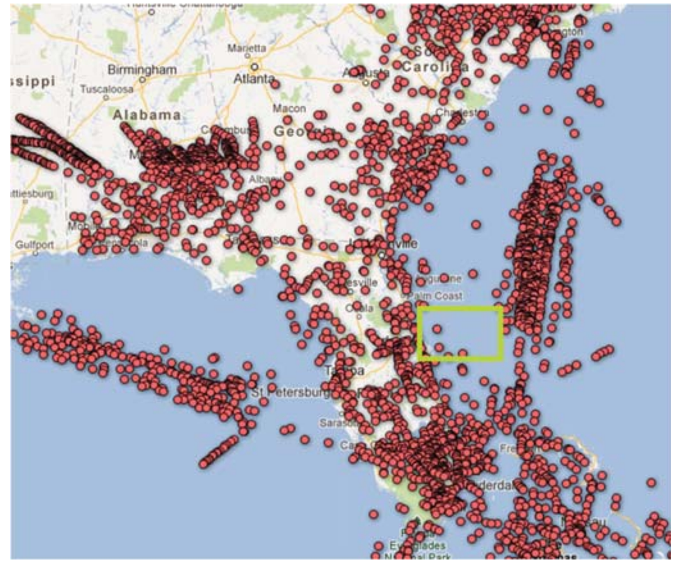
- Sample flight data
- NOTAM information for Cape Canaveral
- Basic program structure outlined
  - Database structure
- Trial data plots



What We Have To Date



What We Have To Date



Future Work

- Continue developing software
  - Integrate time into program
  - Integrate METAR into program
  - Integrate cost analysis into program
- Begin trail runs of software
- Discuss ARTCC procedures
- Discuss procedures with Cape Range Officer

Summary

- Data acquired
- Examined commercial software
  - Determined Excel is not an option
- Begin developing new software
  - Considering weather effects
  - Costs of diversions

Next Steps

- Review pertinent LOAs
- Additional Data
  - Acquire METAR data
  - Acquire IFR international route charts
  - Acquire cost diversion data
  - Acquire range dimensions
- Continue to develop the software
- Resolve outstanding problems

Contact Information

- Dr. Nathaniel E. Villaire, FAsMA
  - Email: natvillaire@cfl.rr.com
- Sebastian Rainer
  - Email: srainer2010@my.fit.edu

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COE CST Second Annual Technical Meeting: Ultrahigh Temperature Composites for Thermal Protection Systems (TPS)

Dr. Jan Gou
Department of Mechanical and Aerospace Engineering
University of Central Florida

October 31, 2012

Overview

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

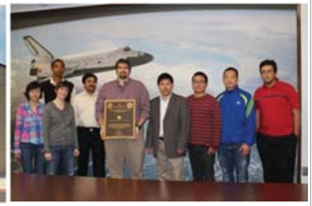
Team Members

Principle Investigators

- **Jan Gou -** Composites design and manufacturing, composites mechanics
- **Jay Kapat -** Heat transfer, film cooling, aerodynamics testing
- **Ali Gordon -** Mechanical property characterization, fatigue and fracture

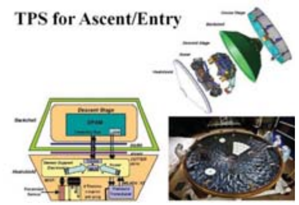
Graduate Students

- **Donovan Lui/J. Gou**: Composites TPS design and manufacturing, ablation testing
- **Cassandra Carpenter/J. Kapat**: Aerothermal modeling
- **Steven Craft/A. Gordon**: Thermal-mechanical testing and characterization

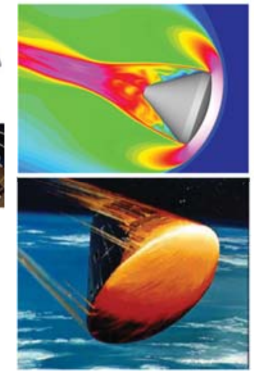
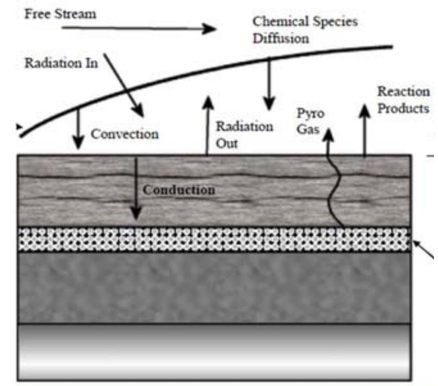



Purpose of Task

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

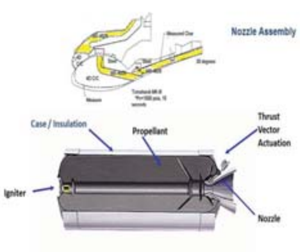


Reentry Vehicles

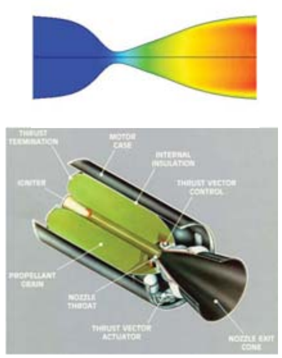
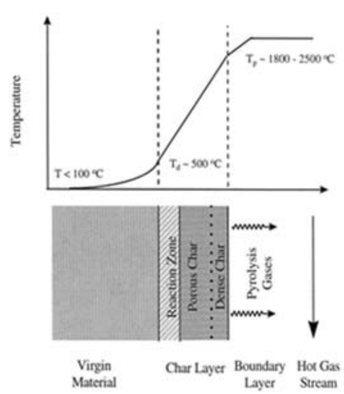



Purpose of Task (Cont'd)

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



Solid Rocket Motor

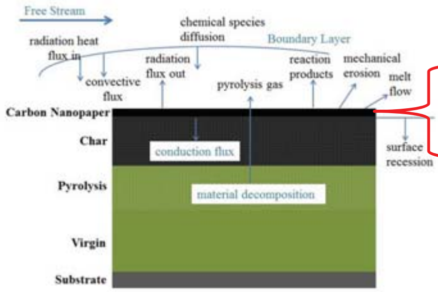
Current Approach

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

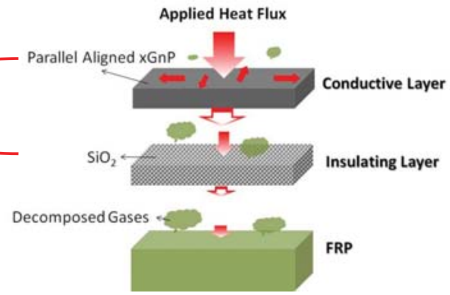
Problems

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

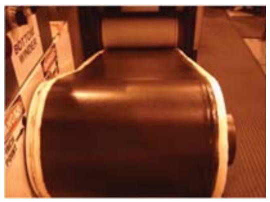
Ablative TPS Design - Nanocomposites Approach



TPS Materials Design



Bi-layer thermal protective coating


Nanocomposite prepreg systems


Nanocomposite thermal protective coating

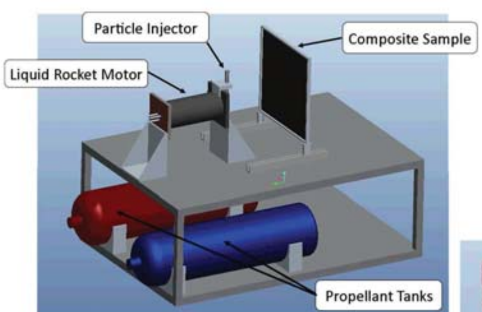
Results - Ablation Testing with Oxyacetylene Torch





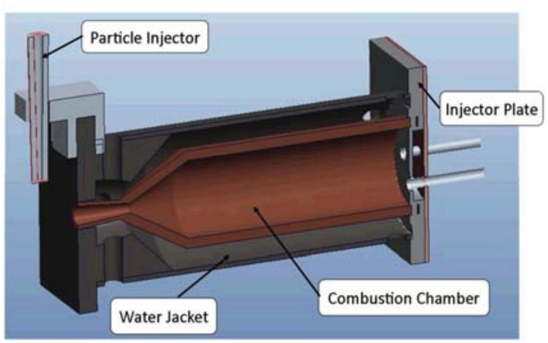
Initial Testing on October 28, 2012 at UCF, Orlando, FL

Results - Ablation Testing with SSRM



Ablation Performance

- Surface Temperature
- Backside Temperature - backside heat soaked temperature
- Ablation rate – peak erosion depth

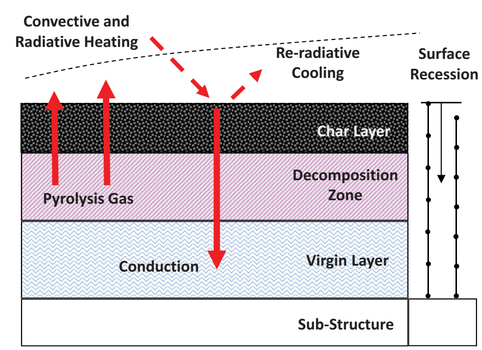


- Simulated Solid Rocket Motor (SSRM) is a small scale, liquid-fueled rocket burning kerosene and oxygen.
- Heat flux of 700 W/cm^2 at 1 inch from the nozzle
- Support sample size of 12"x12"
- Minimum burning time of 10 seconds
- Particle injection mass flow rate of ~ 20 lb/hr
- High exhaust velocity

Results - Ablation Modeling

1-D Material Model

- Acknowledges two material states: virgin and charred
- A mixture law used to interpolate intermediate states



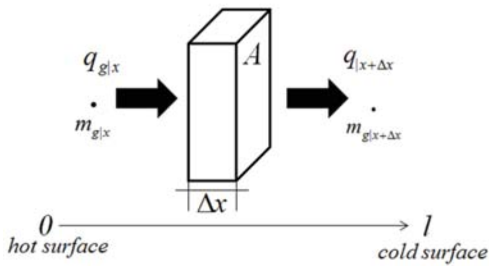
The developed material response code predicts the 1-D thermal distribution, material decomposition, pyrolysis gas generation and the resulting surface recession rate from heat flux and surface temperature values calculated by the commercial solver.

Results - Ablation Modeling (Cont'd)

Assume there is no volume change and enthalpy is a function of temperature only. The governing equation of the decomposition of PMC can be written as:

$$\frac{\partial}{\partial t}(\phi.\rho_g h_g + \rho h) = \frac{\partial}{\partial x}[k_g \phi \frac{\partial T}{\partial x} + k(1-\phi)\frac{\partial T}{\partial x}] - \frac{\partial}{\partial x}(\dot{m}_g h_g) - Q\frac{\partial \rho}{\partial t}$$

- Change in the total energy
- Conduction heat flux
- Endothermic decomposition
- Convection of energy resulting from the gaseous products flowing through the char structure



Results - Ablation Modeling (Cont'd)

Conservation of mass: $\frac{\partial \dot{m}_g}{\partial x} + \phi \frac{\partial \rho_g}{\partial t} = -\frac{\partial \rho}{\partial t}$

- Gas flowing out
- Residual Char
- Mass change of the composites

Gas flow(Darcy's Law): $\dot{m}_g = -\frac{r\rho_g}{\mu}\frac{\partial P}{\partial x}$ $P = \frac{\rho_g RT}{M}$

Decomposition follows Arrhenius reaction:

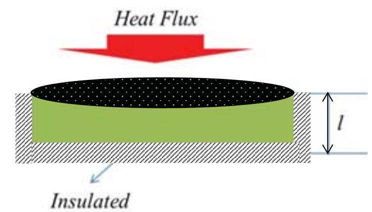
$$\frac{\partial m}{\partial t} = -Am_v[(m-m_e)/m_v]^n \exp(E_a/RT)$$

Boundary conditions:

$$k_g \phi \frac{\partial T}{\partial x} + k(1-\phi)\frac{\partial T}{\partial x} = 0 \quad \dot{m}_g = 0$$

Initial conditions:

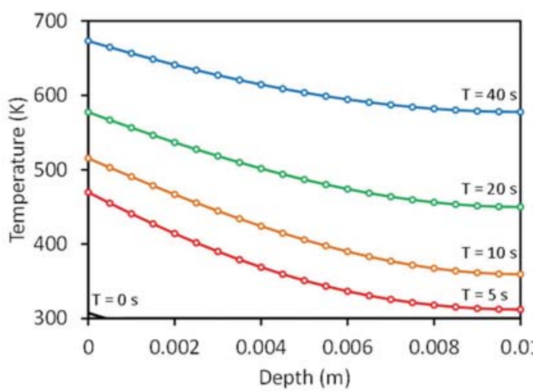
$\rho_g=0$, $T=T_0$, $\dot{m}_g=0$, $\rho=\rho_0$ for $0 \le x \le l$ at $t=0$



Results - Ablation Modeling (Temperature Profile)

T_0 = 300 K
q" = 750 kW/m^2
L = 0.01 m
ρ = 8000 kg/m^3
α = 2.5x10-6 m^2/s

T	k, (W/m-K)	Cv, (J/kg-K)
300	10	500
1300	100	5000

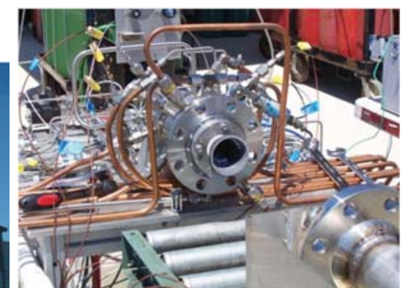


In-depth decomposition ablation model can be coupled to a commercial CFD package to predict the 1-D response for any desired geometry where ablative TPS is applicable.

Collaboration with Dynetics, Inc.

Rocket Nozzle Testing

Kickoff meeting with Dynetics, Inc. at Solutions Complex on October 29, 2012 in Huntsville, AL



Collaboration with AAE Aerospace
Rocket Nozzle Manufacturing

Tape Wrapped Steel Mandrels

Next Steps

- Integration of nanocomposite thermal protective coating with PICA
- Oxyacetylene torch testing of composite panels
- Simulated solid rocket motor (SSRM) hot fire test
- Aerothermal analysis of TPS structures with curved geometry
- Thermo-mechanical characterization and testing for structural integrity evaluation

Contact Information

Dr. Jan Gou
Department of Mechanical and Aerospace Engineering
University of Central Florida
Orlando, FL 32816
Email: jihua.gou@ucf.edu
Phone: (407) 823-2155

COE CST Second Annual Technical Meeting:

Wearable Biomedical Monitoring Equipment for Spaceflight Participants on Suborbital & Orbital Flights

Richard T. Jennings, MD

utmb Health
Aerospace Medicine

November 1, 2012

Overview

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

Team Members

- Jon Clark, MD Baylor Center for Space Medicine
- Duane Chin, Christine Smith, Kate Kubicek, and Jack Rasbury, Wyle
- Sharmi Watkins, MD, USRA/NASA
- Anil Menon,MD, Jennifer Law, MD, Rebecca Blue, MD, and James Pattarini, MD (Residents)
- Wes Persall, Virgin Galactic and Brienna Henwood, NASTAR, ad hoc
- Jim Vanderploeg, MD, UTMB (Co-PI)

Objectives

- Enable human physiological data to be collected for operational, medical or research interests
- Identify and determine appropriate design assumptions and operational constraints
- Test prototype monitoring equipment that integrates into a wearable garments, harnesses, or flight suits to support monitoring by flight surgeons, operators, or scientists

Objectives

- Assure that hardware is compatible for multiple operational and environmental parameters
- Avoid setting monitoring requirements or regulatory monitoring requirements for operators

Research Methodology

- Comprehensive survey of existing wearable biomedical monitoring equipment to determine availability of off-the-shelf hardware. Leverage previous NASA work.
- Survey flight surgeons, scientists, and space vehicle operators to seek input on the features and capabilities needed from biomedical monitoring.
- Compare capabilities of existing hardware and software with the needs and desires of the operational and research community to identify gaps.

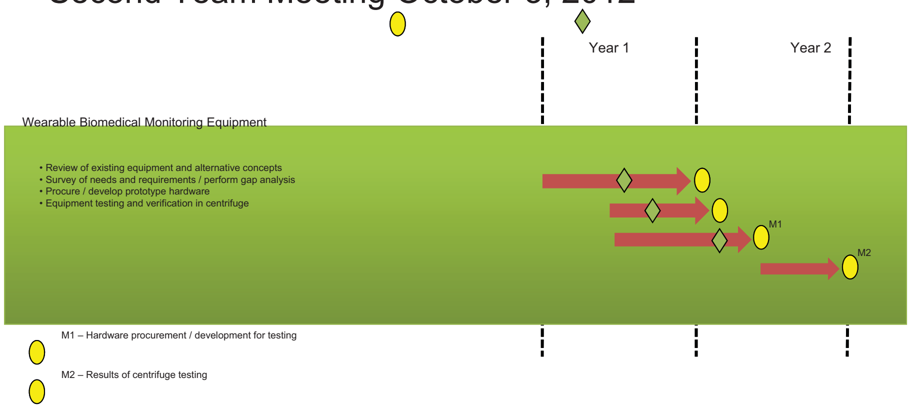
Research Methodology

- Using gap analysis, identify technologies needed to fill gaps and explore which existing technologies can be repackaged and incorporated into a wearable system.
- Prototype hardware configurations will be purchased and tested under expected G profiles in various operator's launch/landing systems using the NASTAR Center.
- Test hardware when opportunities arise in environments such as altitude chambers and zero-g flights

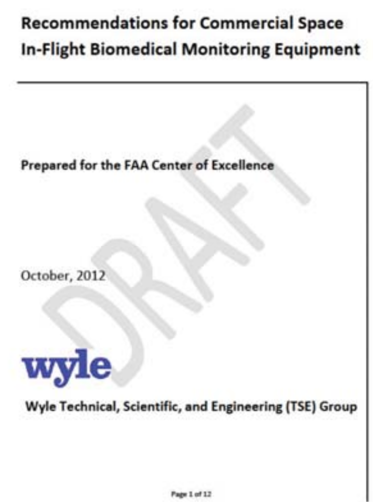
" I see that you've been to NASTAR."

Results and Schedule

- Initial Team Meeting April 27, 2011
- Market Survey Completed(NASA Partnership)
- Draft Recommendations Document Completed
- Second Team Meeting October 3, 2012



Draft Document Finalized



Recommendations for Commercial Space
In-Flight Biomedical Monitoring Equipment

Prepared for the FAA Center of Excellence

October, 2012

DRAFT

wyle

Wyle Technical, Scientific, and Engineering (TSE) Group

Page 1 of 12

Operational Monitoring Capability

#	Capability	Design Criteria
M1	ECG/Heart Rate	• One lead • Range: 0 to 240 beats per minute • Accuracy: +/- 10 % / 5 beats per minute • Non-wet prep electrodes preferred • Continuous data collection
M2	Respiratory Rate	• Range: 5 to 50 breaths per minute • Accuracy: +/- 1 breath per minute • Continuous data collection
M3	Blood Oxygen (SpO2)	• Range: 70 to 100 % • Accuracy: +/- 4 % • Fingertip, earlobe, toes, or forehead • Continuous data collection
M4	Blood Pressure	• Range: 10 to 300 mmHg • Accuracy: +/- 5 % • Continuous data collection
M5	Acceleration	• Range: 0 to 7 G • Accuracy: +/-0.1 G/second • Multi-axis • Head/body acceleration matched to vehicle • Time/event matched (e.g. launch) • Synched with physiological data

Enhanced Monitoring Capability

#	Capability	Design Criteria
R1	ECG	• 12 leads • Range: 0 to 250 beats per minute • Accuracy: +/- 10 % / 5 beats per minute
R2	EtCO2	• Range: 0 to 99 mmHg • Accuracy: +/- 2 mmHg / 6 % • Microphone mounted?
R3	Anxiety	• Eye movements and dilation • Galvanic skin resistance
R4	Blood Sugar	• Range: 20 to 500 mg/dL • Accuracy: +/- 20 %
R5	Core Temperature	• Range: 25 to 45 degrees Celsius • Accuracy: +/- 0.1 degrees
R6	EEG	• Helmet monitoring • IR spectroscopy a consideration • EEG durability for centrifuge • Data transmission with monitoring
R7	Thoracic Bioimpedance	• Cardiac output •
R8	Intracranial Pressure (ICP)	• Difficult with LP requirements • Consider less invasive monitoring such as optic nerve ultrasound
R9	Neuro-vestibular	• Camera on the passenger • Eye motion • Video recording • Kinetic post flight monitoring

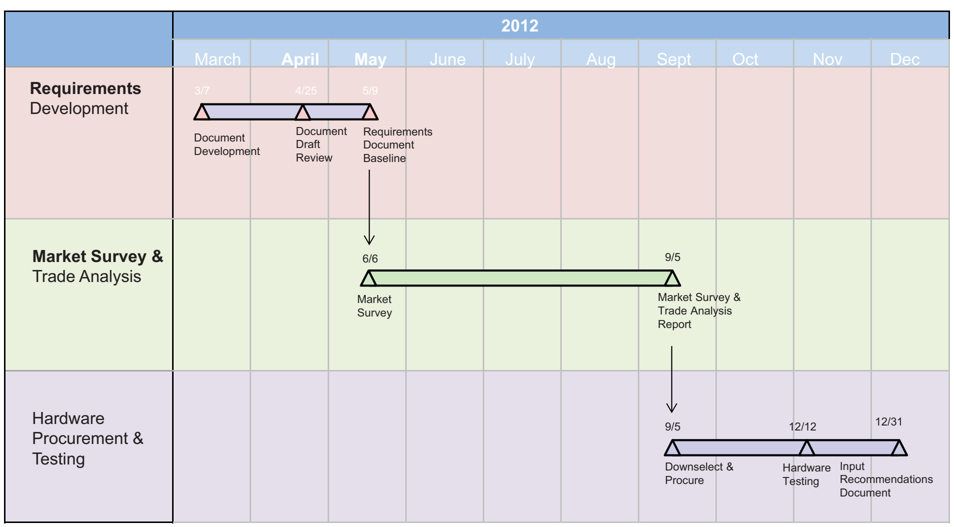
Market Survey Categories

- Multi-parameter
- Respiration
- ECG
- Acceleration
- Blood Pressure
- SPO2

Market Survey Multi-parameter

Device	Manufacturer
Autogenic feedback system	NASA ARC
Equivital EQ02	Hidalgo
VisiMobile	Sotera
Lifeguard (CPOD)	Astrobionics
MW1000A	Mindware Technologies LTD
EQ01-1250	bio-lynx
LINK Armband	BodyMedia
Minitor AR7000	Atlas Researches Ltd.
Wireless Physiological monitor	Biocontrol
ProPaq LT	Welch Allyn
Mini-Medic	Athena GTX
WVSM	Athena GTX
VitaGuard	getemed
ApexPro	GE Medical
MobileMe	Biosentient Corporation
MicroPaq	Welch Allyn
Watch_PAT200	Itamar
BioRadio 150	Cleveland Medical Devices
SmartShirt	Sensatex
g.MOBIlab	Guger Technologies
NeXus-10 MKII	Mind Media
HealthVest	SmartLife Technologies
Spot Vital Signs LXi	Welch Allyn

Biomedical Monitoring Schedule



What We Have To Date

- Assumptions
- Market Survey
- Draft Recommendations Document
- Procuring Hardware
  - Equivital EQ02 by Hildalgo
  - ViSi Mobile by Sotera
- Initial Centrifuge Testing Scheduled December, 2012

Conclusions and Future Work

- Distribute draft recommendations document for review
- Determine best fit hardware during centrifuge studies
- Finalize recommendations document

Future

- Test in other analog environments (eg zero-g or altitude chamber)
- Compare flight data to analog environment data
- Peer-reviewed publications and presentations

Contact Information

• Richard Jennings
University of Texas Medical Branch
301 University Blvd
Galveston, TX 77555-1110
409-747-6131
rjenning@utmb.edu

COE CST Second Annual Technical Meeting:

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

James Vanderploeg, MD

utmb Health Aerospace Medicine

November 1, 2012

Federal Aviation Administration

Overview

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

Team Members

- PI: Jim Vanderploeg, MD (UTMB Aerospace Med.)
- Co-I: Richard Jennings, MD (UTMB Aerospace Med)
- Student: Becky Blue, MD (UTMB Aerospace Med.)
- Student: James Pattarini, MD (UTMB Aerosp. Med.)
- Student: David Reyes, MD (UTMB Aerosp. Med.)
- Brienna Henwood (NASTAR Center)
- Christine Smith (Wyle Laboratories)

Students at NASTAR

NASTAR Center

Purpose of Task

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

Objectives

- Train & evaluate test subjects with a range of medical conditions to characterize their responses to the acceleration environment
- Evaluate biomedical monitoring equipment under the G profiles of commercial space flights
- Develop optimal acceleration training protocols for passengers

Goals

- Expected benefits from this project:
  - Characterization of responses of individuals with several common medical conditions
  - Development of risk mitigation strategies for individuals with those medical conditions
  - Validation of wearable biomedical monitoring equipment for use during commercial space flights.

Completed Milestones

- Completed IRB approval
- Developed online screening medical questionnaire
- Defined medical monitoring protocol
- Secured agreement from Virgin Galactic and XCOR to solicit volunteers for study from their customer lists
- Initiated subject recruitment

Next Steps

- Continue subject recruitment and medical clearance
- Conduct training and evaluation using the NASTAR centrifuge
- Evaluate biomedical monitoring equipment from task 255
- Perform data analysis
- Publish results
- Obtain no-cost extension from FAA AST

Contact Information

- Jim Vanderploeg, MD, MPH
  2.102 Ewing Hall, UTMB
  301 University Blvd.
  Galveston, Texas 77555-1110
  Phone: 1-409-747-6131
  Fax: 1-409-747-6129
  Email: jmvander@utmb.edu

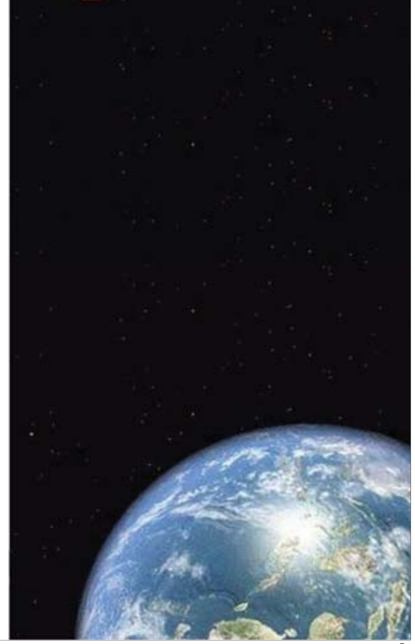
COE CST Second Annual Technical Meeting:

Commercial Spaceflight Operations Curriculum Development

Task 257: Masters' Ops Lab
George H. Born

31 October 2012

Federal Aviation Administration



Overview

- Team Members
- Purpose of Task
- Development Process
- Results
- Next Steps
- Contact Information

Team Members

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

Partnering Organizations

LASP – Laboratory for Atmospheric and Space Physics, University of Colorado at Boulder
arianespace – service & solutions
SPACEX
Orbital
agi – Analysis software for land, sea, air, & space
SNC – Sierra Nevada Corporation – Space Systems
NASA
ULA – United Launch Alliance
Virgin Galactic
Space Foundation
Lockheed Martin
ClearChannel Satellite
JPL – Jet Propulsion Laboratory, California Institute of Technology
Department of the Air Force
Bigelow Aerospace
SwRI
SAS
GeoEye
DigitalGlobe
Aerospace Concepts – Integrated Aviation Solutions
Altius Space Machines

Purpose of 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.

Purpose of Task - Objectives

- Bridge theory and application in the educational process
- Foster and facilitate collaboration between academia and the commercial space industry
- Provide a venue for dialogue and research into operational improvement for the space industry

Purpose of Task - Objectives

- Students should gain:
  - A comprehension of the mission lifetime
  - An understanding of constraints
  - Insight into and understanding of industry practices
  - An overview of project management and team dynamics
  - An understanding of risk

Purpose of Task - Goals

- Develop a one-semester lecture course
- Build an on-campus mission operations lab
- Develop a one-semester lab course
- Refine content based on student and industry feedback
- Standardize and establish a Graduate Certificate
- Increase collaboration between academia and industry

Development Process

- Draft academic objectives and lecture schedule
- Solicit feedback from industry
- Iterate to refine course outline
- First offering of lecture course (fall)
- Collect lessons learned and student feedback
- Refine lecture curriculum
- Second offering of lecture course (fall)

Development Process

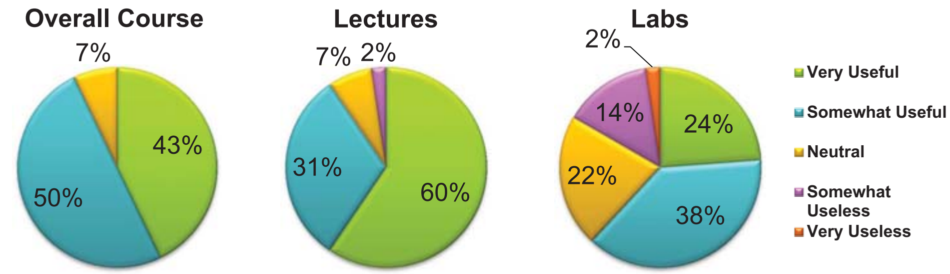
- Consult with industry to build on-campus missions operations center
  - Acquire funding
  - Acquire hardware and industry-donated software
- Develop student labs
- First offering of lab course (spring)
- Collect lessons learned and student feedback
- Refine lab curriculum

Results

- Lecture course curriculum
  - 5 main subject areas
    1. Background
    2. Launch Operations
    3. On-Orbit Operations
    4. End-of-Mission
    5. Mission Planning
  - Assignments: discussion boards, mini research assignments, labs, final research project

Results

- Commercial Spaceflight Operations Lecture
  - Fall 2011: 28 students (19 in-class, 9 distance)
  - Spring 2012: 20 students
  - >20 organizations participating as guest lectures



Results

- Student feedback:
  - *"I really enjoy this course. It is information that every aerospace engineer should know."*
  - *"Guest lecturers…provide an outside-of-academia view, one that I believe is a more practical and real-world view. It's something that's traditionally not provided [in school]."*
  - *"I like the way that the course has been organized as well. It is not an easy thing to coordinate all the guest speakers in an order that makes sense for teaching a class, but on the whole I think that this class has been successful in doing just that."*

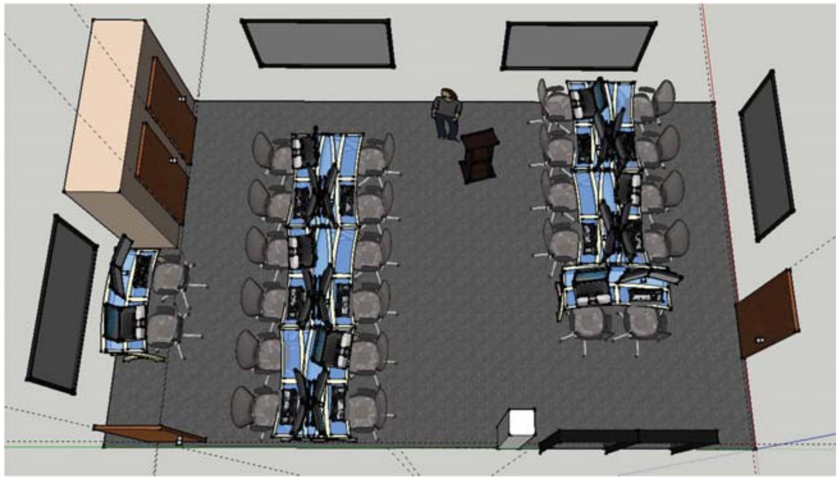
What We Have To Date

- Commercial Spaceflight Operations Lecture (Fall 2012)
  - 20 students enrolled
  - Guest lecturers include:
    - Lori Garver (NASA Headquarters)
    - Bretton Alexander (Blue Origin)
    - Bobby Braun (Georgia Tech)
    - Alan Stern (SwRI)

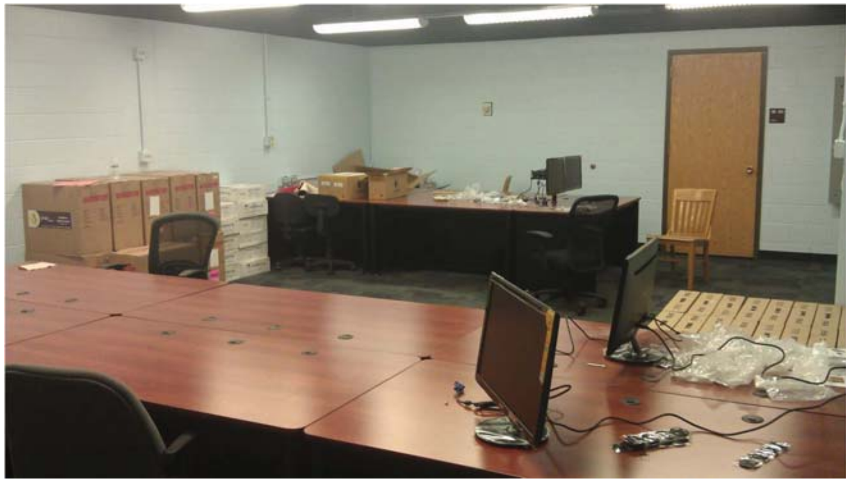
What We Have To Date

- Mission Operations Center
  - Room and hardware procured
  - Software down-select in progress
- Student lab research and development
  - Launch
  - On-Orbit (2)
  - Re-Entry
  - Suborbital

What We Have To Date



What We Have To Date



Conclusions

- Spaceflight operations is an area with great potential for academic involvement
  - Considered to be of great value to industry
  - Not well covered in established academic curriculum
- Comops lecture course has been successful in beginning to address this need
  - Extensive industry involvement
  - Expressed interest by students

Future Work

- Complete development of operations center and lab course
- Continue offering alternating semesters of the lecture and lab
- Develop Graduate Certificate in Spaceflight Operations

Next Steps

- Commercial Spaceflight Operations Lab (Spring 2012)
  - Complete setup of Mission Operations Center
  - Develop student labs (launch, on-orbit, reentry, and suborbital operations)
- Collect feedback from students to refine lab

Contact Information

George H. Born
George.Born@Colorado.edu

Bradley Cheetham
Bradley.Cheetham@Colorado.edu

Juliana Feldhacker
Juliana.Feldhacker@Colorado.edu

Task 258: Analysis Environment for Safety of Launch and Re-Entry Vehicles

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

FAA COE for CST Technical Meeting

October 31, 2012

Overview

- Team Members
- Purpose of Task
- Research Methodology
- 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

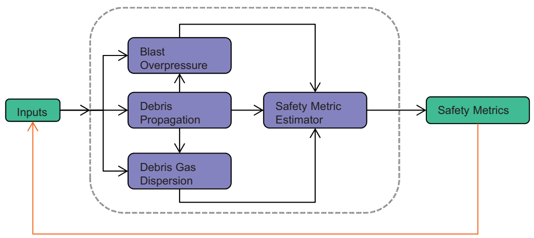
- To provide the FAA and the community with an independent safety analysis capability for launch and re-entry vehicles that is based on tools of the necessary fidelity.
- To develop and establish quantitative safety metrics appropriate for commercial space transportation.
- To validate the resulting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

Research Methodology

- Currently the FAA uses procedures and tools to assess the safety of future commercial launch and re-entry vehicles that are mostly based on ELV 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 considerations may include:
  - Human rating.
  - Acceptable probability of failure.
  - How to account for safety risks not associated with component, sub-system, and system failure (unknown unknowns).
  - Safety assessment modeling is nondeterministic.

Current Approach

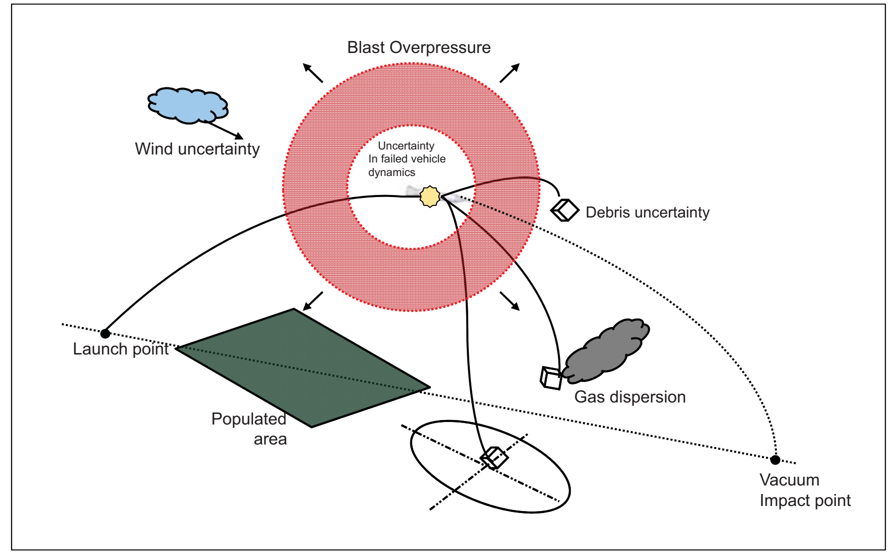
- Main focus is on safety on the ground (expected casualty measures).
- Long term goal is to look at the different licensed activities
  - ELV
  - Suborbital
  - RLV
- Develop safety metrics.



Inverse Problem

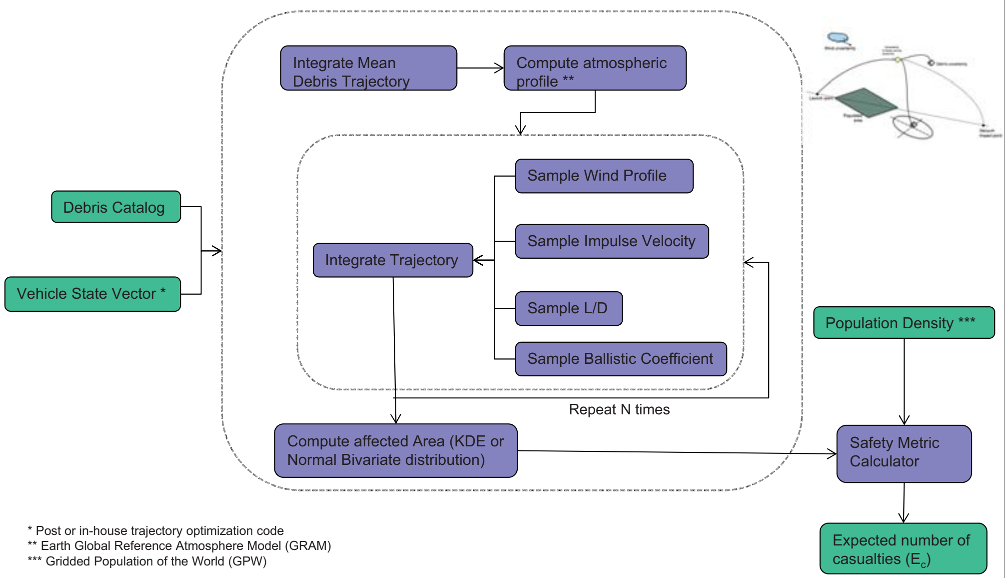
- We are in the process of understanding the input parameter combinations that lead to worst case scenarios (tails of distribution).
- Results obtained by solving the reverse problem could be used to inform licensing restrictions, or influence design

Current Approach



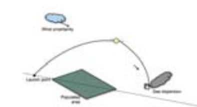
Safety Analysis Environment Schematic

Analysis Environment: Debris Propagation

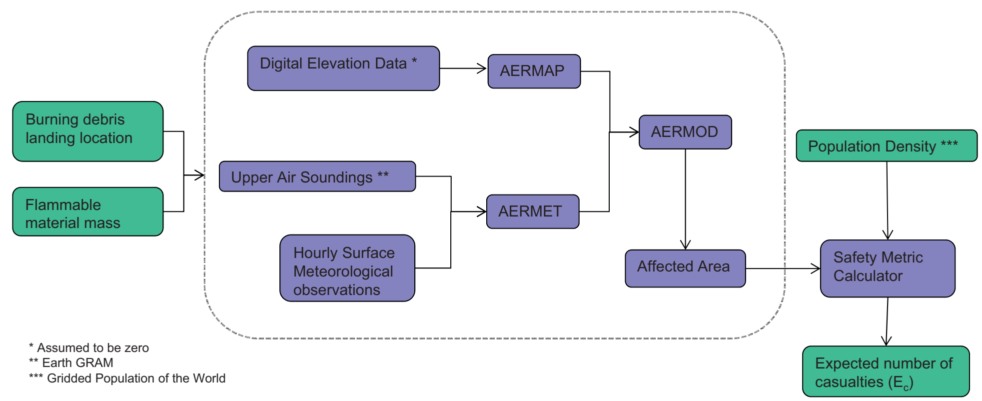


* Post or in-house trajectory optimization code
** Earth Global Reference Atmosphere Model (GRAM)
*** Gridded Population of the World (GPW)

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.

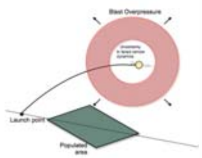


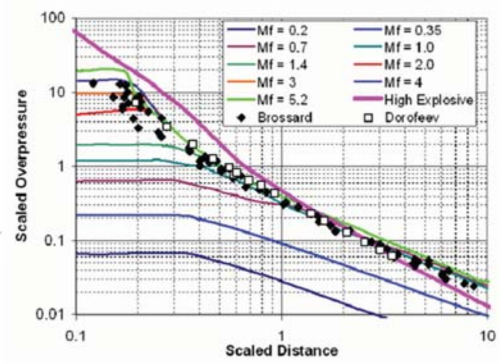
* Assumed to be zero
** Earth GRAM
*** Gridded Population of the World

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.

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





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

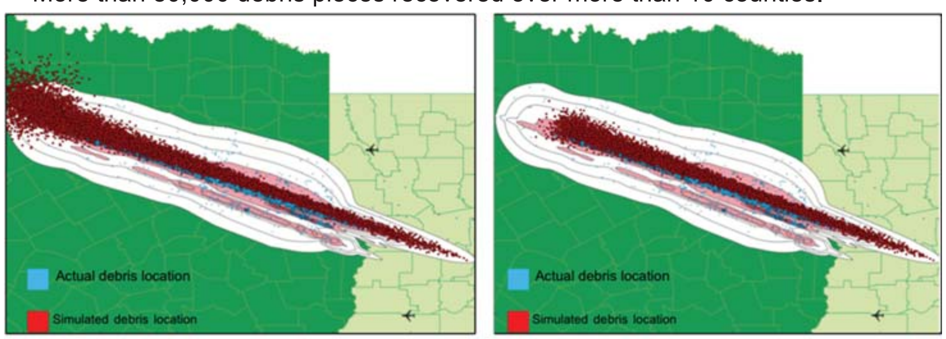
Blast Overpressure Modeling Enhancements for Application to Risk Informed Design of Human Space Flight Launch Abort Systems. Scott Lawrence, and Donovan Mathias

Validation Test Cases

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

Columbia Accident Simulations

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



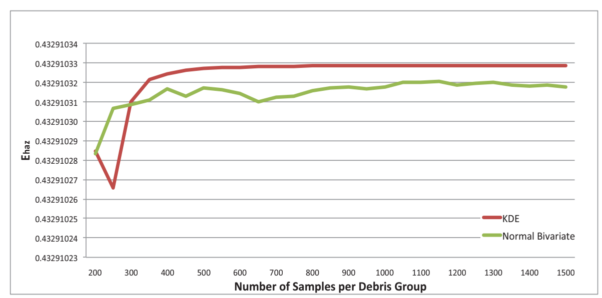
All simulated pieces

Lethal simulated debris pieces

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

Columbia Accident Simulations

- E_{haz} covers cases of impacts without injury, non-fatal injury, and fatal injury.
- Atmospheric profile from Earth GRAM (NASA Global Reference Atmospheric Model).
- No sheltering.



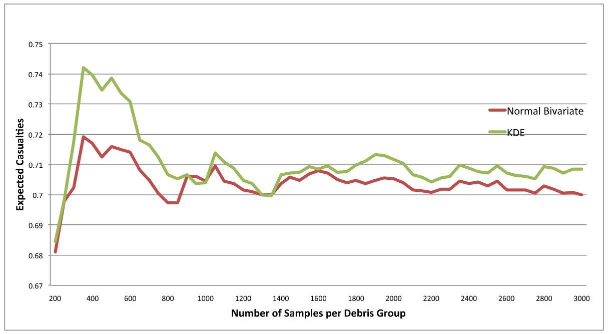
E_{haz} convergence for a constant population of 85 people/nm^2

	Percentage of Total Orbiter and Payload Weight survived	E_{haz}
CAIB Report*	38%	.41
Simulation	38%	.43

*Results from Columbia Accident Investigation Board. Ground wind 10 ft/s and a population density of 85 people/per square nautical mile

Columbia Accident Simulations

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



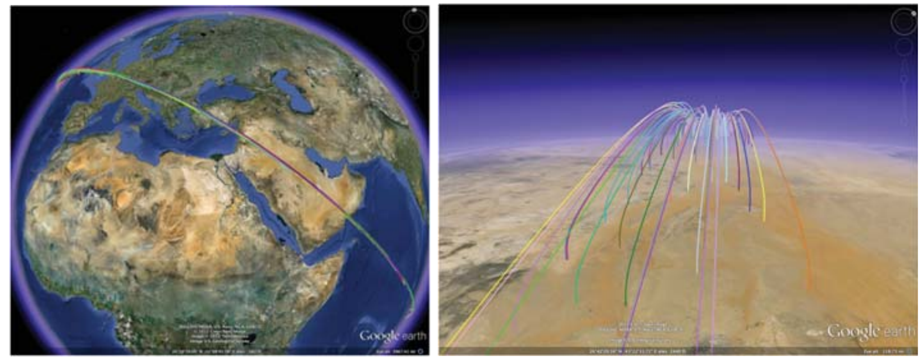
Casualty Expectation Convergence

	% People in the open	E_c
CAIB Report*	30	0.21
Simulation	100	0.71

*Results from Columbia Accident Investigation Board

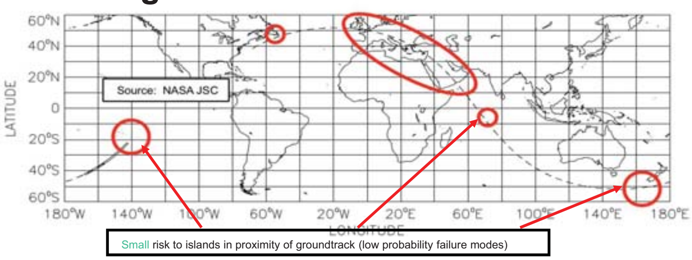
STS-111Over-Flight of Eurasia Simulations

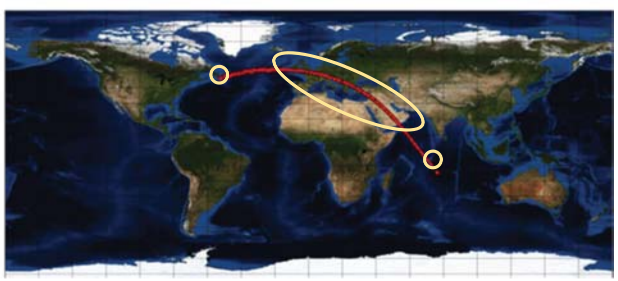
- Stage II, on trajectory, orbiter failures.
- Reentry breakup altitude ~ 250,000 ft.
- Failure times 490-500 seconds.
- Orbiter debris catalog from Columbia accident.
- 3-sigma trajectories provided by Paul Wilde.



Simulated Debris Trajectories

STS-111Over-Flight of Eurasia Simulations





Simulated Debris Impact Location

STS-111Over-Flight of Eurasia Simulations

- 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.

STS-111Over-Flight of Eurasia Simulations

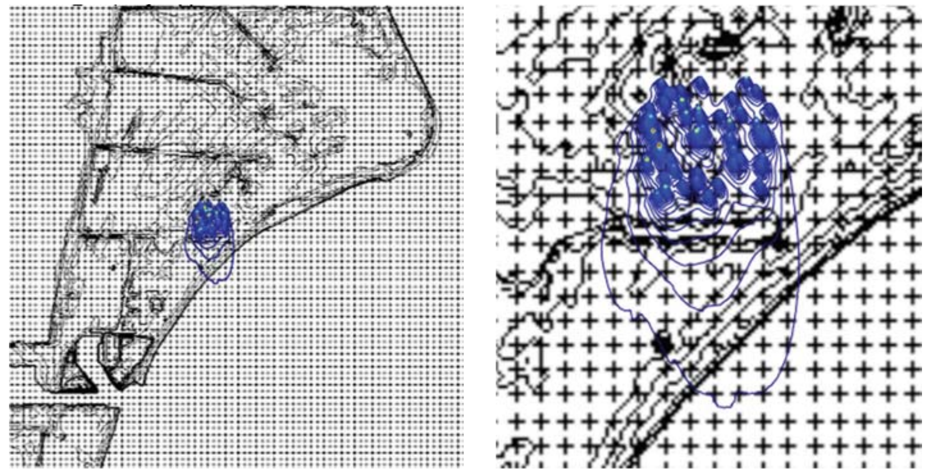
Time (sec)	Ec Mean	Lower Bound (99% confidence)	Upper Bound (99% confidence)
493	8.7826e-13	2.3759e-13	1.9933e-12
494	3.7907e-9	3.0509e-9	4.6156e-9
495	7.3525e-7	6.1156e-7	8.6083e-7
496	8.0740e-6	7.7570e-6	8.3725e-6
497	8.5043e-6	8.0616e-6	8.9514e-6
498	5.9722e-6	5.6483e-6	6.3338e-6
499	7.3254e-7	7.0098e-7	7.6073e-7

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.

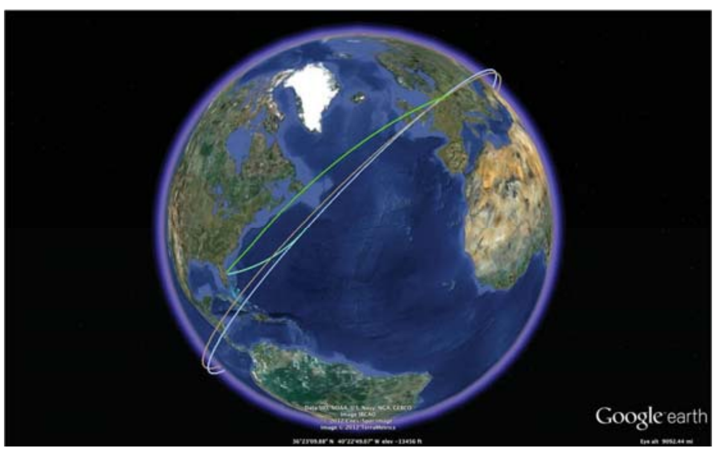
Gas Dispersion Simulation

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



Trajectory Optimization

- 3 DOF trajectory optimization tool based on pseudospectral collocation methods (SU STOP)
- Initial development done in MATLAB, but currently transitioning to PYTHON + FORTRAN



Falcon 9 type launch vehicle trajectory to ISS orbit

Conclusions and Future Work

Conclusions

- A debris propagation tool has been implemented, and successfully automated to generate thousands of Monte Carlo evaluations.
- Kernel density estimation successfully implemented for calculating non-parametric probability density functions.
- Debris propagation tool is capable of using different debris catalog depending on time and/or distance travelled.
- Safety metric estimator coupled with debris propagation tool.
- Gas dispersion and blast overpressure model have been included.
- In-house trajectory optimization code (STOP) can provide initial trajectories for safety assessment.

Future work

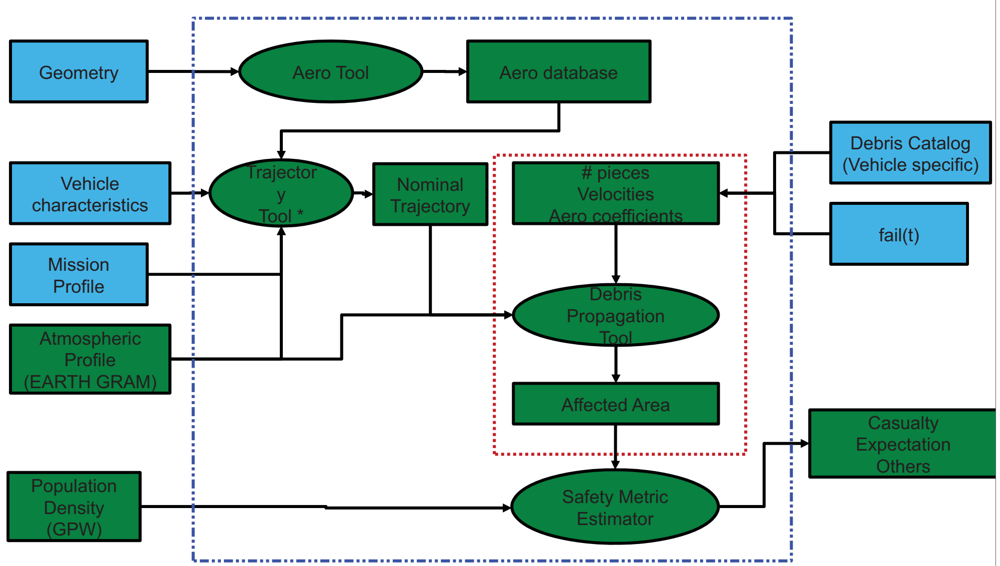
- Add malfunction turns to the simulation.
- Add sheltering models to the Ec calculation.
- Further investigate how input uncertainties affect Ec calculations.
- Further validate the modeling tools.
- Fully integrate all the pieces for the analysis environment.
- Identify parameters of interest to solve the inverse problem.

Contact Information

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

Backup Slides

Debris Modeling



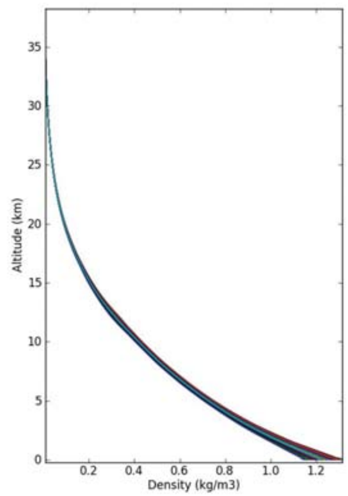
* Access to POST or Stanford Trajectory Optimization Program (STOP)

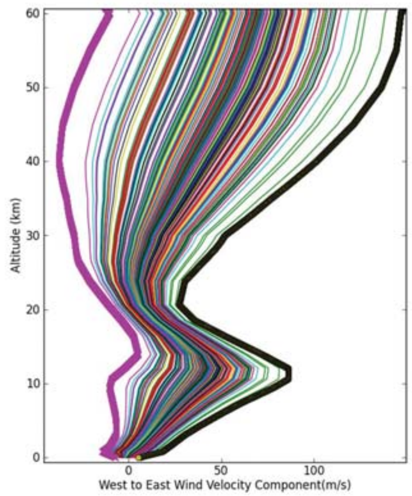
Debris Modeling

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

Debris Propagation

Uncertainty in atmospheric parameters



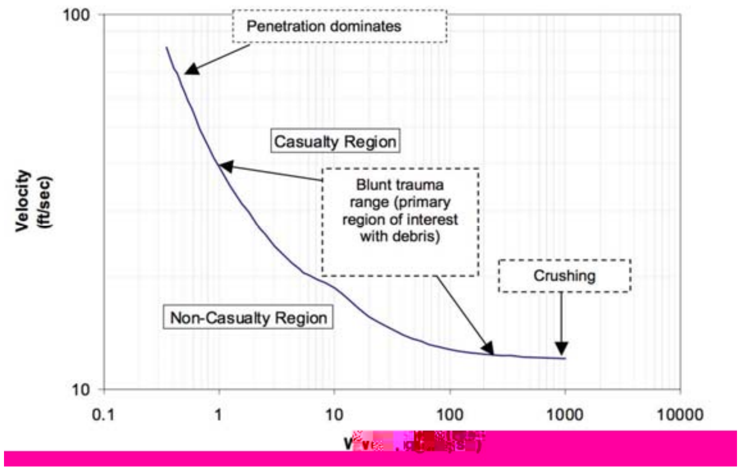


Ec Calculation

- The following assumptions/considerations were made in the Expected Casualty (safety metric) calculation:
  - No sheltering.
  - 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

Technical Approach

Risk area debris formulation

$$X_i = [Latitude_i, Longitude_i]^T$$

Normal Bivariate	Kernel Density
$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$ $S = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})(X_i - \bar{X})^T$ $\hat{f}(x) = \frac{1}{2\pi\sqrt{det(S)}} e^{\frac{1}{2}(x-\bar{X})^T S^{-1}(x-\bar{X})}$	$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} X_i$ $S = \frac{1}{n-1}\sum_{i=1}^{n}(X_i - \bar{X})(X_i - \bar{X})^T$ $\begin{bmatrix} S_1 & 0 \\ 0 & S_2 \end{bmatrix} = U^{-1} S U$ 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.

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*

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

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

Task 259: Flight Software Validation & Verification for Safety

Juan J. Alonso
Department of Aeronautics and Astronautics
Stanford University

FAA COE for CST Technical Meeting

October 31, 2012

Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results / Progress to Date
- Conclusions / Future Work

Team Members

- PI: Juan J. Alonso, Aero & Astro, SU
- Program Manager: Ken Davidian

Purpose of Task/Goals

- The purpose of this task is to hold a workshop, following the roadmapping exercise, to better understand research issues in flight software V&V the FAA CoE CST might tackle in the future
- Outcome: as a result of the workshop we would like to have
  - Broad consensus from relevant participants on requirements for flight software V&V
  - Key bottlenecks and research areas in this topic
  - A document detailing the conclusions of the group

Workshop Preparations

- Over the past 6-8 months, we have been contacting a broad group of players that might participate in the workshop.
- Open to suggestions for additional participants (please email me at jjalonso@stanford.edu)
- 2-day workshop date has been tentatively set for March 20-21, 2013 in Stanford, CA. Location can change to minimize travel impact and encourage FAA participation
- Save-the-date email will be sent by end of November, 2012

Entities Contacted / Consulted

Could use some help with contacts at additional universities/companies

Conclusions and Future Work

- Must finalize list of invitees/participants. Input sought.
- Preparations for workshop ongoing.
- Suggestions for locations other than Stanford, CA, welcome.

Contact Information

- Juan J. Alonso   jjalonso@stanford.edu

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Federal Aviation Administration

COE CST Second Annual Technical Meeting: Non-Linear Structural Models

Dr. Keith Miller
Mr. Joshua Mendoza

Oct-31-2012

Overview

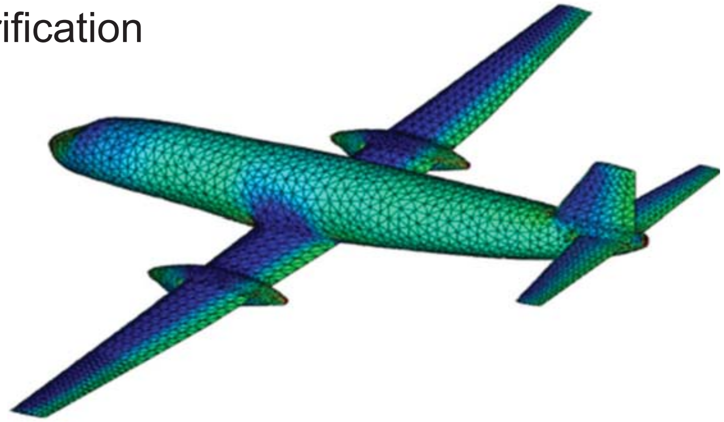
- Program Goal
- Large System Models
- Program Plan
- Numerical Experimentation
- Modal Testing
- FEA and Physical Test Data

Program Goal

- **The objective is to develop computational tools that improve the capability of estimating the performance and safety margins of commercial space vehicles. The focus is to be able to construct non-linear system level models. The models will be derived from reduced order non-linear finite element models and also directly from structural test data.**

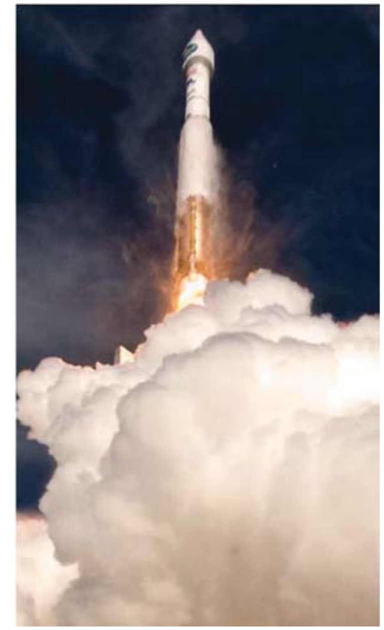
Large System Models

- Computationally Intensive
- Time Intensive
- Model Verification



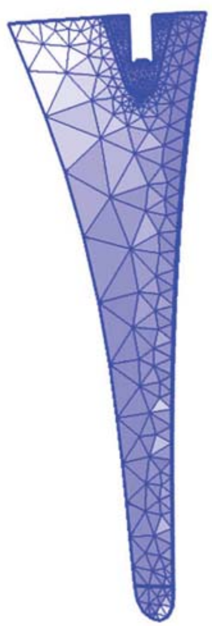
Program Plan

- Numerical Experimentation
- Modal Testing
- FEA Implementing Physical Test Data



Numerical Experimentation

- FE Model Basic Concepts
- Eigenvector Extraction
- Matrix Manipulation
- Model Assembly and Analysis
- Code Analysis



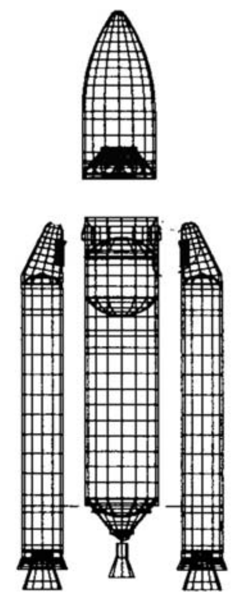
System Substructuring

$$[M_1]*\{\ddot{x}_1\} + [C_1]*\{\dot{x}_1\} + [K_1]*\{x_1\} = \{F_1(t)\}$$

$$[M_2]*\{\ddot{x}_2\} + [C_2]*\{\dot{x}_2\} + [K_2]*\{x_2\} = \{F_2(t)\}$$

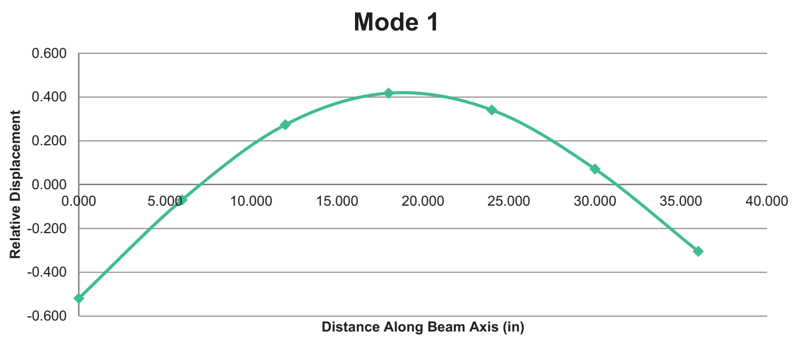
$$[M_3]*\{\ddot{x}_3\} + [C_3]*\{\dot{x}_3\} + [K_3]*\{x_3\} = \{F_3(t)\}$$

$$[M_4]*\{\ddot{x}_4\} + [C_4]*\{\dot{x}_4\} + [K_4]*\{x_4\} = \{F_4(t)\}$$



Images from presentation given by Dr. Keith Miller

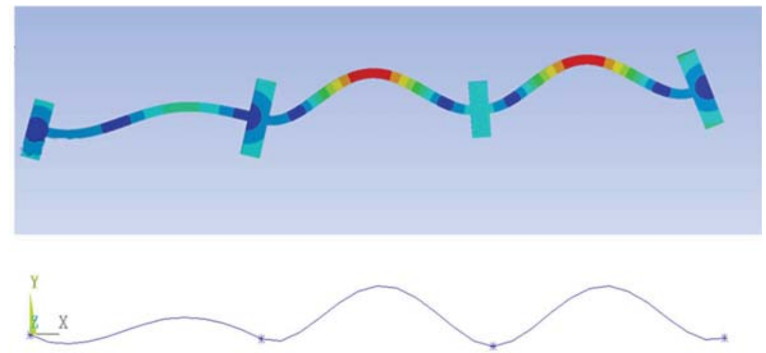
Eigenvector Extraction



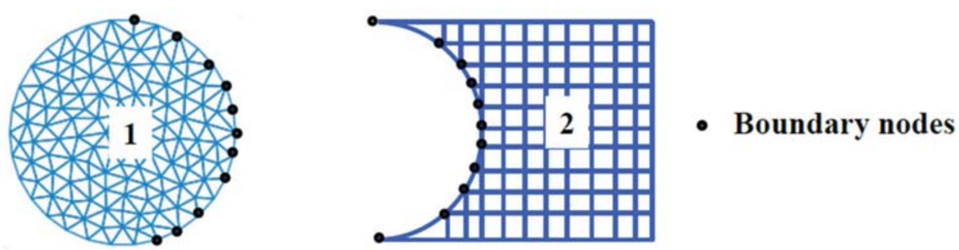
Eigenvectors

Displacements	X	Y	Z	Rot X	Rot Y	Rot Z
Node 1	0.000	-0.519	0.000	0.000	0.000	3.062
Node 2	0.000	-0.070	0.000	0.000	0.000	2.719
Node 3	0.000	0.274	0.000	0.000	0.000	1.669
Node 4	0.000	0.418	0.000	0.000	0.000	0.215
Node 5	0.000	0.341	0.000	0.000	0.000	-1.202
Node 6	0.000	0.071	0.000	0.000	0.000	-2.230
Node 7	0.000	-0.304	0.000	0.000	0.000	-2.592

Model Reduction



Global System Assembly



$$\begin{bmatrix} M_1 & 0 \\ 0 & M_2 \end{bmatrix} \cdot \begin{Bmatrix} \ddot{X}_1 \\ \ddot{X}_2 \end{Bmatrix} + \begin{bmatrix} C_1 & 0 \\ 0 & C_2 \end{bmatrix} \cdot \begin{Bmatrix} \dot{X}_1 \\ \dot{X}_2 \end{Bmatrix} + \begin{bmatrix} K_1 & 0 \\ 0 & K_2 \end{bmatrix} \cdot \begin{Bmatrix} X_1 \\ X_2 \end{Bmatrix} = \begin{Bmatrix} F(t)_1 \\ F(t)_2 \end{Bmatrix}$$

$$\begin{Bmatrix} \ddot{X}_1 \\ \ddot{X}_2 \end{Bmatrix} = [T] \cdot \{\ddot{b}\}$$

nx1

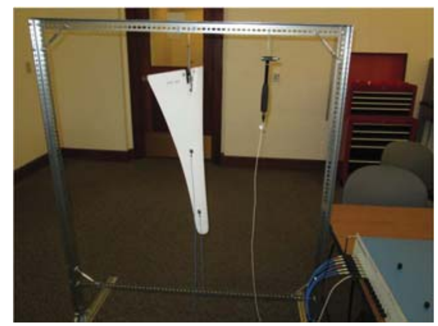
(n-nb)x1

$$[T^T] \cdot [\overline{M}] \cdot [T] \cdot \{\ddot{b}\} + [T^T] \cdot [\overline{C}] \cdot [T] \cdot \{\dot{b}\} + [T^T] \cdot [\overline{K}] \cdot [T] \cdot \{b\} = [T^T] \cdot \{\overline{F(t)}\}$$

$$[M] \cdot \{\ddot{x}\} + [C] \cdot \{\dot{x}\} + [K] \cdot \{x\} = \{F(t)\}$$

Images from presentation given by Dr. Keith Miller

Modal Testing



- Modal Testing Procedures
- Modal Data Gathering
- Frequency Response Function
- Extract Eigenvalues & Eigenvectors

Future Work: Combining FEA and Physical Test Data

- Determine Source of Error in Current FE Models
- Re-Condition Matrices
- Properly Couple Test Data to Model

Federal Aviation Administration

COE CST Second Annual Technical Meeting:

Development of a Minor Injury Severity Scale (MISS) for Orbital Human Spaceflight

Richard T. Jennings, MD

utmb Health
Aerospace Medicine

November 1, 2012

Overview

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

Team Members

- Jonathon Clark, MD Baylor College of Medicine, Center for Space Medicine
- James Vanderploeg, MD, UTMB
- James G. Cushman, MD, UTMB (resident)
- James Gerlach, AST-400 FAA POC
- TBD Additional Partners

Purpose of Task

This proposal responds to an FAA AST request to investigate and develop a Minor Injury Severity Scale (MISS) for Orbital Human Space Flight. Injury severity scoring reduces complex and variable patient data to a single number. This value is intended to accurately represent the injured person's degree of critical illness. The project will conduct the background research and literature review and then develop the MISS for Orbital Space Flight that identifies unacceptable injuries in the course of non-nominal operations.

" Wow! That must have been some landing."

Research Methodology

- Review the medical literature and evaluate existing injury scoring systems that may be useful. Papers to be reviewed include those from the field of space medicine, surgical/trauma care in space, and medical emergencies in spaceflight and analog environments.

Research Methodology

- Identify the rules and assumptions that drive development of the MISS. Ground rules might include the principles:
  - Do no physical harm during nominal/normal operations.
  - Risk may be accepted during non-nominal activities.
  - No permanent injury should be sustained in the performance of the non-nominal activity.
  - Hazards should be mitigated to the extent necessary to prevent permanent injury.
  - No non-nominal operation shall have a life-threatening hazard without a mitigation strategy.

Research Methodology

- The final stage of this research project focuses on defining and developing the Minor Injury Severity Scale and suggesting potential mitigation strategies to optimize the safety of crew members and SFPs.

Results and Deliverables

- Initial findings presented at FAA COE ATM
- A final report that will submitted to the FAA COE CST and AST
- Findings will be submitted for presentation at the annual scientific meeting of the Aerospace Medical Association to be held in May 2014.
- The final report or additional papers may be submitted for publication in *Aviation, Space, and Environmental Medicine*

Summary

- This project is just underway
- Total FAA funding in FY13 is limited to 7K

Contact Information

- Richard Jennings

University of Texas Medical Branch

301 University Blvd

Galveston, TX 77555-1110

409-747-6131

rjenning@utmb.edu

Federal Aviation Administration

COE CST Second Annual Technical Meeting: 295: Effects of EMI and Ionizing Radiation on Implantable Medical Devices

James Vanderploeg, MD

utmb Health Aerospace Medicine

November 1, 2012

Overview

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

Team Members

- PI: Jim Vanderploeg, MD (UTMB Aerospace Med.)
- Co-I: Tarah Castleberry, DO (UTMB Aerospace Med)
- Co-I: Richard Jennings, MD (UTMB Aerospace Med)
- Student: David Reyes, MD (UTMB Aerosp. Med.)
- Melchor Antuñano, MD (FAA CAMI)

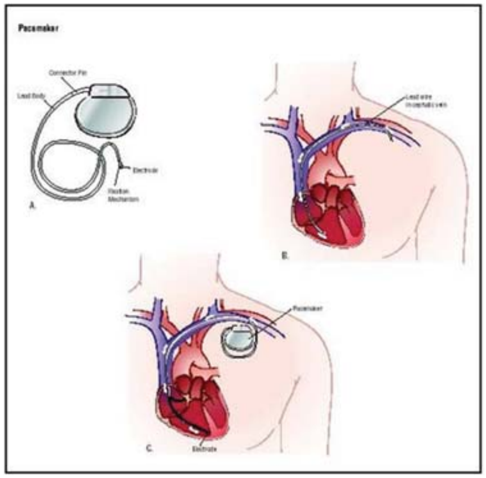
Purpose of Task

- Investigate known effects of electromagnetic interference (EMI) and ionizing radiation environments on the performance of implantable medical devices
- Extrapolate potential impacts on function of implanted medical devices in SFPs flying in spacecraft at suborbital and LEO altitudes

Objectives/Goals

- Characterize EMI and ionizing radiation environment that may impact implanted medical device performance
- Identify known effects of EMI and ionizing radiation on implanted medical devices
- Describe potential adverse impacts on performance of implanted devices
- Suggest mitigating strategies to adverse impacts

Implantable Devices



Research Methodology

- Problem
  - As the commercial market for flying SFPs escalates there very likely will be individuals who wish to fly who have implanted medical devices such as pacemakers, medication pumps, or nerve stimulators.
- Approach
  - Review what is known
  - Extrapolate to space environment
  - Identify mitigation strategies

Results or Schedule/Milestones

- This task is just getting underway with Dr. David Reyes as the student leading the effort

Contact Information

- Jim Vanderploeg, MD, MPH

  2.102 Ewing Hall, UTMB

  301 University Blvd.

  Galveston, Texas 77555-1110

  Phone: 1-409-747-6131

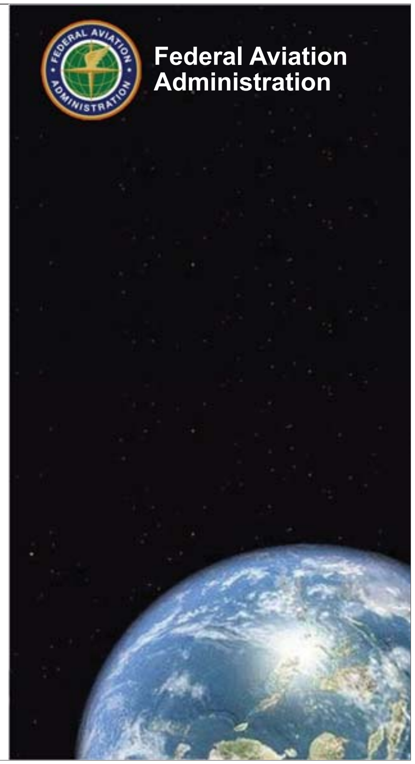
  Fax: 1-409-747-6129

  Email: jmvander@utmb.edu

COE CST Second Annual Technical Meeting: Spaceport Regulation in a Post-modern Pluralistic World

Ram Jakhu, PI
Diane Howard

31 October 2012



Overview

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

Team Members

- Dr. Ram Jakhu, Associate Professor, McGill University, Institute of Air & Space Law
- Diane Howard, McGill University, Arsenault Doctoral Fellow in Space Governance

Purpose of Task

- Purpose: to provide guidance to lawmakers, regulators & stakeholders of spaceports going forward
- Objectives:
  - Describe the current regulations in place in terms of the pluralistic environment in which developing
  - Compare the prevailing systems (US and European)
  - Analyze for points of coherence and inconsistency
  - Make recommendations utilizing techniques found in pluralism scholarship

Purpose of Task cont'd

- Goals
  - to integrate the best parts of the two prevailing systems.
  - Identify emerging norms and procedures for implementing them internationally
    - Fits into FAA's international outreach activities

Research Methodology

- Problem: Why?
  - Extension of Theme 2 of roadmap
  - Suborbital coming online
  - Domestic activity now but probably not forever
  - Interoperability is key to safety which is key to success
  - Legal Aspects (Theme 4 of Roadmap)
    - Regulatory oversight
      - Safety, licensing
      - Liability (space v air regime)

Research Methodology

- So how do I propose to accomplish this?
- Laboratory?

Research Methodology

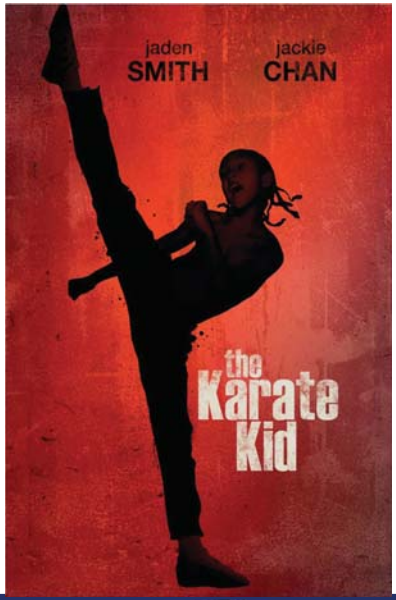
- Task 1
  - Define scope of study, terms, infrastructure
- Task 2
  - Historical examination
    - Laws as they are, how they came to be
- Task 3
  - Comparative exercise
    - Conflicts, gaps, points of connection, possible integration
- Task 4
  - Analysis and recommendations
    - Use tools from pluralism scholarship

Results or Schedule/Milestones

- Tasks 1 – 3 completed
- Task 4 in process
  - Scheduled for completion by end of year

Next Steps

- Complete
- Submit
- Defend



Conclusions and Future Work

Contact Information

- Diane Howard
  diane.howard814@gmail.com

Institute of Air and Space Law

McGill University
Montreal, Canada

http://www.mcgill.ca/iasl/

Professor Dr. Paul Stephen Dempsey
&
Prof. Dr. Ram S. Jakhu

Inner Space: ICAO's New Frontier

- Since the dawn of the space age, most travel has been unidirectional

UP

- Spacecraft didn't make round-trips.

Inner Space: ICAO's New Frontier

- Few conceived of rockets as a form of point-to-point terrestrial travel.
- Nonetheless the Chicago Convention classifies the above as "aircraft" – "Any machine that can derive support in the atmosphere from the reactions of the air other than the reactions of the air against the earth's surface."
- Includes Wright Flyer and SpaceShipTwo.
- Does not include Hovercraft as of 1967.

Inner Space: ICAO's New Frontier

- There is no clear boundary between air & space.

SPACE

AIR

- Previously the lack of agreement on a boundary was of little importance, space activities were in SPACE, airlines flew in the AIR.

Inner Space: ICAO's New Frontier

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- Airlines flew in the AIR.

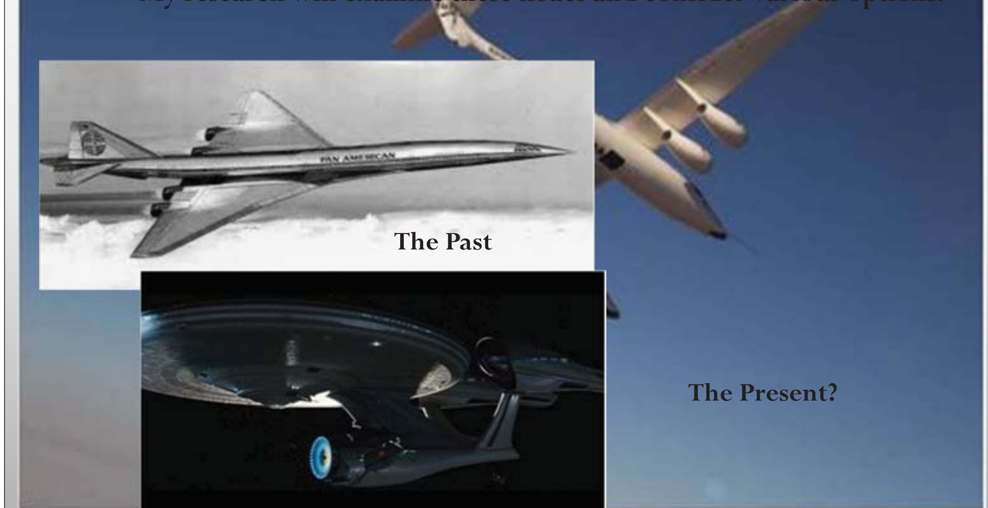
Inner Space: ICAO's New Frontier

- Companies like Virgin Galactic pose new challenges to Space lawyers.

- Is it Space travel, or simply a much faster aircraft?
- If it is an aircraft, it raises ATM, safety and passenger liability issues.
- Its mere existence raises potential conflict between UNCOPUOS and ICAO.

Inner Space: ICAO's New Frontier

- My research will examine these issues and consider various options.



Inner Space: ICAO's New Frontier

- Thank you.

P. Paul Fitzgerald

DCL Candidate
McGill Institute of Air & Space Law
Sessional Lecturer

paul.fitzgerald@mail.mcgill.ca

COE CST

Center of Excellence for Commercial Space Transportation