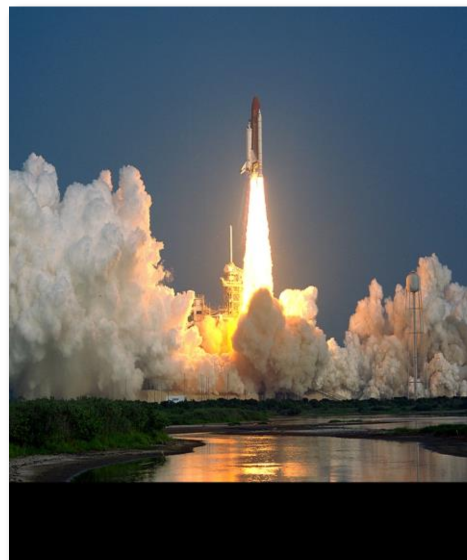
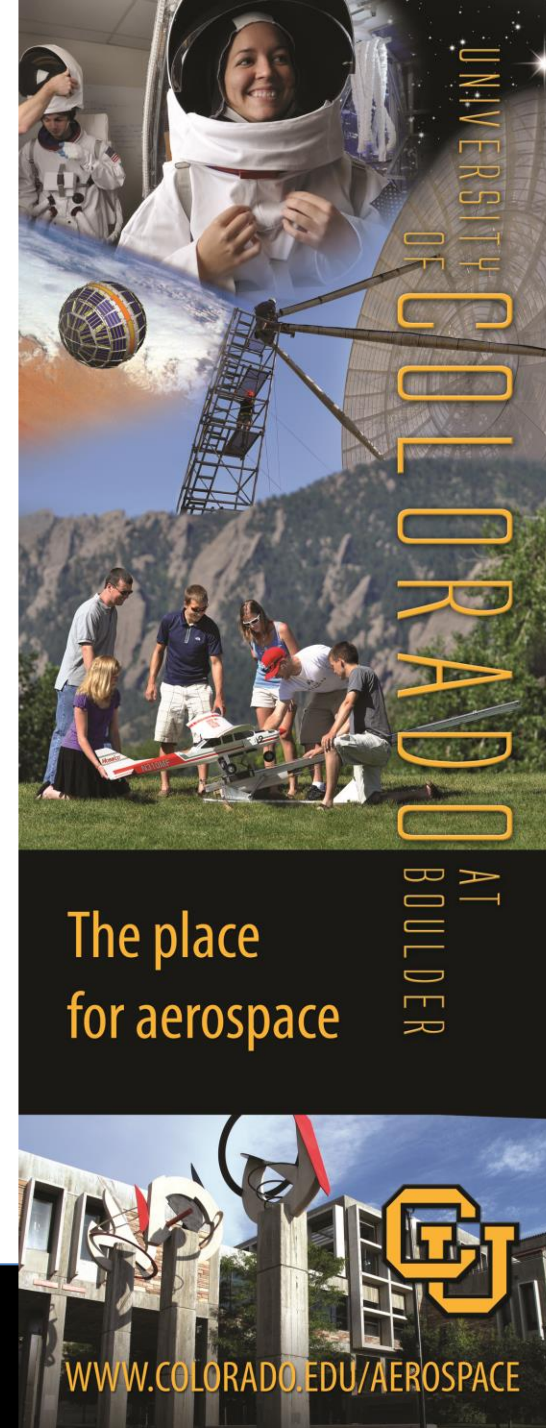
CU-Boulder AeroSpace Ventures

Dr. Penina Axelrad, Chair
Aerospace Engineering Sciences

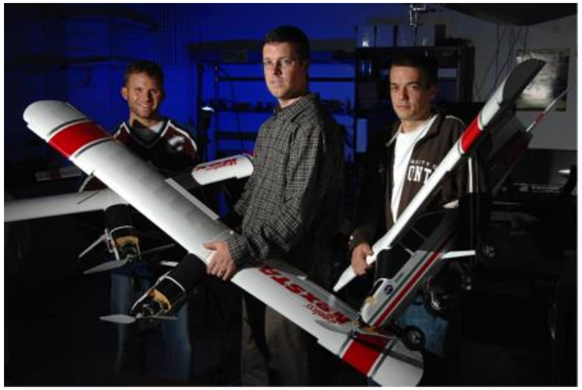
September 22, 2014

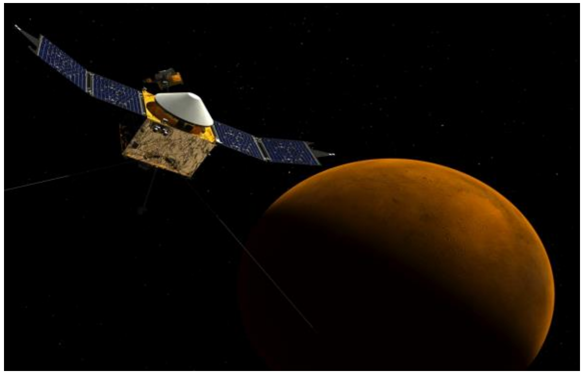




University of Colorado Boulder

CU-Boulder is one of the nation's leading aerospace universities





- **Over a dozen aerospace-related units on campus**
- **#1 public university recipient of NASA awards**
- **Over $100M in aerospace-related research expenditures**

www.colorado.edu/aerospace/cu-aerospace-ventures

CU-Boulder AeroSpace Ventures

Crossing the boundaries between science and engineering & academia and industry

CU AeroSpace Ventures is a collaboration among aerospace-related departments, institutes, centers, government laboratories and industry partners to create knowledge and develop new technologies specifically focusing on:

- Unmanned and autonomous aircraft
- Small satellites
- Earth and space sensors

CU-Boulder AeroSpace Ventures

Through CU-Boulder AeroSpace Ventures, these partnerships will:

- Accelerate discoveries in Earth and space science
- Broadly educate tomorrow's highly-skilled workforce
- Develop technologies that create new commercial opportunities
- Create collaborations that help industry grow

CU-Boulder AeroSpace Ventures…

…In Education

- Hands-on learning; student projects targeted at corporate needs; multidisciplinary teams; professionally-prepared students

…In Research

- Space situational awareness; severe weather and climate; global water cycle; space exploration

…In Industry

- Create new innovations & technologies for new products; bring new funding into Colorado through joint research with industry; distance learning for working professionals

Industrial Partnerships with CU-Boulder

Industrial relationships are important components of CU-Boulder's aerospace research and education programs. Through CU AeroSpace Ventures, there are numerous opportunities to form partnerships with campus activities for mutually beneficial outcomes.

Research	Education
▪ Fundamental and applied ▪ Joint research ▪ Technology transfer ▪ SBIR/STTR partnerships	▪ Student projects ▪ Guest lectures ▪ Interns, co-ops ▪ Future employees ▪ Distance professional development
Services	**Sponsorship**
▪ Facilities use ▪ Special tests ▪ Contract work ▪ Target acquisitions through eSpace	▪ Scholarships ▪ Advisory boards ▪ Endowed chairs ▪ Endowed programs

CU-Boulder AeroSpace Ventures
Founding Corporate Partners

LOCKHEED MARTIN

BRAXTON

Ball

SNC SIERRA NEVADA CORPORATION™
Space Systems

SURREY
SATELLITE TECHNOLOGY US

BCT

*Featured on CU-ASV website.

Thank you to our AeroSpace Ventures Day sponsor!

AEROTEK®

University of Colorado
Boulder

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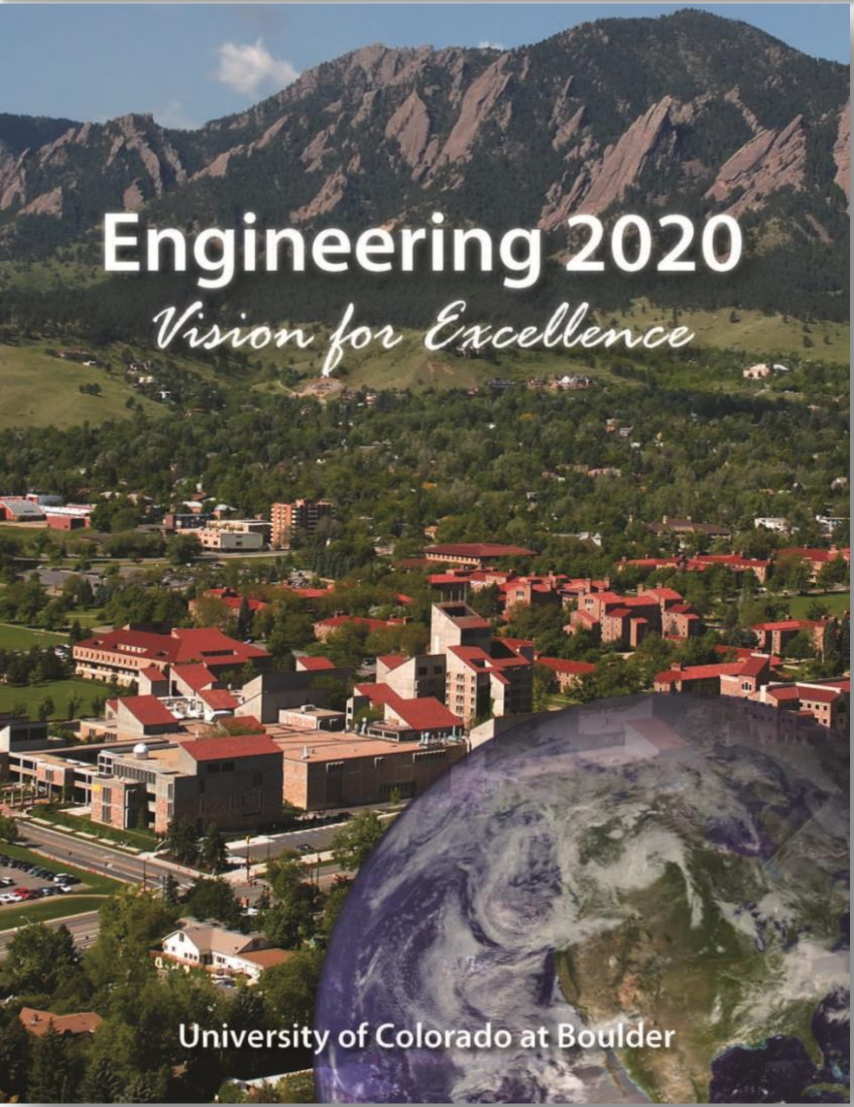
CU-Boulder Engineering Overview



Vision for Excellence:

- World leader in engineering research <u>and</u> education
- Inclusive excellence
- Engineering for global society
- Active, discovery-based learning

I hear . . . I forget
I see . . . I remember
I do . . . I understand

Confucius, c 500BC

University of Colorado Boulder

- Founded 1876 (Engineering started 1893)
- Eight Schools & Colleges
  - Arts & Sciences
  - Business
  - Media, Commun. & Info.
  - Education
  - Engineering & Applied Science
  - Graduate School
  - Law
  - Music
- Dynamic Community of Scholars
  - 25,000 undergraduates
  - 5,000 graduate students
  - 5 Nobel Prize winners
  - 6 federal research labs (NCAR, NIST, NOAA, NREL, USBR, USGS)
  - Strong corporate partners

University of Colorado Boulder

CU-Boulder is the flagship campus of a four-campus system

CU Engineering by the Numbers – Fall 2014

6 Departments
267 full-time faculty

3988 Undergraduates
+41% in past 8 years

938 Female undergraduates
+88% in past 8 years

454 URM undergraduates
+121% in past 8 years

19 Boettcher scholars
(in past 2 years)

1666 Graduate students
+42% in past 8 years

$72M Research grant awards
+109% in past 8 years

Top-ranked program in Mountain Time Zone

Ways to Engage

- Educational partnerships: Senior projects, innovative programs
- Research partnerships: Cooperative grants, research center membership
- Employment opportunities: Internships, co-ops, permanent jobs

- Volunteer service: Advisory committees, guest lectures, alumni events, mentoring
- Philanthropy: Scholarships, fellowships, student societies, programs, facilities, named faculty positions

Thank you, and enjoy AeroSpace Ventures Day!

Lockheed Martin

Kathryn G. Tobey
Vice President/General Manager, Special Programs
Lockheed Martin Space Systems

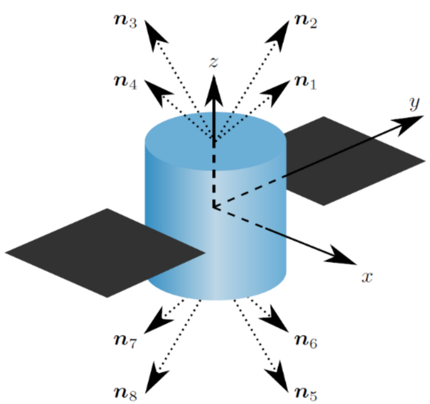
Sun Heading Estimation & Attitude Control
Dr. Hanspeter Schaub

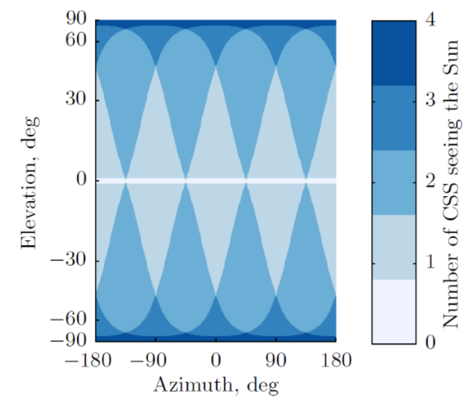
Objectives and Description

- In recent years there has been a significant increase in small satellite interest, but a noticeable lag in development of autonomous and robust ADCS
- ADCS must quickly and robustly achieve and maintain a power-positive state from any initial orientation with no prior knowledge of attitude

GOAL:

- **Develop low cost, reliable, robust attitude determination and control systems for spacecraft**





Status and Approach

- Partially underdetermined sensor configurations
- Simultaneous estimation and control
- Monte Carlo analysis shows successful sun heading estimation using only coarse sun sensors
- Currently exploring
  - Increasing robustness
  - Sensitivity to sensor accuracy
  - Sensitivity to sensor failure
  - Autonomous detection of sensor failure

Industry Application

Strengths	Application to Industry
• Spacecraft attitude, determination, and control • Small satellites • Reducing spacecraft costs	• High-fidelity hardware in the loop ADCS simulation • Reduce sensor costs • Decrease calibration testing, costs, and time • Increase robustness

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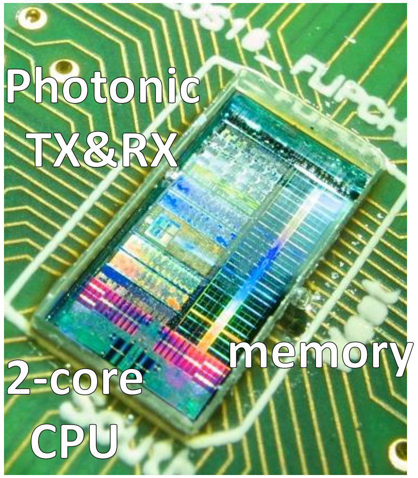
AVS Lab
Autonomous Vehicle Systems Laboratory
University of Colorado Boulder

Silicon Photonics in a Commercial Microprocessor Foundry

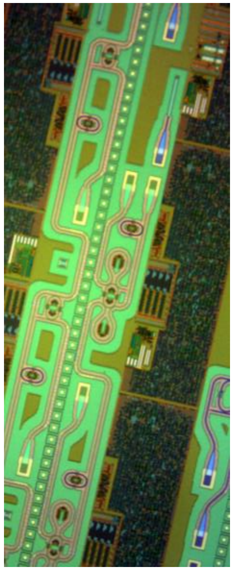
Dr. Milos Popovic

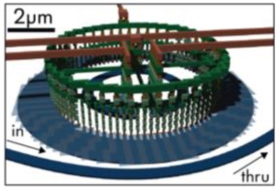
Objectives and Description

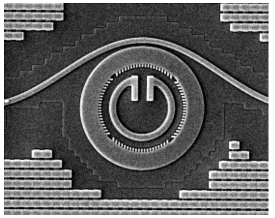
- Enable VLSI optical (photonic) circuits on CMOS chip
- Invent photonic technology compatible with fabrication in standard commercial CMOS microelectronics foundry
  - Tight integration with state-of-the-art CMOS electronics
  - Design for manufacturability
  - Rapid design cycle
  - Immediate scale-up to production
- Photonics as a "More-than-Moore" technology – provides disruptive capability and new applications
- Enable industry standard microelectronics design flow/tools

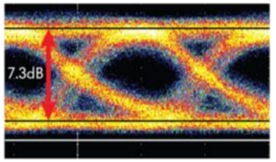


70M transistors, 1000's of photonic devices









Status and Approach

- Demonstrated photonics platform in "zero-change CMOS"
  - 45nm and 32nm IBM CMOS (e.g. IBM Power7)
  - High-performance electronics up to 250-485GHz fT
  - 300mm commercial foundry – Trusted Foundry
- Record-energy photonic transmitters: 20fJ/bit, 5Gbps
- First bulk CMOS chip-to-chip optical comm link
- First microprocessor with photonics on same die
- >20 chips designed

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NNMI: Looking for industry partners

Industry Application

Strengths	Application to Industry
Low-energy	CPU-memory, high performance SoC
5-200 GHz RF BWs	Communication, Remote sensing, Ultrawideband RF
Radiation hard SOI	Space applications
Photonic ASIC	Silicon imager/sensor, neuro-sensing, metrology, combs, quantum sensing/networks

Email: milos.popovic@colorado.edu
Web: http://plab.colorado.edu

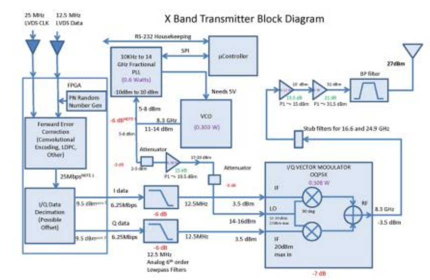
ECEE

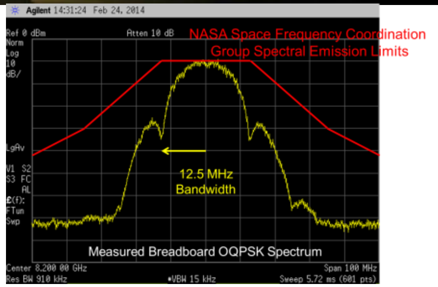
High Rate Cubesat Radio

Dr. Scott Palo

Objectives and Description

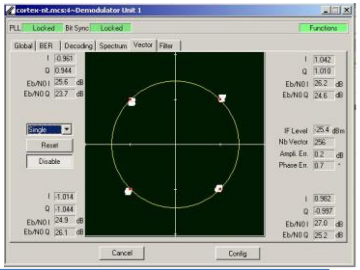
- Design and build an X-Band 12.5Mbps OQPSK radio compatible with a cubesat which can be scaled to 125Mbps.
- Design and build a compatible S-Band 300kbps BPSK TT&C receiver
- One current limitation of cubesats is the availability of high rate radios that are compatible with the size and power limitations of cubesats.
- NASA is interested in using cubesats for exploratory science and a high rate data linkis required to meet most science goals.
- Current options operate at UHF, require an 18m ground antenna and achieve 3Mbps.





Output spectrum compliant with FCC

Can close LEO link with 6m ground antenna



Status and Approach

- Selected as one of 10 NASA STMD small satellite cooperative agreements in August 2013
- Funding approved in August 2014 for 2nd year of 2 year effort
- Joint project with CU AES, LASP and NASA GSFC and MSFC with input from JPL.
- X-band transmitter began at TRL-3 and is currently at TRL-3 with T-vac testing scheduled for Oct. 2014 (TRL-5)
- GSFC investigating a Q4 balloon launch
- Remainder of year 2 dedicated to development of s-band BPSK receiver

Industry Application

Strengths	Application to Industry
• Frequency agile • LVDS input • Output rate scalable with input data clock • Single stage vector modulator design • On board FPGA has resources for FEC and encryption	Rugged, resource limited high rate communications • Low power • Low mass Small satellites, UAS and ground vehicles

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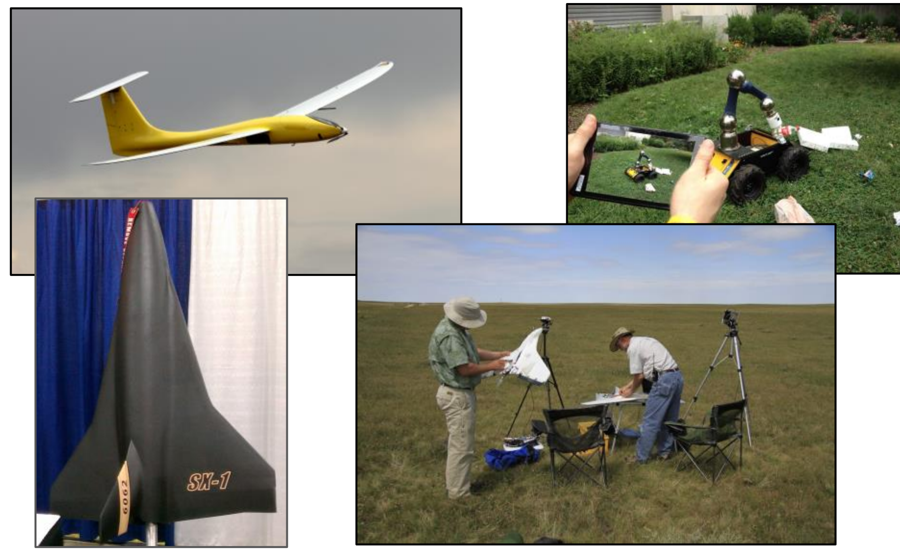
Aerospace Engineering Sciences
UNIVERSITY OF COLORADO BOULDER

LASP
Laboratory for Atmospheric and Space Physics
University of Colorado Boulder

Research and Engineering Center for Unmanned Vehicles (RECUV)
Dr. Eric Frew

RECUV draws faculty and students from across the University of Colorado to address technical challenges with the development and application of unmanned vehicle systems.



Technology Areas

Mission-Derived sUAS Design
Mobile Ad Hoc Communications
Vehicle-Sensor Integration
Cooperative Control
Advanced Propulsion Systems
Airspace Integration
Intelligent Human-UAS Interaction
Perception under Uncertainty

Applications

Applications	Capabilities
Polar science	Nomadic CONOPs
Severe weather	Supersonic UAS
Precision agriculture	Wind / turbulence
Wind energy	Ad-hoc networking
Autonomous driving	FAA COAs
Search and rescue	Multi-vehicle ops
National defense	Localization / mapping

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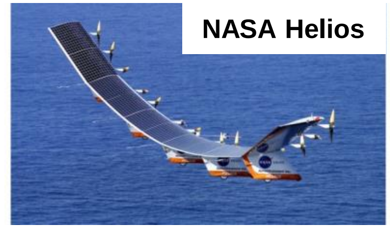
Experimental Aerodynamics and Flow Control
Dr. John Farnsworth

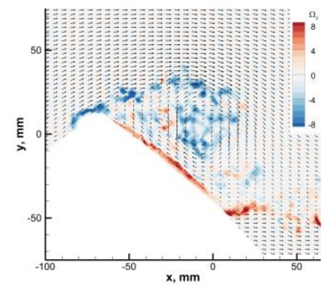
Objectives and Description

Understand & Control complex 3-D unsteady flow fields for aerodynamic applications

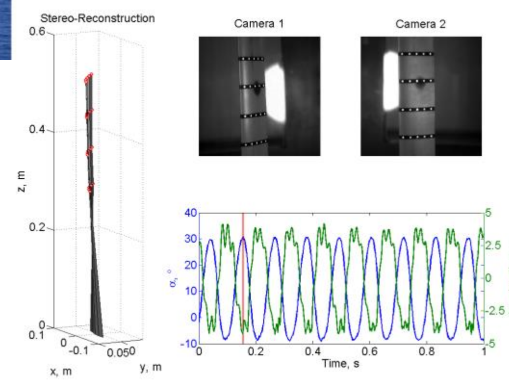
- Focus on detailed experimental investigations into the flow physics (i.e. field measurements)
- Integrate flow control and quantify how it alters the fluid dynamics of a baseline flow field
- Utilize flow control to better understand the baseline flow (i.e. receptivity)
- Can the flow control be tailored to enhance an aerodynamic system's performance and/or reliability?



Noll, T. E. et al., NASA Mishap Report, 1 (2004).



AFOSR Sponsored Research:
Flow Control of Flexible Structures
(in collaboration with USAF Academy)



Status and Approach

- New faculty member as of ***August 2014***
- Building research group and laboratory infrastructure at CU – Boulder
- ***Plan to bring new wind tunnel laboratory online by August of 2015!***
- Collaborating with the Department of Aeronautics at the US Air Force Academy on AFOSR sponsored research controlling high aspect ratio wings undergoing aero-elastic flutter with flow control (i.e. Synthetic Jets)

Industry Application

Strengths	Application to Industry
• Designing and integrating fluidic control (i.e. jets in a cross-flow) • Experimental Design and Measurement Techniques • Facilities and Infrastructure (Low-Speed Wind Tunnel, Stereo-PIV, etc.)	• **Aviation:** replace vehicle control surfaces with flow control actuators • **Wind Energy:** extend power capture and enhance blade robustness • **Hydrodynamics:** design & test novel propeller systems • **Biomedical** • **Electronics Cooling**

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Aerospace Engineering Sciences
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Verification of Control Systems
Dr. Sriram Sankaranarayanan

Objectives and Description

- Aerospace systems are often safety-critical.
- Freedom from harmful software defects is guaranteed by a rigorous development process (DO-178C).
- Broad Goal: Automatic Verification techniques.
  - Automate discovery of harmful defects in software systems
  - Prove components are free from certain defects.
- Specific Goals:
  - S-Taliro: Automatic discovery of property violations in Simulink/Stateflow models.
  - Flow*: Verification of closed-loop models.

https://sites.google.com/a/asu.edu/s-taliro/s-taliro

Joint work with Prof. Georgios Fainekos at Arizona State University

Status and Approach

- S-Taliro has been under development for over 5 years.
- Applications to automotive domain:
  - Collaboration power-train control group at Toyota Motors.
  - Applications to requirements mining for legacy systems.
- Applications to medical devices:
  - Verification of Artificial Pancreas Control Systems.
  - Collaboration with biomedical researchers at UC Denver and RPI.

Industry Application

Strengths	Application to Industry
Guided Random search for defects in systems.	Verification and Validation of Controllers
Integrates into Model-Based Design.	Handles Simulink/Stateflow. Software/Hardware-in-the-loop test automation.
Supports multiple search techniques and parallel search.	Large scale model validation.

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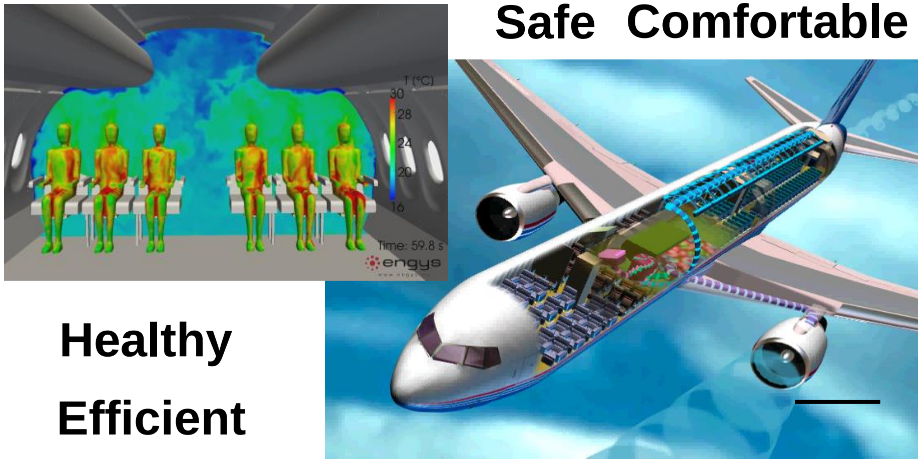
Inverse Design and Optimization of Aircraft and Spaceship Indoor Environments

Dr. John Zhai

Objectives and Description

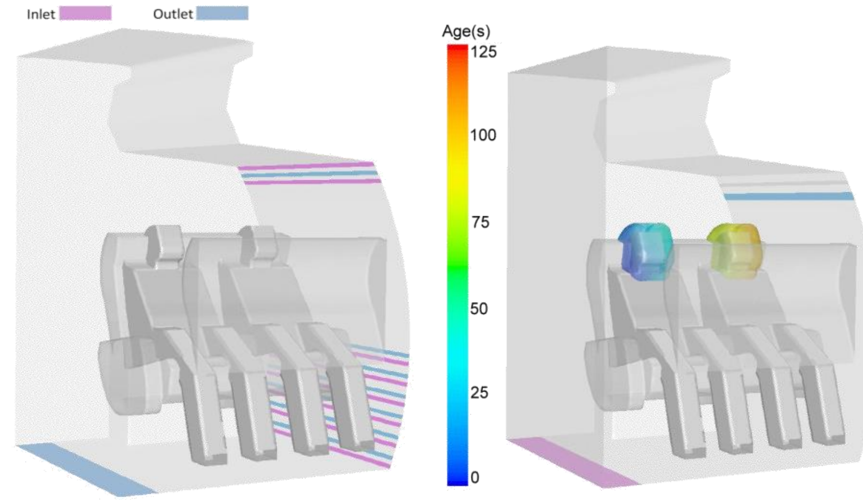
Safe Comfortable



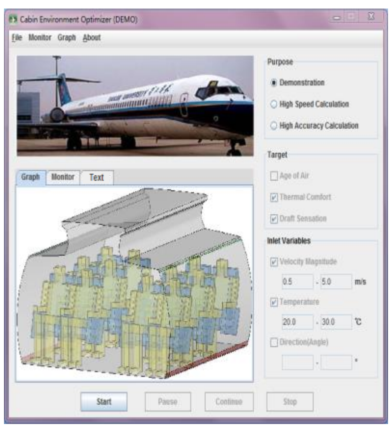
Healthy

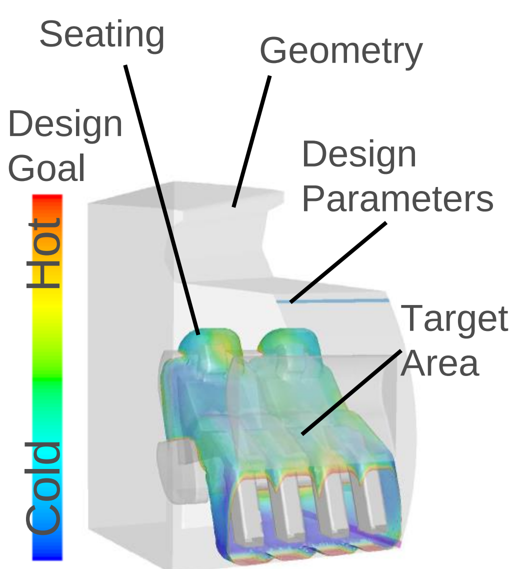
Efficient

Result Demonstration



Status and Approach





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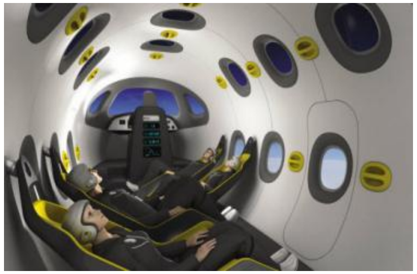
Industry Application



Middle Atmosphere Remote Sensing
Dr. Cora Randall

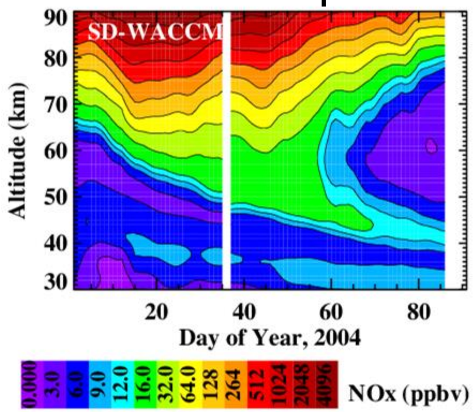
Objectives and Description

How and to what extent are different regions of the atmosphere coupled, and what are the implications for climate?

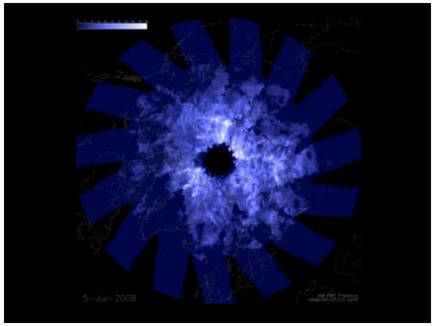
– Effects of Energetic Particles

– Polar Mesospheric Clouds as Indicators of Teleconnections

Particle Precipitation



Polar Mesospheric Clouds



Status and Approach

- Satellite remote sensing & global modeling
- Measure temperature, composition, winds from the stratosphere to the lower thermosphere
- Daily sampling, polar emphasis

Industry Application

Strengths	Application to Industry
•Cross-disciplinary •Growing interest in coupling •Tractable problems	Scientific basis for research missions, e.g., NASA Explorer Program.

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Dept of Atmospheric & Oceanic Sciences

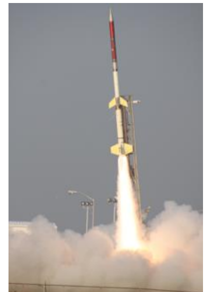
ATOC

LASP
LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS
UNIVERSITY OF COLORADO AT BOULDER

Colorado Space Grant Consortium
Brian Sanders, Deputy Director

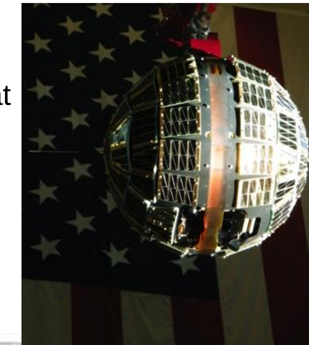
Objectives and Description

- Statewide consortium of 17 institutions to provide hands-on space related experiences to higher education students. CU Boulder is the lead institution.
- Interdisciplinary student led projects.
- Three satellite launches, six sounding rocket payloads and many sounding student built balloon experiments in the past three years.



DANDE student team at first contact

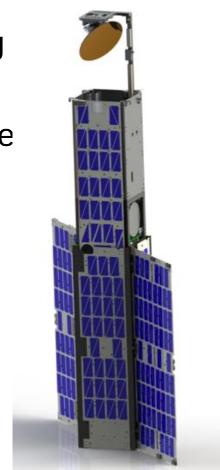
The DANDE satellite during delivery



ALL-STAR students during satellite delivery and integration

Status and Approach

- PolarCube is a 3U temperature sounding CubeSat with a 118GHz radiometer to better understand polar and lower latitude mesoscale weather phenomena.
- Based on a previously launched student developed satellite bus that integrates a 1.5U radiometer from the Center for Environmental Technology with a hoped launch in 2016.



Industry Application

Strengths	Application to Industry
Real world application of knowledge and skills	Industry can mold an experienced workforce
Wide range of previous project scope	Meaningful industry collaborations
Interdisciplinary student led teams	Developing student leaders and collaborative teams

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http://spacegrant.colorado.edu/

Brian Sanders, brian.sanders@colorado.edu

COSGC

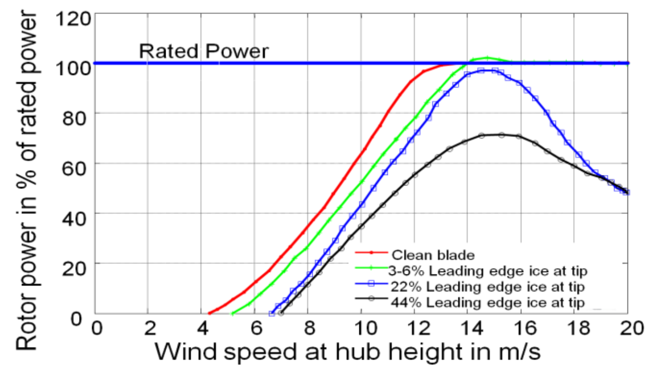
Direct Optical Ice Sensing and Active De-Icing

Drs. Lucy Y. Pao & Robert R. McLeod and PhD Student Shervin Shajiee

Objectives and Description

- Ice accretion causes problems: wind speed and direction errors, aerodynamic power loss, added fatigue loads and mass imbalance, mechanical and electrical failure
- Direct ice sensing and active de-icing is much more effective under severe icing events.
- Large variation of heat loss across the aerodynamic surfaces highly motivates distributed de-icing
- Optical frequency domain reflectometry (OFDR) is used for direct detection of ice on the blade

A typical 300 KW wind turbine with pitch control

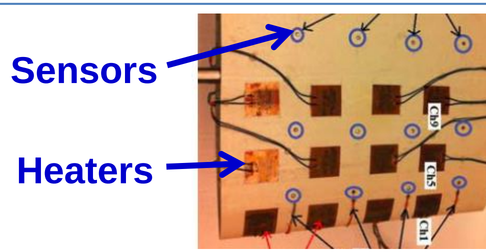


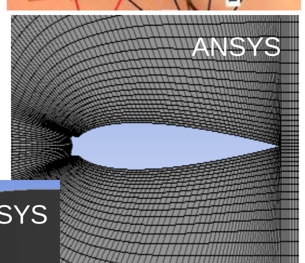
[Reproduced based upon Seifert & Richert, 2003]

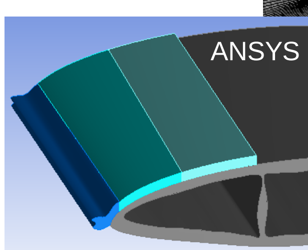
Icing changes the shape and reduces power generation

Status and Approach

- Preliminary profitability analysis
- Development of an experimental setup
- Numerical/CFD analysis for optimizing the layout of heaters







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Industry Application

Strengths	Application to Industry
• Accurate and direct ice sensing • Improving de-icing efficiency and reducing power consumption • More robust to faults in the power and electrical network	• Wind turbines • Aircrafts • Helicopters • Safe aerial missions in polar regions • Health monitoring under icing events

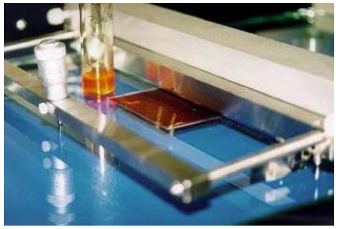
CREW Center for Research and Education in Wind

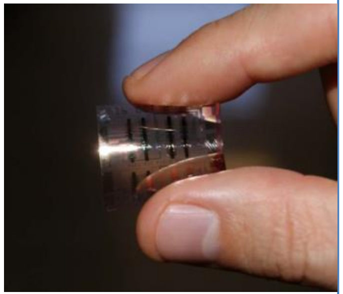
Solution-Processed Electronics for Lightweight Photovoltaics and Logic Circuits

Dr. Sean Shaheen

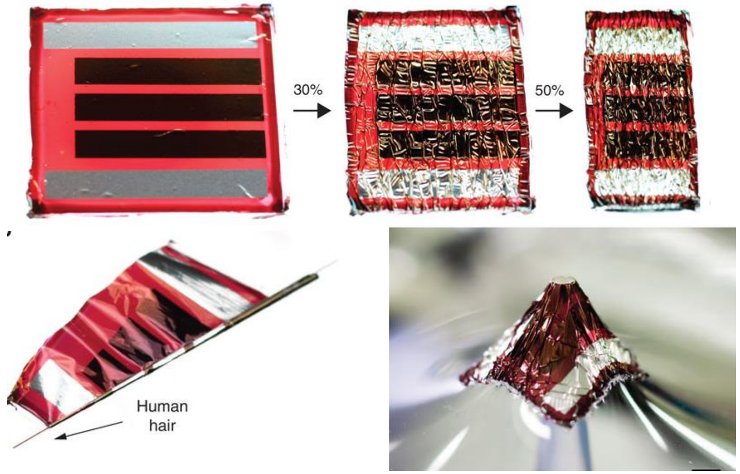
Objectives and Description

- **Organic and hybrid Perovskite electronics** are processed from chemical solution, which provides robust mechanical properties and fast design-to-fabrication cycles.





An example of the mechanical properties of an ultra-lightweight organic photovoltaic device[1]



Status and Approach

- Fabrication via low-temperature methods compatible with very light-weight and flexible substrates
- Demonstrated efficiencies of 10-15+% for photovoltaics
- Demonstrated speeds in the MHz+ for simple field effect transistor (FET) circuits
- Demonstrated integration of multiple device types into the same logic circuit

Industry Application

Strengths	Capability
• Highest power-to-weight ratio (10 W/g) of any PV technology • Excellent mechanical durability and thermal cycling • Excellent radiation hardness in the 100's of krad[2]	• The Shaheen group has capabilities to design, build, and test many types of solution-processed devices, including PVs, FETs, and memory devices.

[1] Ultrathin and lightweight organic solar cells with high flexibility, M. Kaltenbrunner et al., *Nature Communications* **3**, 770 (2012).
[2] X-ray irradiation effects in top contact, pentacene based field effect transistors for space related applications, R.A.B. Devine, et al., *Appl. Phys. Lett.* **88**, 151907 (2006).

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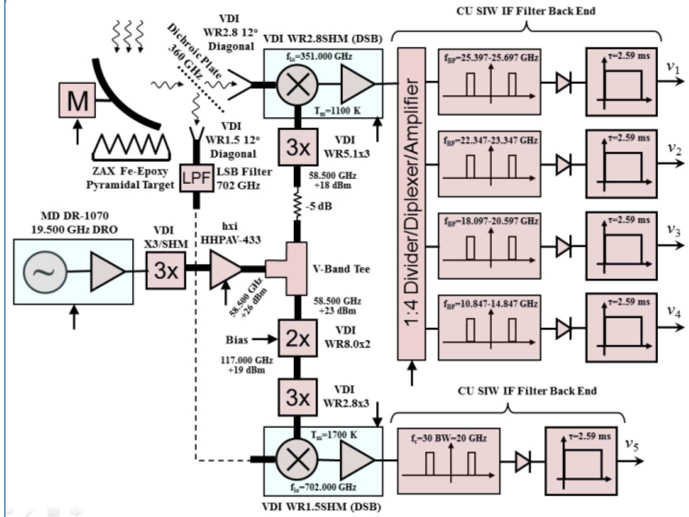
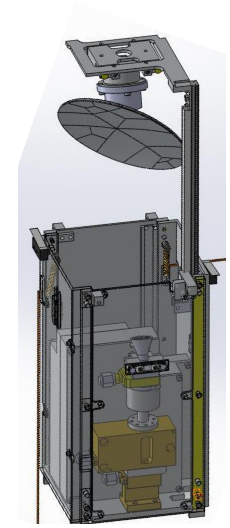
contact: sean.shaheen@colorado.edu

Tandem 3U CubeSat Mission for Global Cloud Ice Mass Measurement
Dr. Al Gasiewski

Objectives and Description

- Demonstrate 3U tandem CubeSat constellation for a key global climate feedback study:
  - Cloud ice water path (IWP) measurement from ~20 to ~2x10^4 g/m^2
  - Mean ice size from ~50 to ~1000 μm
  - Tropospheric temperature and water vapor profiling
- Achieve secondary NRC Decadal Survey ACE objectives at very low cost during a key era of potential global atmospheric albedo evolution
  - Precede EuMetSat MTG satellite cloud ice measurements by 5-7 years
  - Develop pre-launch NIST SI traceable calibration of SMMW radiometric instruments
- Demonstrate principal element of ~30 member 3U CubeSat constellation for weather forecasting and polar monitoring
- Uses robust inexpensive 3-axis stabilized bus (CU ALL-STAR) with cross-track scanning mirror (16 km nadir resolution)
  - 8-channel 118.7503 GHz O_2 temperature imager/sounder
  - 4-channel 325.153 GHz H_2O water vapor imager/sounder
  - 1-channel 672 GHz cloud ice mass imager
- Bus and payloads designed and fabricated by CU student team





Status and Approach

- PolarCube:
  - NASA ELaNa launch awarded (ready ~2015)
  - USAF University Nanosat Program Phase I award
- CloudIceCube:
  - Airborne & ground based SMMW radiometer development since 1991
  - NSF CubeSat proposal (submitted May 2014)
- 4-m Earth Station for CubeSat tracking & communications
- Future S/C builds to focus on:
  - Downlink communications
  - Dual-band payload integration (325, 672 GHz)
  - Precision deployable scanning antennas

http://spacegrant.colorado.edu/allstar-projects/polarcube

Industry Application

Strengths	Capability
Spaceborne remote sensing mission design, S/C and sensor development, calibration , demonstration, and climate science Advanced training of students for entry into the aerospace industry	• Passive submillimeter-wave sensor concept development • Microwave imaging system design and development • Climate system studies • Precision traceable microwave radiometer calibration • Training for a world-class aerospace & scientific workforce

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AIR FORCE RESEARCH LABORATORY
NASA
COSGC
CIRES
NSIDC
National Snow and Ice Data Center
CET
Center for Environmental Technology

Fiske Planetarium
Doug Duncan, Director

Objectives and Description

Fiske is the #1 university planetarium in the US, with the best video image ever shown (8,000 x 8,000 pixels, 60’ dome!)

We *educate* and *inspire*.

Status and Approach

We have scientists, educators, video and audio professionals on staff – easy to work with (Companies; missions, individual scientists)

We produce for national distribution.

Industry Application

Strengths	Application to Industry
Full, professional video production studio. Low cost – some work is done by students.	We can create any video you can imagine. We can create any video you can imagine - inexpensively.

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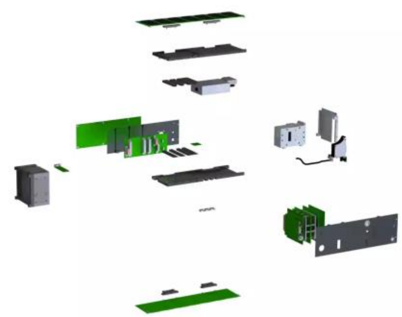
FISKE PLANETARIUM

Miniature X-Ray Solar Spectrometer (MinXSS) CubeSat
Dr. Xinlin Li & Graduate Student James Mason

Objectives and Description

- 3U CubeSat (34 cm x 10 cm x 10 cm, ≤ 4.8 kg)
- April 2015: Launch on Antares/Cygnus to International Space Station
- ~ 7 month expected lifetime before orbit decay
- Measure soft x-ray spectrum from Sun (~0.4 – 30 keV, 0.4 – 30 Å) at mid-high resolution (0.15 keV)
- Provide unique input to Earth atmospheric models and complementary data for solar flare analysis



"A sparrow has all the same working parts as an ostrich."
– Chinese proverb

Status and Approach

- AES graduate project started in Fall 2011
  - 40 students to date (36 graduate, 3 undergrad, 1 high school)
- Strong collaboration with LASP
- Currently in test phase – functional, performance, environmental
- More info: lasp.colorado.edu/home/minxss or stop by across the hall (W125)

Industry Application

Strengths	Application to Industry
• High-precision 3-axis ADCS • Usage of COTS part for primary science (Amptek X123) • Potential space weather nowcasting	• Heritage for Blue Canyon Technologies XACT • Proof of publishable science on CubeSat platform • Space weather preparedness

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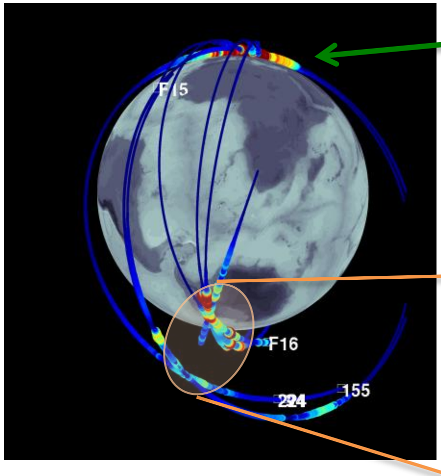
LASP
Aerospace Engineering

Space Environment Data Analysis (SEDA)Group
Dr. Delores Knipp

Objectives and Description

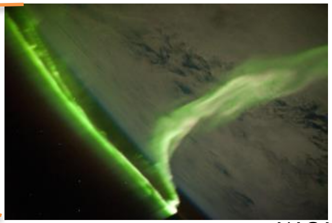
- Analyze, Understand, Predict the effects of aerospace environment on
  - Humans, hardware and signals
- Focus: energy deposition in LEO
  - Energetic particle flux and characteristics
  - Electromagnetic energy flux
  - Local deposition, but global effects
- Do measurements from different sensors on the same magnetic field line agree?

DMSP Circular orbit and ST-5 Eccentric orbit



Color = Magnetic Disturbance Magnitude

Do perturbations on the same field line agree?



NASA

Status and Approach

- Convert to common coordinate frame and altitude to facilitate data and phenomena comparison
- Computer conjunctions in magnetic space
  - Determine size of volume that constitutes a conjunction
- Compare observations/Compute Statistics

- Results from LEO Comparisons:
  - DoD vs commercial constellation: systematic bias
  - DoD vs NASA ST-5 constellation: very good agreement

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Industry Application

Strengths	Application to Industry
New comparison technique for space-based LEO data Fields and Particles	Determine “coincidence” of measurements in the geomagnetic field
Common reference frame	Future application to spacecraft charging
Statistical investigation of space-based data	High-level data products for SSA?
Assimilation of various space-sensing data	

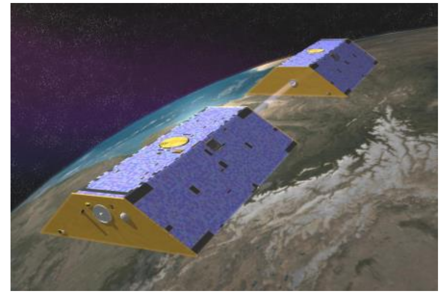
Aerospace Engineering

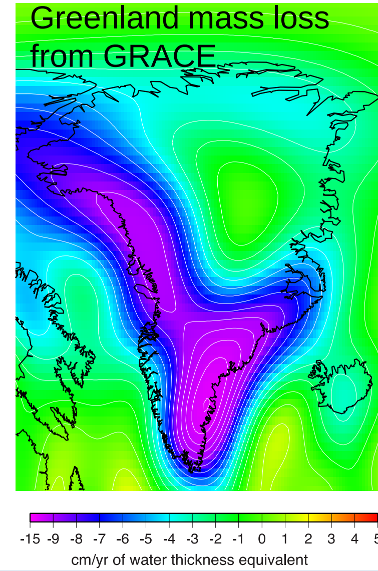
Earth Gravity Measurements from Space
Dr. Steve Nerem

Objectives and Description

- Precisely measure the Earth's gravity field from space.
- Measure the time variations of the gravity field with at least monthly temporal resolution.
- Spatial resolution for monthly estimates is currently at 300-400 km, but better spatial resolution is desired.
- Applications in glaciology, hydrology, oceanography, climate change science, and orbit determination.

GRACE Mission





Status and Approach

- Current approach uses a single pair of satellites (GRACE and GRACE Follow-On) employing GNSS, intersatellite ranging, and precise accelerometry.
- Future concepts should be focused on improving the spatial resolution provided by these missions.
- Developing cheaper "GRACE like" missions would allow multiple pairs of satellites to be flown simultaneously, thereby improving spatial resolution.
- Other concepts are also being explored by NASA and their partners.

Industry Application

- Need advances in:
  - Precision intersatellite tracking
  - Precise accelerometer measurements
  - Micro-thrusters (drag-free technology)
  - Satellite attitude control
  - Small satellite technology.
- Opportunities for university/industry proposals to NASA to advance satellite gravity measurements.

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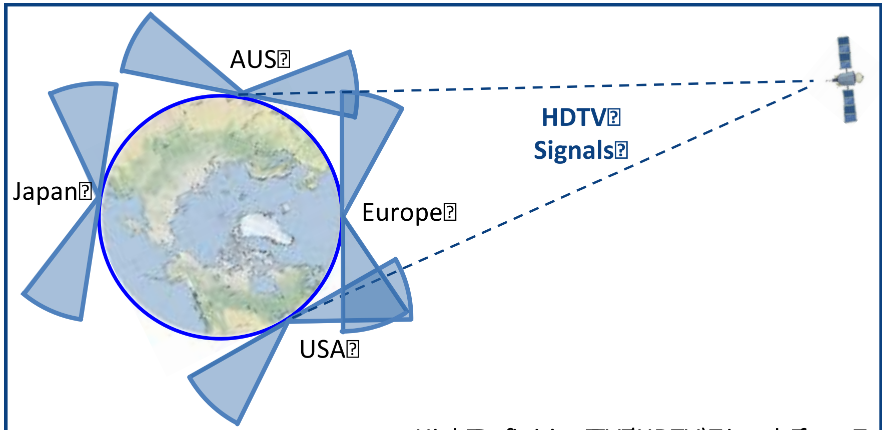
Aerospace Engineering

Spacecraft Navigation Using HDTV

Dr. Jeff Parker

Objectives and Description

- Over **8800 HDTV towers** broadcast with enough power to be easily received at the **Moon** or beyond.
- These signals may be converted into navigation data for spacecraft, from Earth orbit out to the Moon.
- One tower is sufficient, but we can uniquely identify dozens of towers at any given time.
- Objective of research: to demonstrate autonomous spacecraft navigation using these ***Signals of Opportunity*** (***SoOps***).



Towers broadcast up to 15° above the horizon, and up to 1.3 MW in power

High Definition TV (HDTV) signals from over 8800 towers may be used to navigate satellites and spacecraft as far away as the Moon.

Status and Approach

- Characterizing the Loctronix ASR-2300 software-defined radio, which can pick up any HDTV tower transmissions, GNSS, and even S-Band.
- Demonstrating HDNav navigation on the ground.
- Preparing to demo HDNav on an aircraft.
- Preparing to demo HDNav on a high-altitude balloon.
- This work will support a 6U-cubesat mission to be deployed on Orion's EM-1 mission to the Moon in 2017.

Industry Application

- **Low-Cost Navigation**: HDTV transmissions can be received using COTS hardware and omni-antennae.
- **Autonomous Spacecraft Navigation**: HDNav does not require active ground tracking.
- **Improved Navigation Accuracy**: There is an immense amount of free tracking data available to be used stand-alone or to supplement ground tracking.
- **Applications**: GPS updates, GPS-deprived sats, GEO navigation, autonomous operations, Orion navigation.

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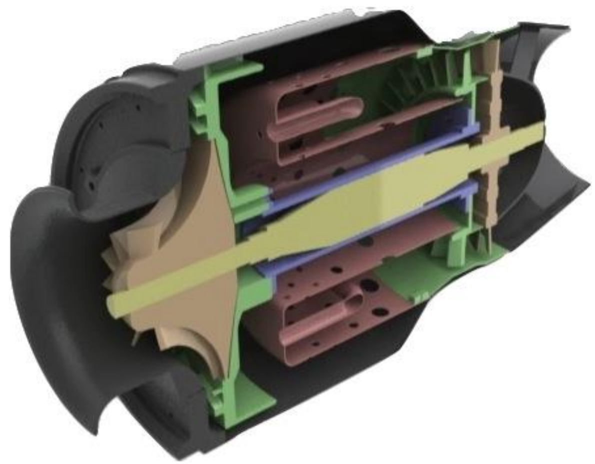
CCAR Colorado Center for Astrodynamics Research

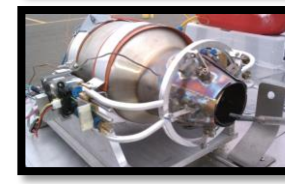
Efficient Small Scale Propulsion
Dr. Ryan Starkey

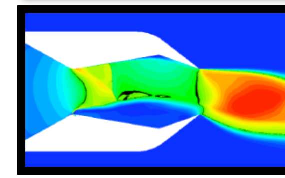
Objectives and Description

- Develop the next generation of efficient small scale propulsion systems for use in:
  - Unmanned aircraft
  - Gliders (take-off/sustainer propulsion)
  - Decoy and missile systems
  - Research aircraft
- Enables new systems due to advanced capabilities compared to state-of-the-art:
  - 2X efficiency, >20X time-between-overhaul

Turbojet Engines







Status and Approach

- Eliminate lubrication and starter systems
  - Advanced bearings and overall engine design
- Reduce system part count
- Improve component design/interoperability
- Improved compression and combustion
- Unique capabilities include: articulating nozzle, afterburner, power generation, thrust vectoring

Industry Application

Strengths	Capability
High Thrust	200+ lbf
Highest Fuel Efficiency (~2X)	0.7 lbm/(lbf hr)
Expanded Operability	40+ kft, 1000+ mph, 1000+ hrs TBO
Ease of starting	Wind-Milling
Storability, Reliability	No oil/pyro systems
Light Weight	< 14 lbs
Low Cost	TBD

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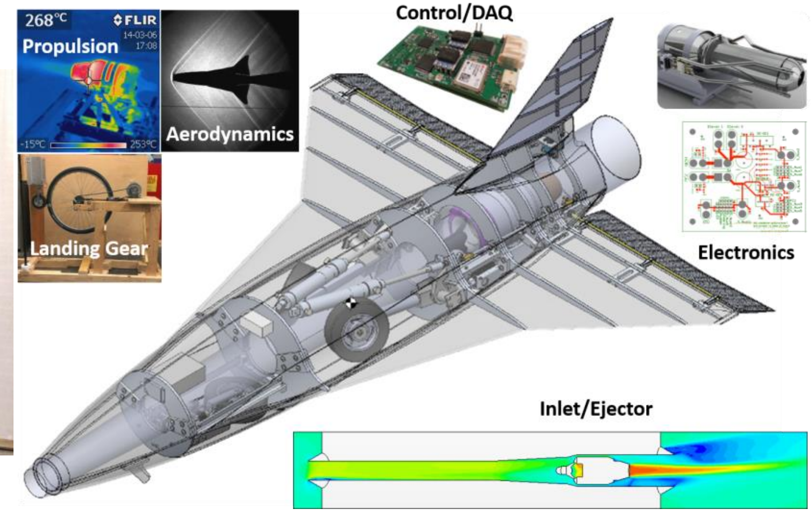
Aerospace Engineering Sciences
UNIVERSITY OF COLORADO BOULDER

High-Speed Unmanned Aircraft
Dr. Ryan Starkey

Objectives and Description

- Develop technology for low cost, unmanned aircraft for high-speed flight testing:
  - Novel configurations/control systems
  - Sonic boom reduction
  - Hurricane penetration
  - Transonic/supersonic testing
  - Missile, ISR applications
  - Advanced engine testing (combined-cycles)
  - Component testing/qualification in relevant environments

Supersonic Aircraft



Status and Approach

- All major components designed, built, verified
- Integration beginning Spring 2014
- Low-speed flight testing (250 mph) Fall 2014 at New Mexico UAS Flight Test Center
- Data to be used to finalize supersonic design Spring 2015
- Supersonic flight testing Fall 2015

Industry Application

Strengths	Capability
High Speed	Mach 1.4 (~1000 mph)
Low Cost	$50,000
Light Weight	100 lbs
High Thrust-to-Weight	2 (vertical take-off?)
Small scale	6 ft long x 5 ft span
Long range	~200 miles @ M=1.4
	500+ miles @ M=0.9

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Aerospace Engineering Sciences
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Instrument Development for the Detection of Particulates in Space
Dr. Zoltan Sternovsky

Objectives and Description

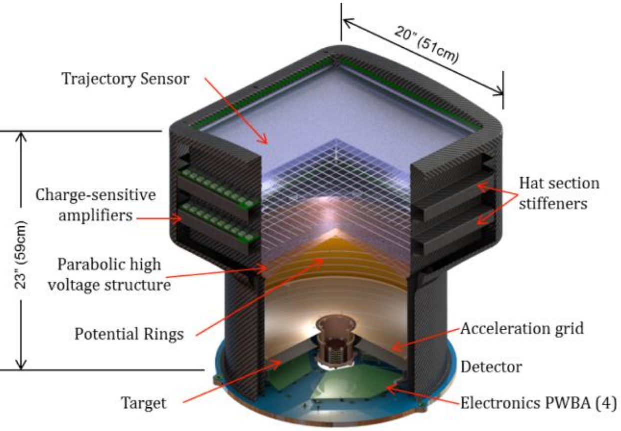
- In-situ cosmic dust detection and analysis
  - Spacecraft/mission safety
  - Space debris
  - Interplanetary dust (cometary, asteroidal, ….)
  - Interstellar dust
  - Surface composition of airless bodies (Moon, Europa, …)
  - Meteoric smoke particles in the mesosphere
- Hypervelocity dust impacts
- Dust-S/C interactions
- Meteoric ablation

Unique 3 MV Dust Accelerator operated at CU

IMPACT.colorado.edu

Institute for Modeling Plasma, Atmospheres and Cosmic Dust

Status and Approach



- Dust Astronomy
- Trajectory and Velocity Measurement
- Low Mass Instrument Design
- Composite Materials

Industry Application

Strengths	Application to Industry
Instrument development	Novel design approach, advanced materials
Impact physics	S/C safety, debris generation
Experimental meteoric ablation studies	Atmospheric entry
Basic comic dust research (planetary, heliophysics)	NASA missions

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NASA funded instrument development

LASP
LABORATORY FOR ATMOSPHERIC AND SPACE PHYSICS
UNIVERSITY OF COLORADO AT BOULDER

Office of Industry Collaboration (OIC)
Jeff Sczechowski, Associate Director

Objectives and Description

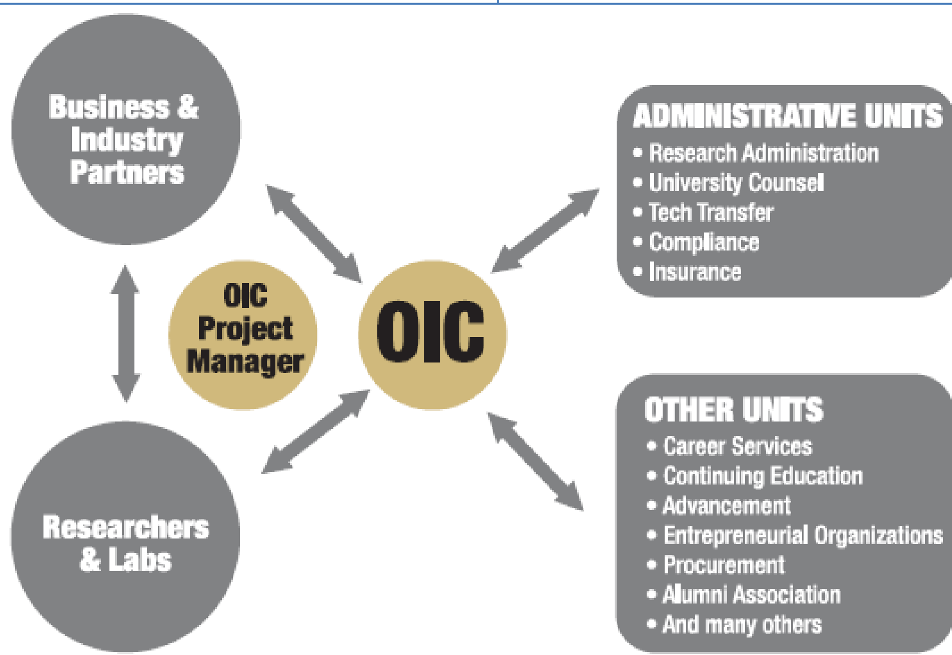
OIC increases interactions between industry and CU-Boulder to benefit companies, students, economy, and university

- **Connect industry partners to CU-Boulder**
- **Support faculty collaborations with industry**
- **Promote CU technical facilities and capabilities**
- **Improve administrative processes for industry agreements**
- **Monitor and support project completion**

Industry Opportunities at CU-Boulder

- **Build and Develop Your Workforce**
  - **Hiring**
  - **Internships**
  - **Student projects**
  - **Employee development**
- **Improve Your Products and Services**
  - **Custom research & development**
  - **Licensing technology**
  - **Services: Facilities & Testing, Consulting**
- **Engage with CU-Boulder**
  - **Promotion: advertising, sponsorship, philanthropy, etc.**
  - **Employee enrichment**

How can CU-Boulder support your company?



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Office of Industry Collaboration
UNIVERSITY OF COLORADO BOULDER

Technology Transfer Services
MaryBeth Vellequette, Director

Corporate Relations

Access to university students + faculty

Access to intellectual property

Research collaboration

Business community engagement

Giving opportunities

Technology Transfer

Inventory unique research assets

IP management

Patentability assessment

Copyright management

License negotiation

Commercialization Support

Entrepreneurship education

Connect to innovation ecosystem: entrepreneurs, business advisors + mentors

Discover relevant market needs

SBIR/STTR support

Proof-of-Concept funding

Seed funding

Student engagement for market assessment, business planning

Industry Contracts

Research collaboration agreements

Industry research agreements

Other industry contracts

TTO Core Functions

TTO Support Areas

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UNIVERSITY OF COLORADO BOULDER

University of Colorado
Boulder | Colorado Springs | Denver | Anschutz Medical Campus
TECHNOLOGY TRANSFER OFFICE

Colorado
Office of Economic Development and International Trade

Aerospace and Defense Industry

Launching Colorado To The Next Level

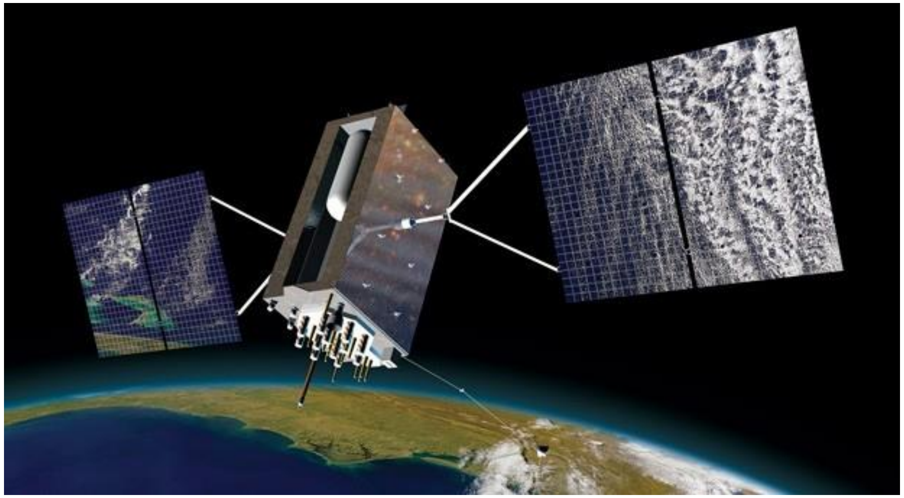
Aerospace & Defense Industry Champion
Jay Lindell

CU Aerospace Ventures 22 Sep 14

Colorado
Office of Economic Development and International Trade

Colorado Aerospace Economy

- **400 + companies provide space-related products, services; 84% small business, 54% fewer than 10 employees; tier 2/3 suppliers**
- **1st in nation per capita in aerospace employment; 25,153 jobs**
- **3rd in nation in private aerospace direct employment**
  - **170,000 + in adjacent jobs (telecomm, IT)**
  - **17.3% CO growth in past 10 years (6.1% nationally)**
- **3rd in nation in science & technology investments**
- **4th in nation in NASA funding R&D at $1.7B (FY14)**
- **Anchored in government funded programs**



"The space economy is an outsized driver of Colorado's economy"
Brookings Institute, Launch Report , Feb 2013

DigitalGlobe WorldView-3

Ball Aerospace & Technologies Corp.

DigitalGlobe™

ULA® United Launch Alliance

EXELIS

LOCKHEED MARTIN

"The fact that this cutting-edge satellite was built for a CO company, by CO companies, and launched by CO companies, speaks to our state's remarkable aerospace industry and economy." -- Governor Hickenlooper

Colorado Office of Economic Development and International Trade

Launching CO To The Next Level!

Jay.Lindell@state.co.us

Together We Will Build A Stonger Colorado!

National Aeronautics and
Space Administration

• NASA
• Colorado
• Space Technology

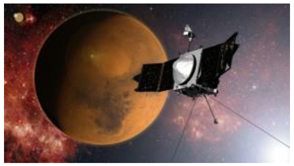
AeroSpace Ventures Day

Art Maples
Director of Strategic Partnerships – Colorado
Space Technology Mission Directorate

September 22, 2014

www.nasa.gov/spacetech

NASA and Colorado

MAVEN – CU/LASP, Lockheed Martin, ULA

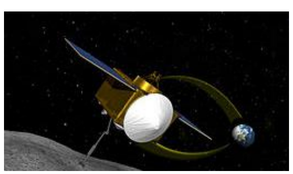
 

Orion – Lockheed Martin, ULA

JWST – Ball Aerospace

Dream Chaser – Sierra Nevada, ULA

OSIRIS REx – Lockheed Martin, ULA

GPIM – Ball Aerospace

…and many more!

Why Invest in Space Technology?

- Enables a **new class of NASA missions** beyond low Earth Orbit.
- **Delivers innovative solutions** that dramatically improve technological capabilities for NASA and the Nation.
- Develops technologies and capabilities that make NASA's missions **more affordable and more reliable.**
- Invests in the economy by **creating markets and spurring innovation** for traditional and emerging aerospace business.
- **Engages the brightest minds** from academia in solving NASA's tough technological challenges.

Value to NASA **Value to the Nation**

Addresses National Needs

A generation of studies and reports (40+ since 1980) document the need for regular investment in new, transformative space technologies.

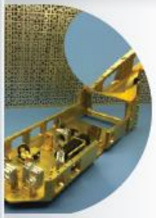
Who:
The NASA Workforce
Academia
Industry & Small Businesses
Other Government Agencies
The Broader Aerospace Enterprise

Deep Space Exploration is Near

Space Technology will focus investments in 8 key thrust areas that will enable or substantially enhance future NASA mission capabilities.

High Power Solar Electric Propulsion

Deep space human exploration, science missions and commercial applications with investments in advanced solar arrays and advanced electric propulsion systems, high-power Hall thrusters and power processing units.



Space Optical Comm.

Substantially increase the available bandwidth for near Earth space communications currently limited by power and frequency allocation restrictions, and increase the communications throughput for a deep space mission.

Advanced Life Support & Resource Utilization

Technologies for human exploration mission including Mars atmospheric In-situ resource utilization, near closed loop air revitalization and water recovery, EVA gloves and radiation protection.

Mars Entry Descent and Landing Systems

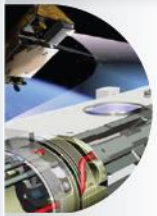
Permits more capable science missions, eventual human missions to mars including, hypersonic and supersonic aerodynamic decelerators, a new generation of compliant TPS materials, retro-propulsion technologies, instrumentation and modeling capabilities.

Space Robotic Systems

Creates future humanoid robotics, autonomy and remote operations technologies to substantially augments the capability of future human space flight missions.

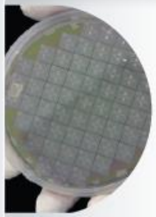
Lightweight Space Structures

Targets substantial increases in launch mass, and allow for large decreases in needed structural mass for spacecraft and in-space structures.



Deep Space Navigation

Allows for more capable science and human exploration missions using advanced atomic clocks, x-ray detectors and fast light optical gyroscopes.



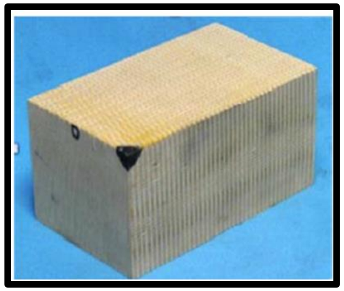
Space Observatory Systems

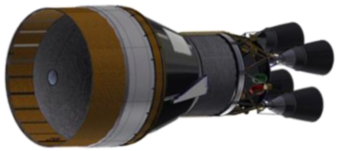
Allows for significant increases in future science capabilities including, AFTA/WFIRST coronagraph technology to characterize exo-planets by direct observation and advances in the surface materials as well as control systems for large space optics.

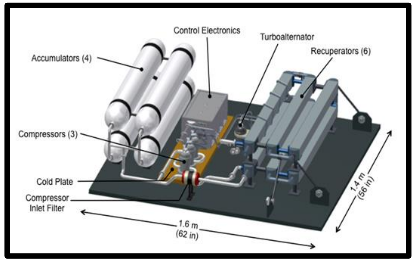
THRUST AREAS

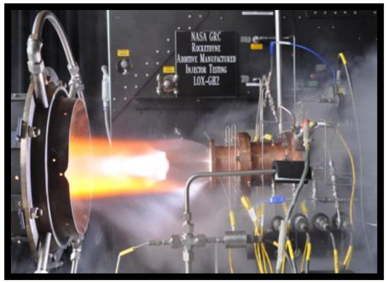
STMD Investments to Advance Future Capabilities of Space Launch System (SLS) & Orion

- Composite cryogenic propellant tanks and dry structures for SLS block upgrades
- Evolvable Cryogenics (eCryo) develops advanced cryogenic propellant management technologies for SLS future missions.
- Composite Evolvable Upper Stage (CEUS) helps to develop composite structures technologies for the SLS.
- Additive manufacturing and testing of upper stage injectors, combustion chambers and nozzles
- Phase change material heat exchangers for Orion in lunar orbit
- 3D Multifunctional Ablative TPS (3D MAT); Woven TPS infusion for Orion heat shield compression pads
- Develop high capacity cryocooler to enable zero boil-off of liquid hydrogen
- Advanced air revitalization for Orion upgrades



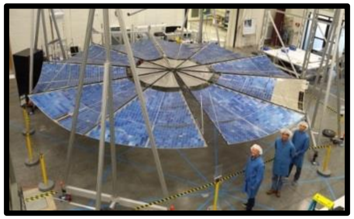


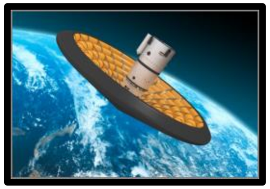


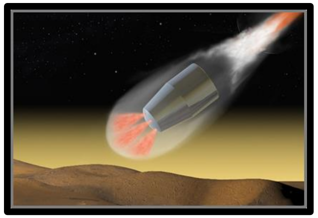


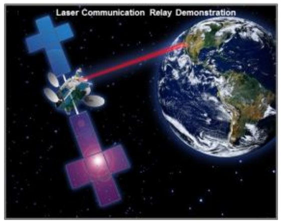
STMD Investments to Advance Human Exploration of Mars

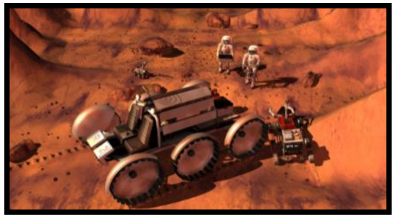
- High-powered solar electric propulsion – cargo and logistics transportation to Mars
- eCryo-chemical advanced cryogenic - in-space propulsion for crew transportation
- Advanced large-scale composite structures (CEUS) - for large In-Space transfer stages for crew transportation
- Composite cryogenic propellant tanks and dry structures – exploration upper stage
- Small Fission Power / Stirling Engine Power – Mars surface power
- Aerodynamic decelerators – deployable entry systems for large mass landers
- Supersonic decelerators - descent of large landed masses at Mars
- Supersonic retro-propulsion – large mass Mars landing and reusable launch vehicles
- Woven thermal protection system – more efficient and flexible TPS materials for entry
- Advanced close loop Air revitalization and water recovery – reduced consumables
- Mars atmospheric ISRU (oxygen) – life support and ascent vehicle oxidizer
- Humanoid robotics – enhanced exploration and crew workload relief
- Advanced mobility rover – remotely operated exploration
- Optical communications – high bandwidth communications at Mars





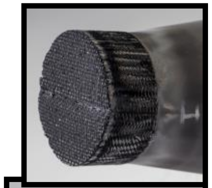


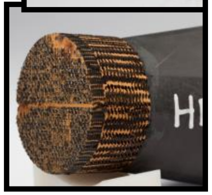




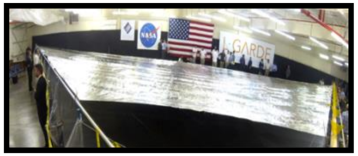
Advancing Science Mission Capabilities

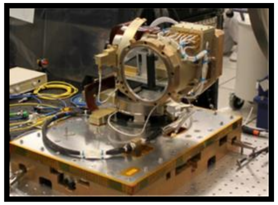
- **Entry, Descent, & Landing**
  - Instrumentation & Entry Systems Modeling – Mars EDL systems design
  - Woven Thermal Protection System – Venus, Mars & Outer Planets
  - Low Density Supersonic Decelerator – increased mass to Mars surface
  - Hypersonic Inflatable Aerodynamic Decelerator & Adaptable, Deployable Entry Placement Technology – deployable heat shields for Venus and Mars provides much lower entry loads



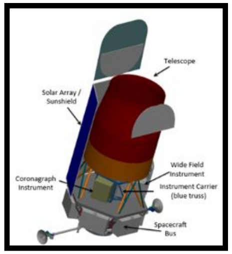


- **Propulsion & Power**
  - Green Propellant Infusion Mission - alternative to hydrazine
  - Solar Electric Propulsion – enabling new science missions
  - Solar Sail – enables unique vantage points for heliophysics
  - Small Fission – power for outer planet missions



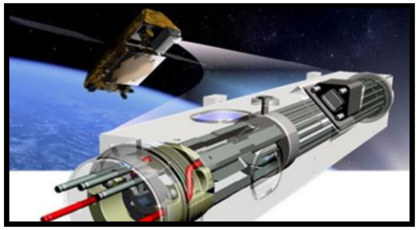


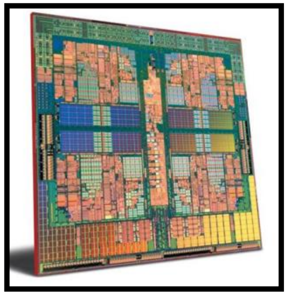
- **Communication & Navigation**
  - Deep Space Optical Comm & Laser Communication Relay Demo – up to 10x data return for planetary and near-Earth missions
  - NICER/SEXTANT & Deep Space Atomic Clock – navigation using celestial x-ray sources & highly accurate deep space navigation



- **Instruments, Sensors, & Thermal**
  - High Performance Spaceflight Computing – broadly applicable to science missions
  - AFTA / WFIRST Coronagraph – to perform direct observations of exoplanets and determining their atmospheric content

STMD - Aerospace Industry Alignment Examples

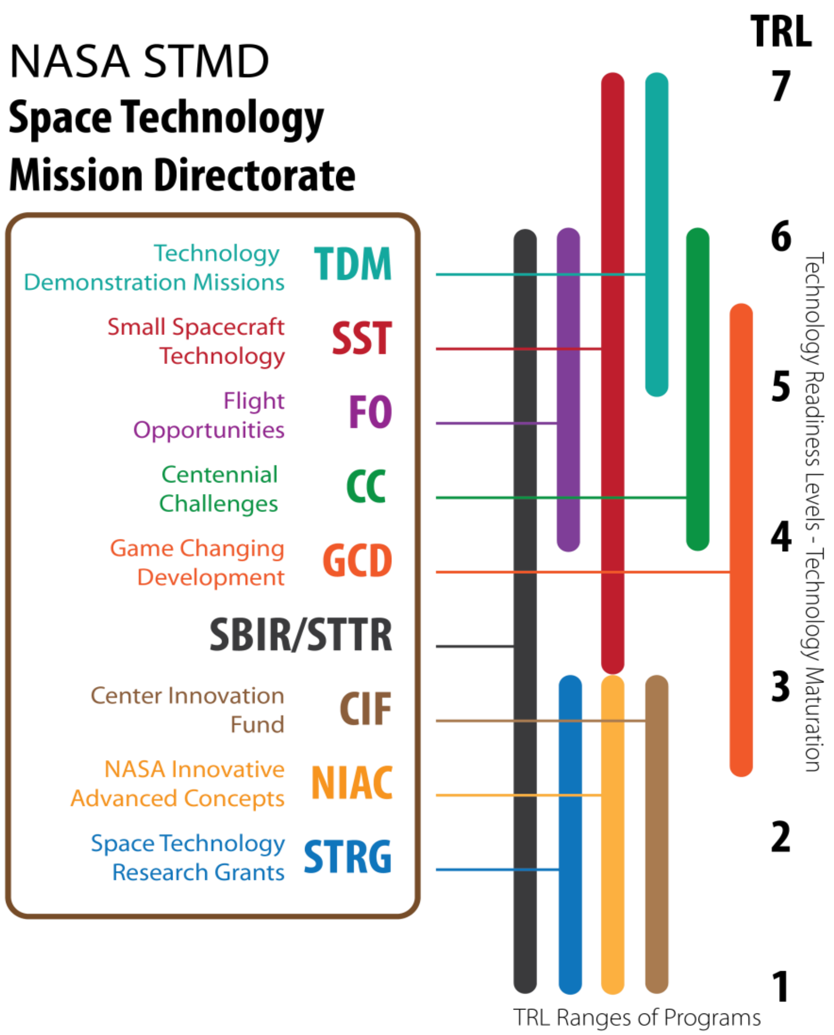




- **Structures and Materials**
  - Composite Tanks & Structures – for improved launch vehicle performance
  - Hypersonic Entry Technology – for orbital down mass capability
- **Propulsion & Power**
  - Green Propellant Infusion Mission – improved spacecraft performance & reduced toxicity and ground processing costs
  - Solar Electric Propulsion – enabling increased power, reduced mass and longer life for commercial communication satellites
- **Communication & Navigation**
  - Laser Communications – replacing radio frequency based gateway links with optical links and reduces spectrum utilization on commercial satellites
  - Deep Space Atomic Clock – improved timing for next generation GPS satellites
- **Instruments, Sensors, & Robotics**
  - High Performance Spaceflight Computing – for more capable radiation hard avionics for commercial communication satellites
  - Human Robotic Systems – to perform environmentally hazardous tasks and operate within terrestrial settings

STMD Programs

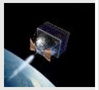
- **NASA Innovative Advanced Concepts (NIAC)** focuses on visionary aeronautics and space system concepts. Annual Awards ranging from $100K for Phase I and $500k for Phase II
- **Space Technology Research Grants (STRG)** engages academia in innovative research in advanced space technology. Annual Awards ranging from $60k to $250k
- **Small Business Innovative Research (SBIR)** and Small Business Technology Transfer (STTR) programs engage small businesses in aerospace research and development for infusion into NASA missions and the nation’s economy. Annual Awards; up to $125K for Phase I and up to $750K for Phase II
- **Game Changing Development (GCD)** focuses on maturing advanced space technologies that may lead to entirely new approaches for the Agency's future space missions.
- **Centennial Challenges** offers incentive prizes to stimulate innovative solutions by citizen inventors and independent teams out side of the traditional aerospace community. Prize Funding Varies
- **Flight Opportunities (FO)** facilitates low-cost access to suborbital environments for a broad range of innovators as a means of advancing space technology development and supporting the evolving entrepreneurial commercial space industry.
- **Small Spacecraft Technology (SST)** develops and demonstrates subsystem technologies and new mission capabilities for small spacecraft.
- **Technology Demonstration Missions (TDM)** seeks to mature laboratory proven technologies to flight-ready status.



STMD Partners with Universities to Solve The Nation's Challenges

U.S. Universities have been *very* successful in responding to STMD's competitive solicitations

- STMD-funded university space technology research spans the entire roadmap space
- More than **130** U.S. universities have led (*or are STTR partners on*) more than **550** awards since 2011
- In addition, there are many other partnerships with other universities, NASA Centers and commercial contractors

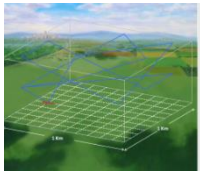
Program	# awards	# University-led awards	Upcoming Opportunities
Space Technology Research Grants 	284	284	• Early Career Faculty • Early Stage Innovations • NASA Space Technology Research Fellowships ***Annually***
NIAC 	93	26	• NIAC Phase I • NIAC Phase II ***Annually***
Game Changing Technology Dev 	37	14	Various topics released as Appendices to SpaceTech-REDDI ***Annually***
Small Spacecraft Technology 	22	13	Smallsat Technology Partnerships Cooperative Agreement Notice every two years, with the next opportunity in 2015
Flight Opportunities 	117	50	Tech advancement utilizing suborbital flight opportunities – NRA to U.S. Universities, non-profits and industry are planned. ***Twice Annually***
STTR 	*192*	*181 w/ univ partners*	*Annual STTR solicitation*
Centennial Challenges 	*4 Challenges (2 university-run)*	*40 teams (9 univ-led, 1 univ-led winner)*	• *One or more challenges annually* • ***Challenge competitions** with a **procurement track** to fund **university teams** via grants*

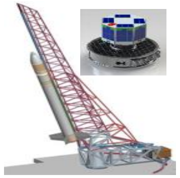
Collaborations with Other Government Agencies

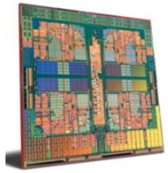
Currently, significant engagements include:

- Green Propellant Infusion Mission partnership with **Air Force Research Laboratory (AFRL)** propellant and rideshare with **DoD's Space Test Program (STP)**
- Solar Sail Demonstration partnership with **NOAA**
- **AFRL** collaboration Phase I of a High Performance Space Computing for a low power multi-core processor increasing performance a 100 fold.
- UAS Airspace Operations Prize Challenge coordinated with **FAA**
- Working with the **USAF Operationally Responsive Space Office (ORS)** for launch accommodations for the Edison Demonstration of Smallsat Networks (EDSN) mission.
- Partnership with **DARPA** on "Next Generation Humanoid for Disaster Response"
- Collaboration with **ARPA-e/Dept. of Energy** in new battery chemistries to aide in battery tech development
- Collaboration with **Space Missile Command** on use of Hosted Payload IDIQ contract mechanism for low cost access to space

STMD has ***45 activities*** with ***43 other government agencies***, and ***10 activities*** with ***14 international organizations***. STMD is sharing rides for ***13 activities***.







A Look Ahead

- Technology Demonstration Mission Program
  - BAA (topic areas under consideration)
- Solar Electric Propulsion
  - SEP tug
  - High powered solar arrays
  - Electric propulsion system
  - Low-cost solar arrays
- Advanced In-Space Propulsion
- Ultra Lightweight Composite Core Materials
- Outer Planet Exploration Technologies
  - Icy surface landings
  - Radiation protection
  - Robotics
  - Navigation
  - Communication
- Advanced Manufacturing

Partnering & Technology Transfer

NASA's Technology Transfer Program ensures that technologies developed for missions in exploration and discovery are broadly available to the public, maximizing the benefit to the Nation.

http://technology.nasa.gov/

For more information

www.nasa.gov/spacetech

art.maples@nasa.gov