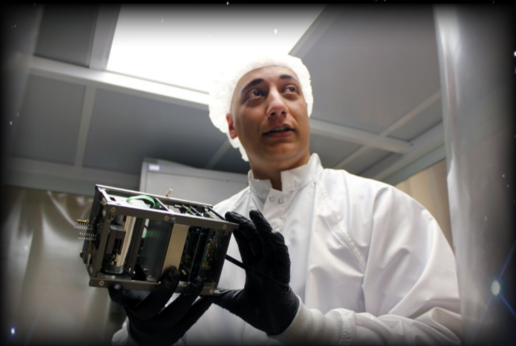
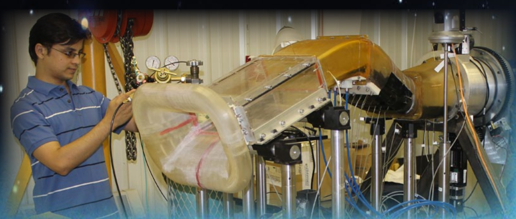
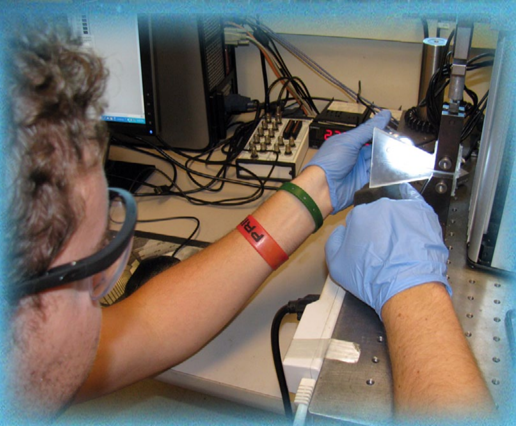
Aerospace Engineering Research Highlights

University of Illinois at Urbana-Champaign

September 2013







aerospace.illinois.edu

ILLINOIS

Foreword

Welcome to this first edition of the Research Highlights of the Department of Aerospace Engineering at the University of Illinois. The objective of this document is to give a snapshot of some of the research projects currently led by AE professors and their graduate students. These projects involve a wide range of experimental, theoretical and numerical techniques, and cover many topics in the three traditional areas of aerospace engineering:

- aerodynamics, fluid mechanics, combustion and propulsion
- dynamics, controls and space research
- advanced aerospace and energetic materials.

Aerospace engineering is very multidisciplinary by nature, so many of these projects cross discipline boundaries, building on the strong University of Illinois tradition in multidisciplinary research, and taking advantage of the availability of state-of-the-art facilities at the Beckman Institute for Advanced Science and Technology, the Coordinated Science Laboratory, the National Center for Supercomputing Applications, the new Blue Waters petascale computing system, and others. Examples of multidisciplinary projects listed in this document include the aero-thermo-structural simulations of supersonic and hypersonic vehicle structures, the modeling of plasma-based manufacturing techniques for nanostructured materials, the investigation of brain-machine interfaces, and the integrated systems engineering analysis of aerospace (systems of) systems.

I invite you to discover this limited, but representative set of research projects. Do not hesitate to contact the faculty members involved in these projects and/or the Department at aerospace@illinois.edu or 217-333-2651 if you have any questions.

Sincerely,
Philippe H. Geubelle
Bliss Professor and Head

Table of Contents

In-Situ Optical Flow Diagnostics Applied to a Large-Scale Low-Boom Inlet

Currently aircraft are not permitted to fly over-land in the United States at supersonic Mach numbers due to the sonic boom that is generated. A key component in lowering the overall sonic boom created is the inlet, which must be designed to achieve a low sonic boom while providing the necessary performance for the engine. In order to meet these goals, an improved understanding of the flow field internal to the inlet is needed, particularly when flow control devices are present.

Objective: Provide surface flow property measurements in a supersonic inlet to evaluate the performance of flow control devices and better understand the details of the flow field created for validation of computational models.

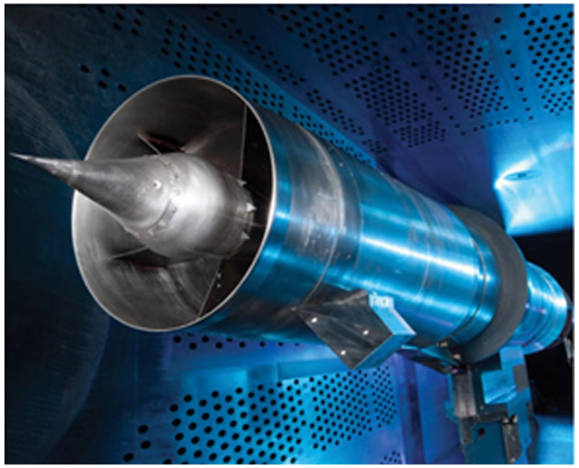
Approach: With research partners from Gulfstream and NASA, a supersonic inlet model was designed to be tested in the 8'x6' supersonic wind tunnel at NASA Glenn Research Center. The tests were conducted to investigate the use of flow control devices and associated performance improvements on a relaxed compression inlet. Integrated into the model was a camera and lighting system that allowed surface flow visualizations and pressure measurements to be obtained using pressure-sensitive paint on the center-body and struts internal to the inlet. With these "full surface" measurements, data were utilized to compare with computer simulations and to better understand the enhancements gained by the flow control devices.

Significant Results and Potential Impact: In addition to the data obtained on the flow field in the vicinity of the flow control devices, the methodology of providing advanced diagnostics mounted on a model in the harsh environment of a supersonic flow was demonstrated. This proof of concept allows researchers a new tool to obtain full-field optical-based diagnostics in similar wind tunnel models or for in-flight measurements.

Principal Investigators:
Gregory S. Elliott and J. Craig Dutton

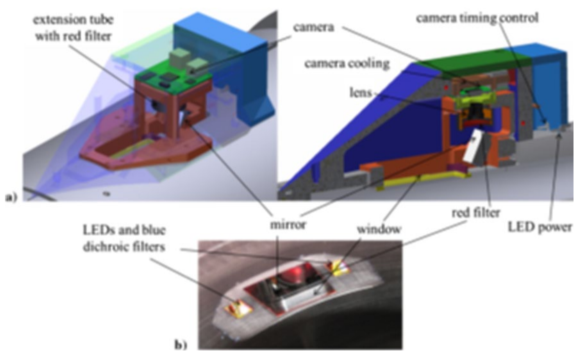
Funding: *Development of a Large Scale Low Boom Supersonic Inlet for Investigating Micro-Array Flow Control, NASA*

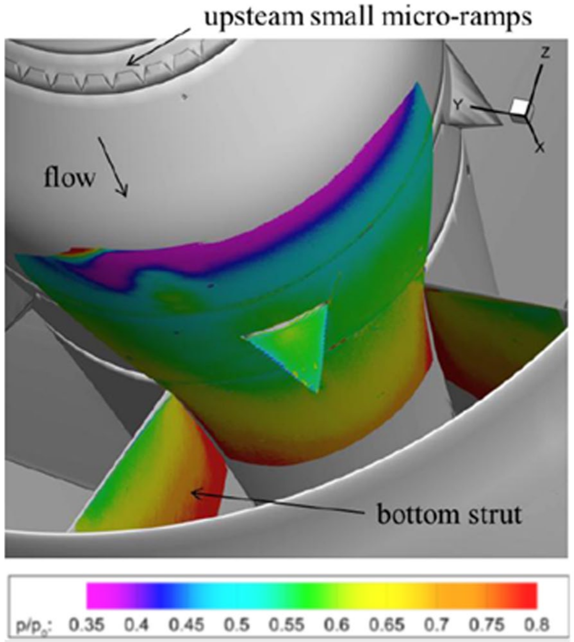
Key Publications: *1) Herges, T., Dutton, C., and Elliott, G., "Surface Flow and PSP Measurements in the Large-Scale Low-Boom Inlet," AIAA Journal of Propulsion and Power, Vol. 28, pp. 1243-1257, 2012. 2) Herges, T., Dutton, C., and Elliott, G., "High-Speed Schlieren Analysis of Buzz in a Relaxed-Compression Supersonic Inlet," AIAA Paper 2012-4146, 48th AIAA/ASME/SAE/ASEE Joint Propulsion Conference & Exhibit, Atlanta, Georgia, 2012.*



Single-stream large-scale low-boom inlet on the test strut in the supersonic wind tunnel.

Camera-housing components viewed a) from outside the inlet cowling and b) through the inside of the inlet.





Surface pressure in the inlet with upstream and downstream micro-ramps in a Mach 1.7 free stream measured with in-situ PSP.

Back to Table of Contents

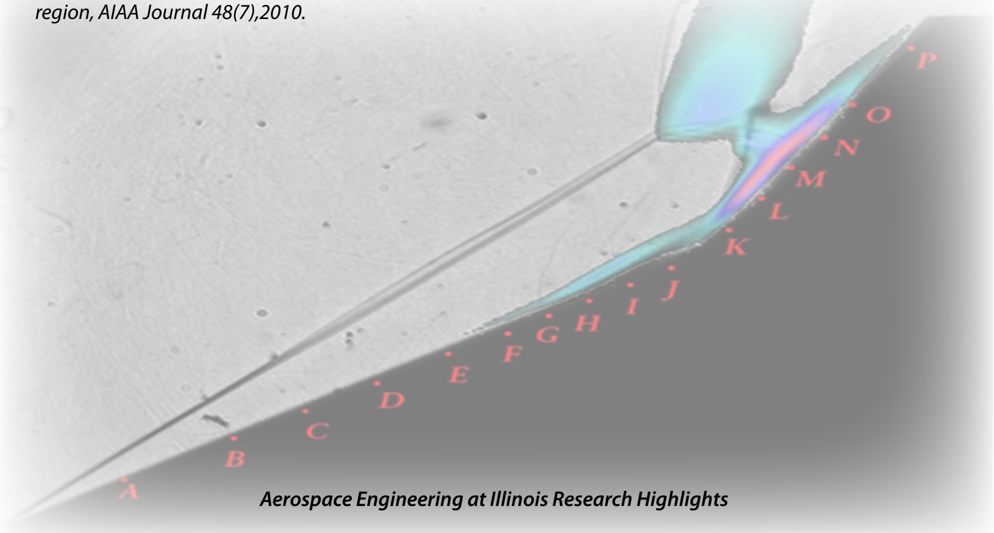
Hypervelocity Flight

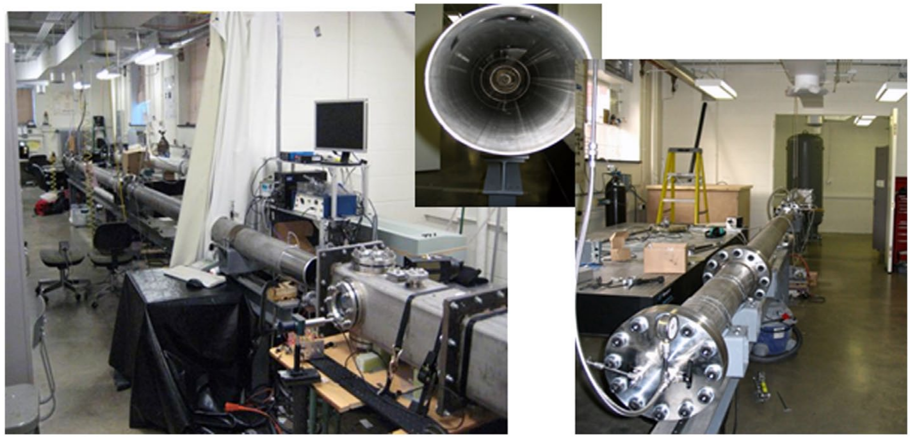
In hypervelocity flight, the energy exchange between the molecules in the atmosphere can significantly impact the thermal and aerodynamic loading on vehicles or naturally-occurring objects during planetary entry. Accurate prediction of heat transfer in the presence of these real gas effects can be critical to vehicle survival; however, creating such realistic flight conditions in ground testing facilities is challenging.

Objective: Our studies aim to contribute to the fundamental understanding of the nonlinear coupling of gas dynamics and molecular processes in hypervelocity flight.
Approach: An experimental facility which uses a novel method of gas acceleration to access a broad range of hypersonic conditions without contaminating the thermochemical state of the flow was built at Illinois.
Significant Results and Potential Impact: A simple scaling for heat transfer augmentation due to local and global distortion of the boundary layer based on the principle of local similarity has been identified. This scaling has been shown to be good agreement with the data even in cases of large distortion where approximate methods severely under-predict the heat transfer, and to be robust in the presence of imposed vortical structures.

Principal Investigator:
Joanna M. Austin

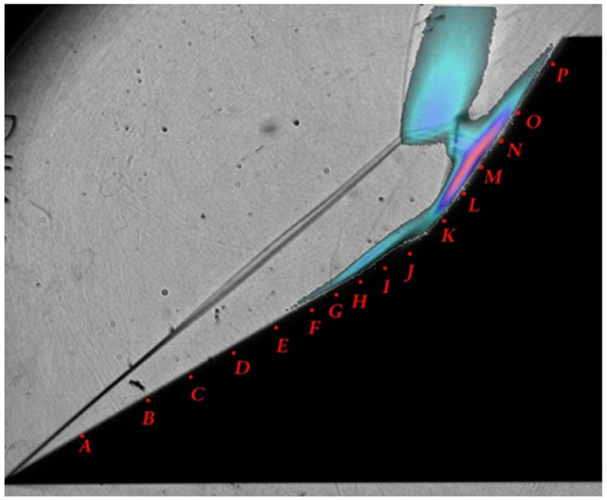
Funding: *Air Force Office of Scientific Research Young Investigator award FA9550-08-1-0172 with Dr. John Schmisseur as program manager*
Key Publications: *(1) Flaherty, W., and Austin, J.M, Scaling of Heat Transfer Augmentation due to Mechanical Distortions in Hypervelocity Boundary Layers, submitted to Physics of Fluids (2) Flaherty, W. and Austin, J.M., Comparative surface heat transfer measurements in hypervelocity flow, Journal of Thermophysics and Heat Transfer25(1): 180-183, 2011. (3) Sharma, M., Swantek, A.B., Flaherty, W., Austin, J.M., Doraiswamy, S. and G.V. Candler, Experimental and numerical investigation of hypervelocity carbon dioxide flow over blunt bodies, Journal of Thermophysics and Heat Transfer 24(4):673-683, 2010. (4) Sharma, M., Austin, J.M., Glumac, N.G. and L. Massa, NO and OH spectroscopic vibrational temperature measurements in a post-shock relaxation region, AIAA Journal 48(7),2010.*

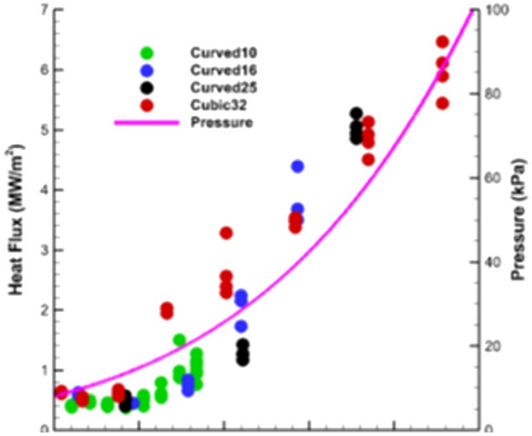




Hypervelocity expansion tube (HET) facility built at Illinois is capable of Mach numbers from 3.0 to 7.5 at realistic, high temperature conditions for planetary entry including real gas, thermochemical effects.

Overlay of shock configurations and emission indicating thermochemical activity in a Mach 7 hypervelocity shock-boundary layer interaction.





Collapse of heat transfer data with local turning angle and pressure.

Back to Table of Contents

Modeling the Aerodynamics of Aircraft in Stall/Spin Flight Conditions

Aircraft stall/spin is a common factor in many general aviation accidents. A common scenario occurs when a pilot inadvertently applies cross controls when turning onto final in a crosswind landing. This maneuver might happen near an altitude of 1000 ft AGL. Aerodynamically, the airplane is at a high angle of attack in high sideslip with a high bank angle, and without sufficient airspeed and altitude, the pilot may have just inadvertently committed the airplane to the basic stall/spin entry without enough time to safely recover. Taken together, stalls, deep stall/mush, and sometimes subsequent spin entry and spin make up a large fraction of fatal accidents in general aviation.

Objective: The objective of this research is to develop a methodology that can be used to simulate and better understand stall/spin aerodynamics and flight dynamics to improve aviation flight safety.

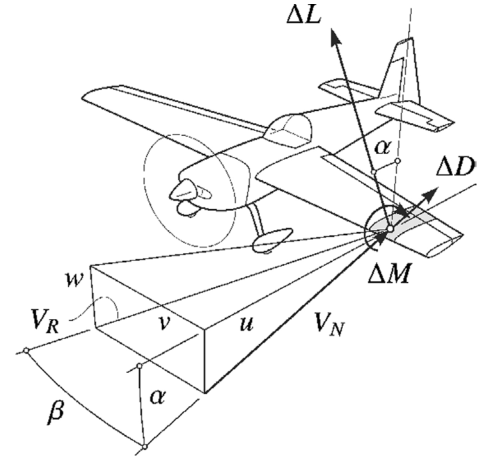
Approach: New methods in 6-DOF realtime flight simulation are being developed and validated to model the complex aerodynamics and flight dynamics of aircraft in unusual-attitude, upset, and stall/spin scenarios. In this research, the framework will be applied to explore aerodynamic concepts for expanding the flight envelope to increase the margin of safety by improving the stall/spin characteristics. The approach being developed relies on a component-based model that uses full aerodynamic coefficient data model any-attitude flight dynamics/aerodynamics.

Significant Results and Potential Impact: The method paves the way to exploring spin-resistant concepts such as leading-edge droop, discontinuous wing leading-edge modifications, airfoil modifications, and others. Tradeoffs related to these technologies will also be examined, e.g. effects on payload, range, and maneuverability. This research will be used to help define new concepts, guidelines and goals for spin-resistant technologies and safety of maneuvering flight.

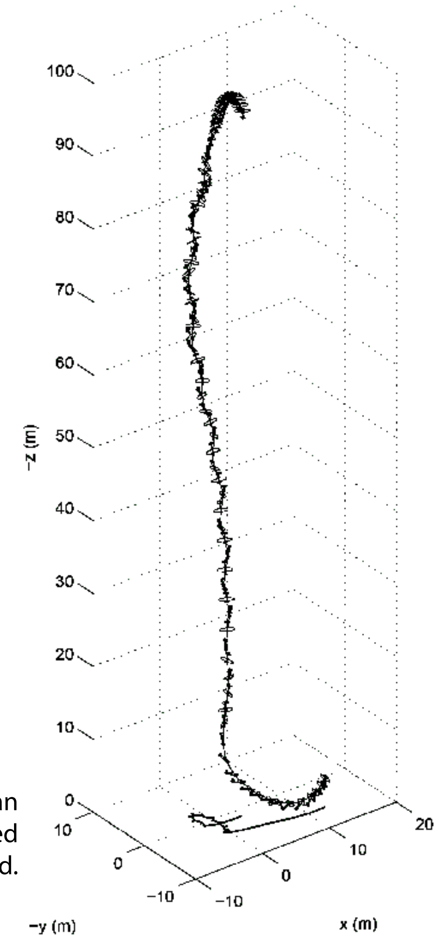
Principal Investigator:
Michael S. Selig

Funding: *University of Illinois at Urbana-Champaign*

Key Publications: *(1) Selig, M.S., "Modeling Full-Envelope Aerodynamics of Small UAVs in Realtime," AIAA Atmospheric Flight Mechanics Conference, AIAA Paper 2010-7635, Toronto, Ontario, Canada, August 2010. (2) Ragheb, A. M. and Selig, M. S., "Stall/Spin Mitigation Flight Testing with a Subscale Aerobatic Aircraft," AIAA Paper 2013-2806, AIAA Applied Aerodynamics Conference, San Diego, CA, June 2013. (3) Dantsker, O. D., Johnson, M. J., Selig, M. S., and Bretl, T. W., "Development and Initial Testing of the Aero Testbed: A Large-Scale Unmanned Electric Aerobatic Aircraft for Aerodynamics Research," AIAA Paper 2013-2807, AIAA Applied Aerodynamics Conference, San Diego, CA, June 2013.*



The graphic above shows decomposition of the wing into segments, each exposed to the local relative flow yielding the aerodynamic lift, drag and moment for a segment.



The graphic to the right shows an aircraft stall/spin trajectory predicted by the method.

Preparations for flight testing the 35% scale Extra 260 at Eli Field (Monticello, IL) to obtain inflight data for use in validating the stall/spin trajectory prediction methodology.

Passive and Active Control of Massively Separated High-Speed Flows

Base drag is a dominant drag component for missiles and projectiles in supersonic flight and is difficult to predict with typical computational tools. Experimental efforts to control the base flow field and reduce the base drag by passive and active means are being made.

Objective: Perform novel passive and active flow-control experiments on high-speed base flows to exploit the stability characteristics of these flows, as determined in previous experimental and numerical studies.

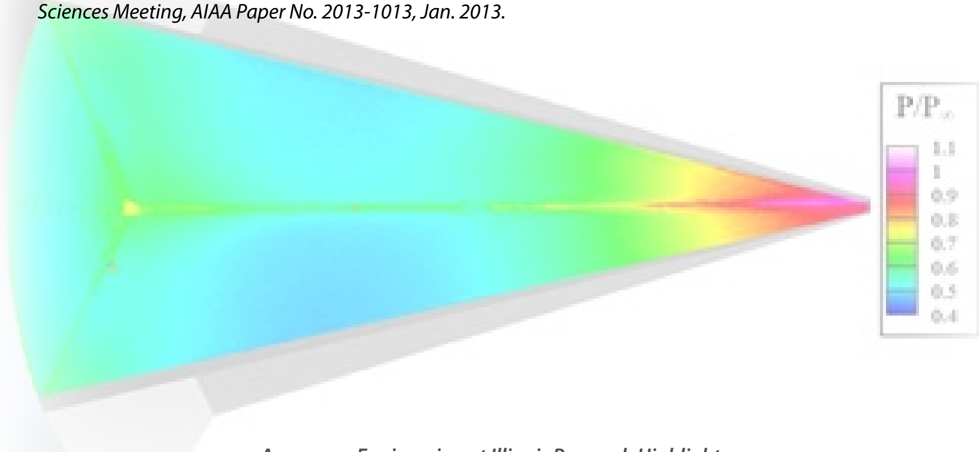
Approach: The specific passive-control studies that are being conducted consist of inserting splitter plates into the recirculation region to alter the stability characteristics and structure of the near-wake flowfield. The open-loop active control methods that are being employed use electric-arc excitation to force or inhibit specific instability modes for these high-speed separated flows. Two electric-arc actuator types are being investigated: localized arc-filament plasma actuators and pulsed plasma-jet actuators. In each case, the studies are motivated by our previous experimental investigations that have characterized the uncontrolled flow fields and also by recent DNS/stability studies of others.

Significant Results and Impact: Both the passive splitter plate and localized arc filament plasma actuators have demonstrated the ability to significantly alter the near-wake velocity distributions, base pressure distribution, shear layer growth rate, etc. However, the effects of control on the mean base drag have been modest. Actuators with enhanced control authority and/or covering a significantly larger portion of the base circumference are believed to be required.

Principal Investigators
J. Craig Dutton and **Gregory S. Elliott**

Funding: *Army Research Office*

Key Publications: *1) Reedy, T.M., G.S. Elliott, J.C. Dutton, and Y. Lee, "Passive Control of High-Speed Separated Flows Using Splitter Plates," AIAA Journal, 50:7, 1586-1595, July 2012. 2) DeBlauw, B.G., G.S. Elliott, and J.C. Dutton, "Active Control of Supersonic Base Flows with Electric Arc Plasma Actuators," 51st AIAA Aerospace Sciences Meeting, AIAA Paper No. 2013-1013, Jan. 2013.*



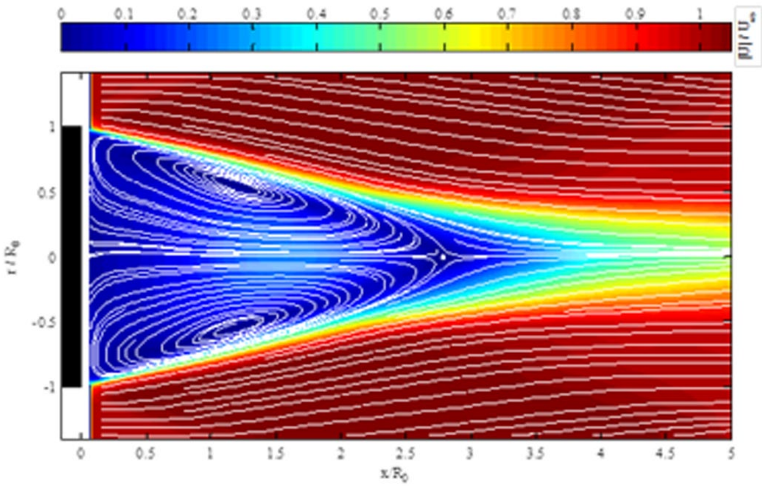


Image of mean velocity field and superimposed streamlines for no-control supersonic base flow; measured by particle image velocimetry (PIV)

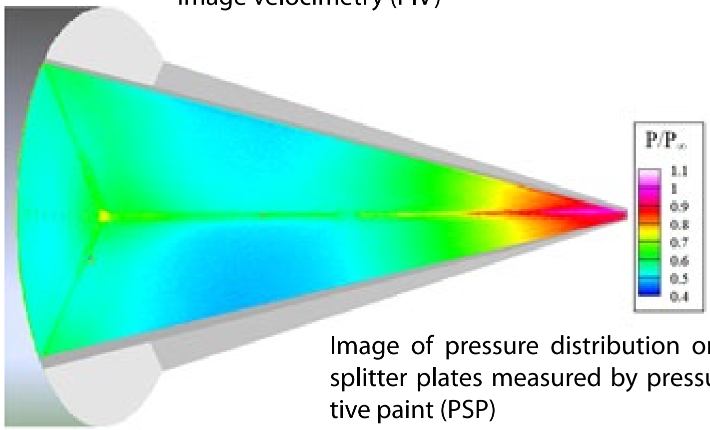


Image of pressure distribution on passive splitter plates measured by pressure-sensitive paint (PSP)

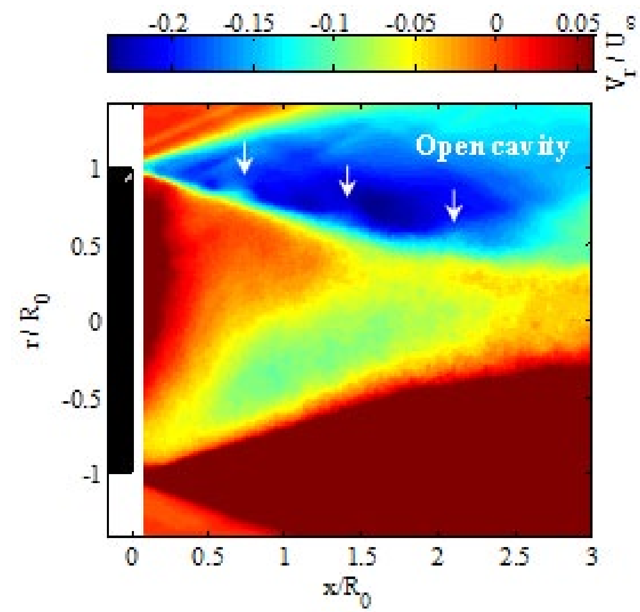


Image of transverse velocity field as affected by localized arc filament plasma actuator located at upper base corner (PIV)

Back to Table of Contents

Safety Enhancement of Energetic Materials through Multiscale Simulations

Energetic materials are used extensively for both civilian and military applications, such as rocket launch, explosives for construction and demolition, automotive airbags, and pyrotechnic fasteners and actuators for space applications. The increased performance of modern energetic materials also has created the possibility of new applications, such as chip power generation and shockwave generation for medical imaging. An understanding of the materials' potential initiation and explosion is vital for their safe storage, handling, and transportation. For example, the safety of the launch services program has always been NASA's top core value.

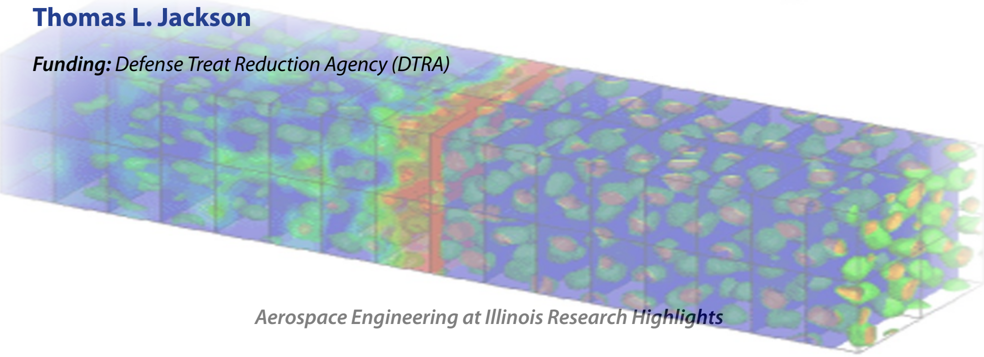
Objective: Improve understanding of the behavior of energetic materials through numerical simulations and develop computational tools to simulate the behavior of energetic materials in accident scenarios.

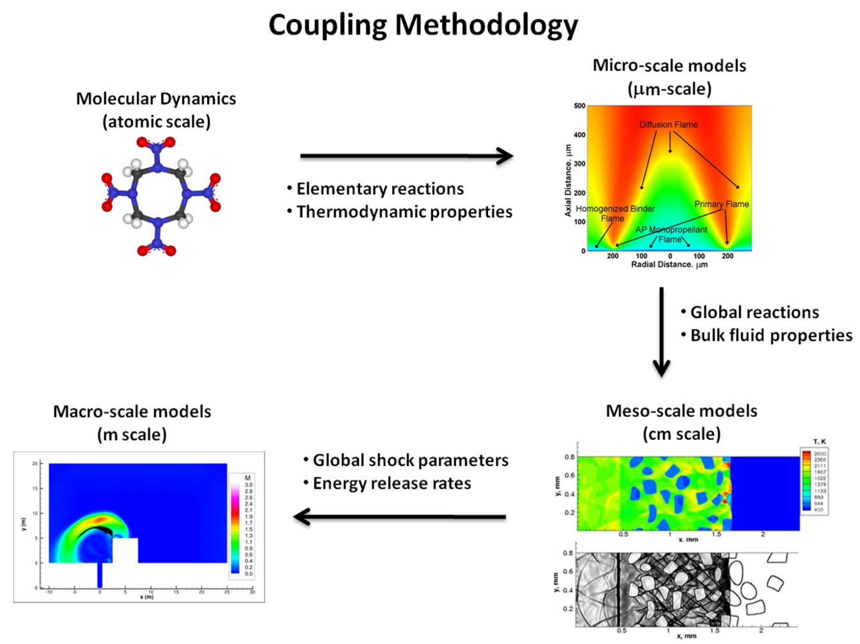
Approach: The problem from initiation to the eventual fast reaction wave is inherently multiscale and multiphysics. Chemical reactions occur on length and time scales several orders of magnitude smaller than those of the actual system at the macroscale. Energetic materials are typically heterogeneous with micro-structures formed by crystals embedded in a polymer binder. In addition, the resulting fast reaction wave from the energetic material will be a multi-phase flow. To simulate each of the flow regimes discussed above, an overall numerical infrastructure is required, one that includes (i) a molecular dynamics code to determine chemical kinetics and thermodynamic parameters, (ii) a microscale code utilizing the detailed species, transport, and kinetics parameters, (iii) mesoscale codes that can generate the heterogeneous material pack, initiate and propagate a fast reaction wave through the energetic material, and (iv) macroscale codes that can simulate multi-phase flow at the system or device scale.

Significant Results and Potential Impact: Each of these targeted physics areas themselves is a major challenge numerically. When these codes are coupled together for predictive simulations, the challenges increase. This work takes a multiscale approach to couple methodologies of various multiphysics codes.

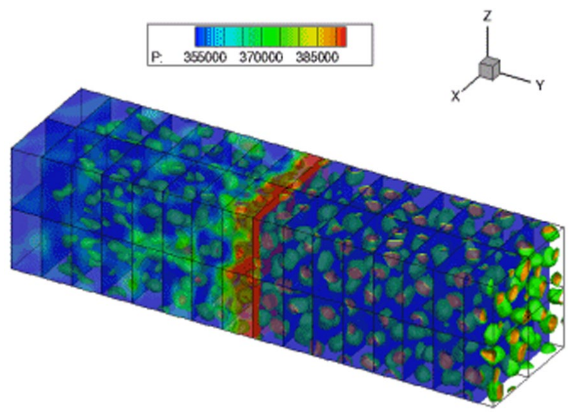
Principal Investigator:
Thomas L. Jackson

Funding: *Defense Treat Reduction Agency (DTRA)*





Multiscale coupling strategy.



Three-dimensional simulation of shock-to-detonation transition.

Effect of Ice Accretion on Full-Scale, Swept-Wing Aerodynamic Performance

Ice accretion and its aerodynamic effect on highly three-dimensional swept wings are extremely complex phenomena important to the design, certification, and safe operation of small and large transport aircraft. Significant knowledge gaps remain for swept-wing geometries and supercooled, large-droplet icing conditions including freezing drizzle and freezing rain.

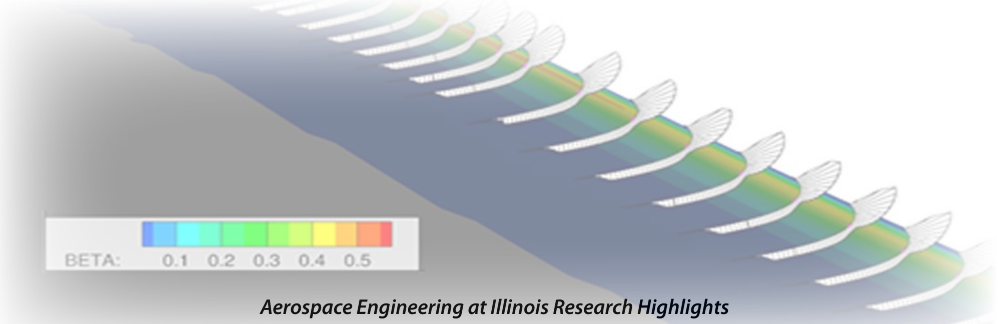
Objective:
Provide an overall methodology for the study of three-dimensional swept wing aerodynamics including both wind tunnel testing and computer simulation capabilities. Additionally, produce data for comparison and validation for other investigations.

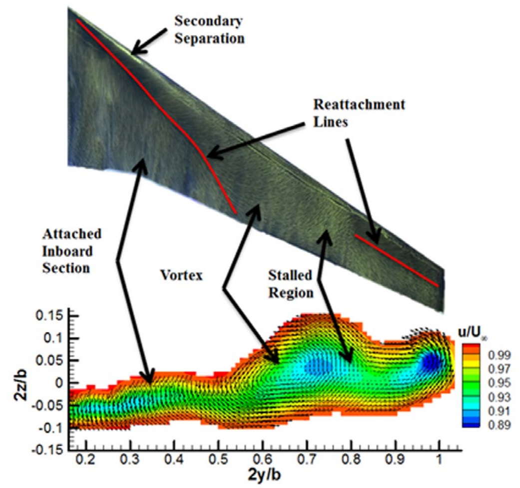
Approach:
In collaboration with NASA, FAA, ONERA, and Boeing, a multi-phase research effort has been developed to address some of these knowledge gaps. A wing geometry has been selected which is similar to a modern, transonic, commercial transport aircraft. Sections of this wing will be testing in NASA's Icing Research Tunnel while simultaneously they will also be modeled using CFD and computational ice accretion tools. With this improved understanding of the ice formation on a swept wing, several campaigns of aerodynamic experiments will be conducted in order to improve the understanding of the flowfield associated with swept wings with these ice accretions.

Significant Results and Potential Impact:
In addition to improving our understanding of the underlying physics, the certification process for aircraft in icing conditions will be improved by this study's production of an overall process for swept wing icing analysis. This methodology should lead to efficiency increases and cost savings for aircraft manufacturers along with improved aircraft safety.

Principal Investigator:
Michael B. Bragg

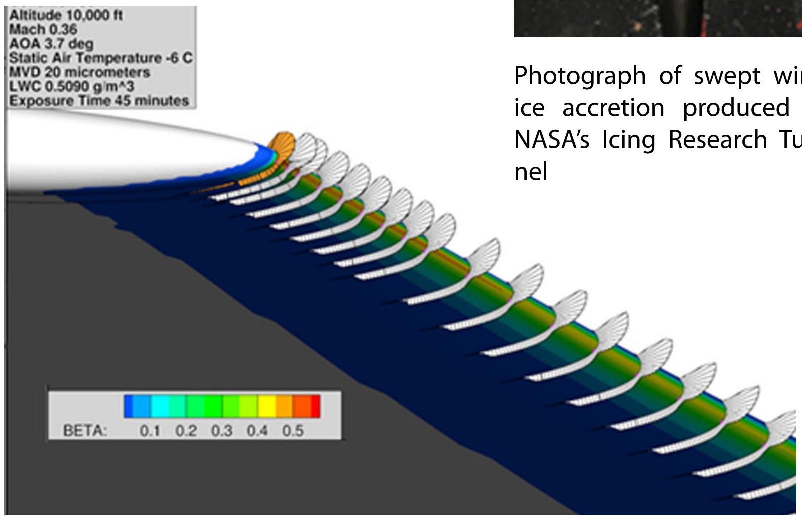
Funding: *FAA Cooperative Agreement 10-G-004 and NASA NRA Grant NNX12 B04A.*
Key Publications: *1) Diebold, J.M., Broeren, A.P., and Bragg, M.B., "Aerodynamic Classification of Swept-Wing Ice Accretion," AIAA 2013-2825. 2) Fujiwara, G.E.C., Woodard, B.S., Wiberg, B.D, Mortonson, A.J., and Bragg, M.B., "A Hybrid Airfoil Design Method for Icing Wind Tunnel Tests," AIAA 2013-2826. 3) Diebold J.M. and Bragg, M.B., "Study of a Swept Wing with Leading-Edge Ice Using A Wake Survey Technique," AIAA 2013-0245. 4) Diebold, J.M, Monastero, M.C. and Bragg, M.B., "Aerodynamic of a Swept Wing with Ice Accretion at Low Reynolds Number," AIAA 2012-2795.*





Wind tunnel results showing a comparison of surface oil flow visualization (top image) with 3-D wake surface data (bottom image) showing contours of streamwise velocity with vectors of transverse velocity for a swept wing with artificial ice shape.

Photograph of swept wing ice accretion produced in NASA's Icing Research Tunnel



Results from computational models showing the predicted ice-shapes and collection efficiency (Beta) for the outboard portion of a swept wing in icing conditions.

Plasma-Surface Interaction: High Fidelity Modeling of Surface Pattern Formation at the Nanoscale

The nanotechnological manufacturing of nanostructured material surfaces has been inspired by the unprecedented properties of numerous functional surfaces found in nature. Successful mimicking of such hydrophobic nanostructured surfaces for aerospace structures could be the key to significantly reduced skin-friction drag, thereby lowering fuel consumption and carbon emissions. In addition, the self-cleansing properties of such surfaces will completely eliminate the need for de-icing, which will translate to reduced maintenance costs. Plasma-based processes demonstrate the most promise for deterministic nanofabrication of these surfaces. However, the interrelationship between the basic plasma parameters and the resulting surface nanostructure is complicated by the synergism between the gas phase plasma chemistry, the surface chemistry as modified by radiation, and the film growth mechanisms, which remains a critical roadblock to controlled patterning of materials at the nanoscale.

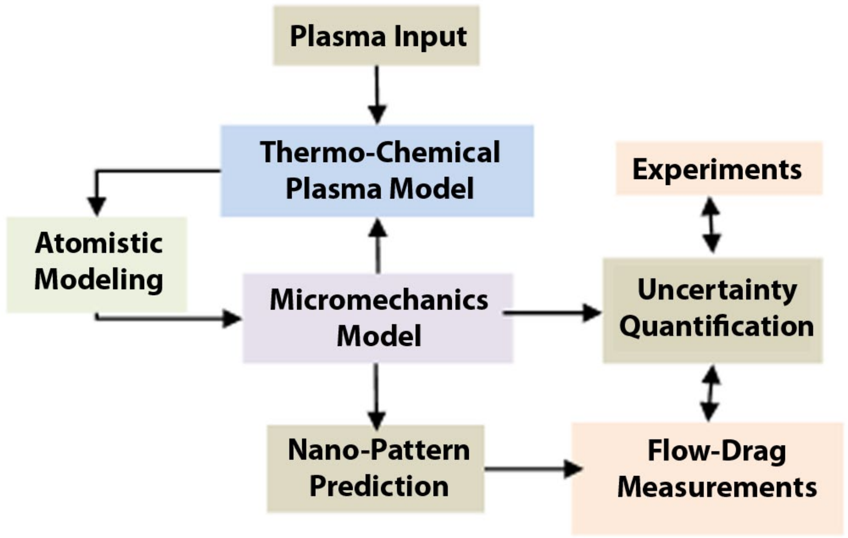
Objective: The objective of this effort is to elucidate the plasma-surface interactions during plasma deposition processes and establish the relationship between film composition, structure, properties, and basic plasma parameters.

Approach: The complex interaction of gas phase chemistry taking place in the plasma and the surface reactions is modeled by a multi-scale, multi-physics model that fully couples a novel thermo-chemical model for the plasma with an atomistic-informed model for the material. The coupled chemo-mechanical model takes into consideration the reactions at the substrate surface, and calculates feedback of species/fluxes to the plasma discharge.

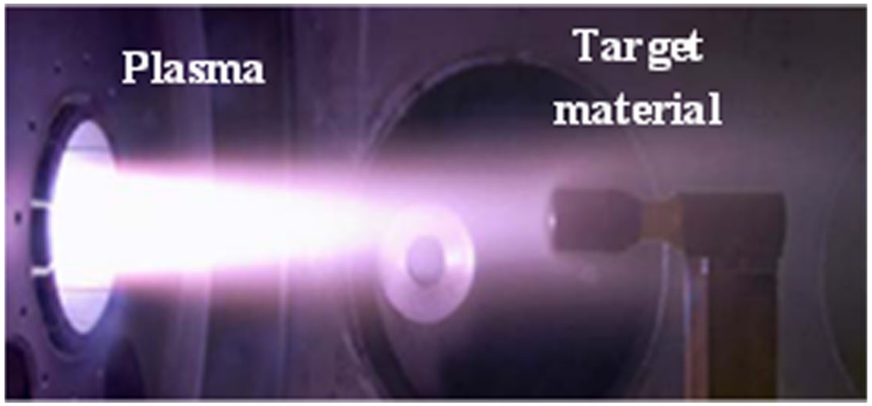
Significant Results and Potential Impact: This model framework permits high-fidelity physics-based predictions under a wide range of plasma conditions and target materials, even without any experimental data. The established framework will enable deterministic nano-scale patterning of nanostructured surfaces, which can significantly improve the drag-reduction and self-cleaning capabilities of planes and ships.

Principle Investigators:
Huck Beng Chew and **Marco Panesi**

Funding: *AE Multidisciplinary Initiative 2013*



Coupling of the thermo-chemical model for the plasma with an atomistic-informed model for the material.



Nanoscale surface pattering by RF plasma.

Back to Table of Contents

Predicting Aerodynamic-Structural Interaction for Improved Vehicle Robustness

Predicting the aerodynamic and thermal loads applied to an air vehicle is critical to ensure robust, lightweight designs. Historical, semi-empirical load models do not explicitly account for aerodynamic-structural coupling and often make "worse case" assumptions that lead to overly conservative and heavy designs.

Objective: Examine the dynamic coupling between aerodynamic, structural, and thermal components of representative aerospace structures to evaluate (a) the degree of coupling and (b) the ability of reduced order models to accurately predict the dynamic response.

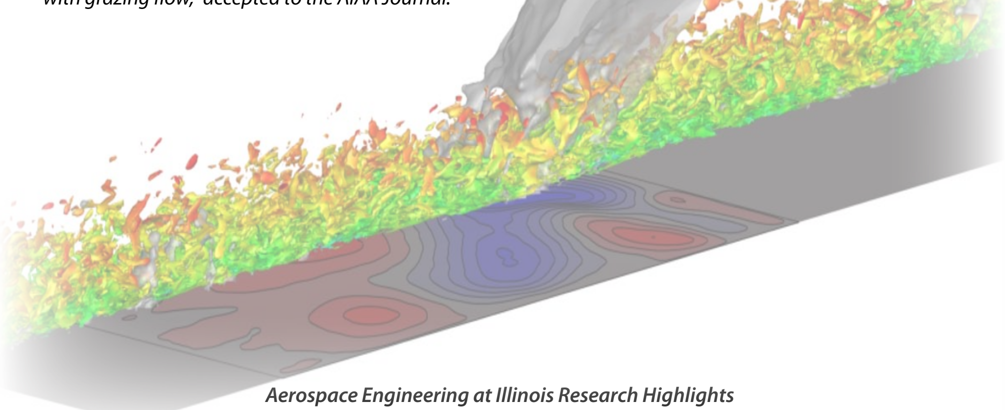
Approach: Solve directly the compressible Navier-Stokes equations, equations of nonlinear elasticity, and equation of heat conduction using high-order finite difference direct numerical simulation and finite element methods without reduced order models. The structural and aerodynamic domains are coupled using a conservative load transfer method. Use large parallel computers to simulate the coupled system and generate numerical databases for post-processing.

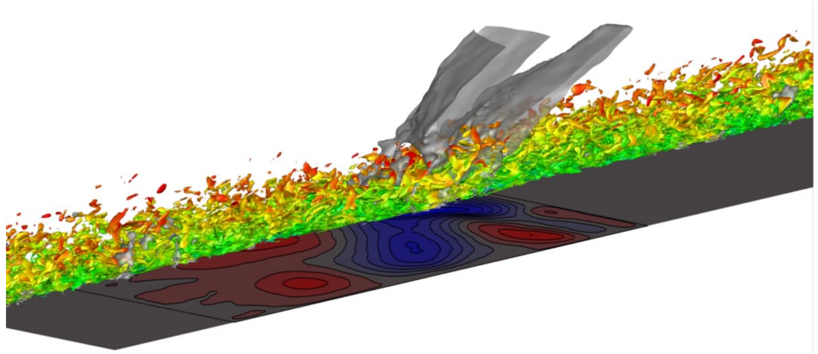
Significant Results and Potential Impact: Commonly-used piston theory models fail to predict maximum heat loads around and downstream of surface protuberances in a hypersonic environment with a laminar boundary layer. For turbulent boundary layers the dynamic surface motion can modify the turbulence production and render typical Reynolds-averaged Navier-Stokes (RANS) models inaccurate and generate increased aeroacoustic noise.

Principal Investigators:
Daniel J. Bodony and **Philippe H. Geubelle**

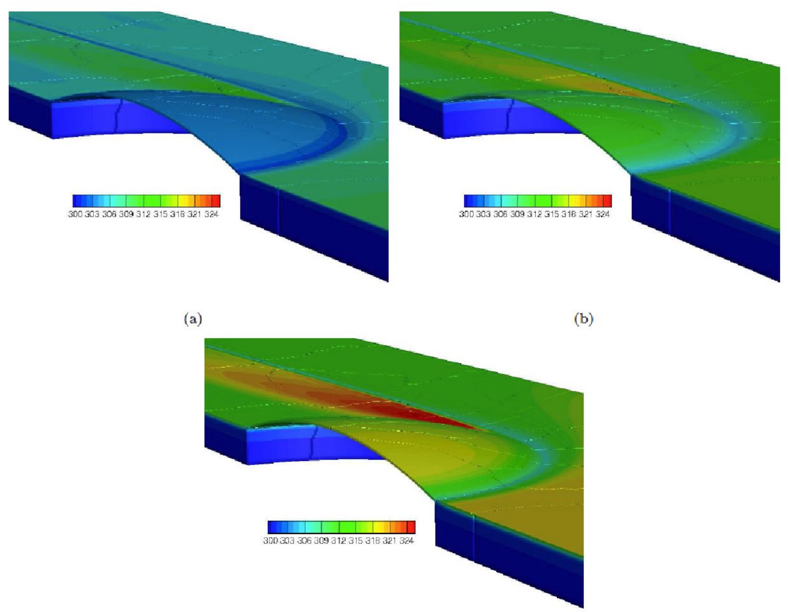
Funding: *United States Air Force Research Laboratory (Dayton, OH) and National Science Foundation CAREER Award.*

Key publications: *(1) Ostoich, C., Bodony, D. J., and Geubelle, P. H. (2012) "Coupled fluidthermal response of a spherical dome due to a Mach 6.59 laminar boundary layer," AIAA Journal, Vol. 50(12), pp. 2791-2808; (2) Ostoich, C., Bodony, D. J., and Geubelle, P. H. (2013) "Interaction of a Mach 2.25 turbulent boundary layer with a fluttering panel using direct numerical simulation," accepted to the Physics of Fluids; (3) Sucheendran, M., Bodony, D. J., and Geubelle, P. H. (2013) "Coupled structural-acoustic response of a duct-mounted elastic plate with grazing flow," accepted to the AIAA Journal.*





Mach 2.25 turbulent boundary interacting with a clamped steel-like panel. Panel deformation is shown along with panel-generated acoustic waves and boundary layer vorticity.



5-second evolution of surface temperature of an Aluminum dome fixed to a ceramic panel in a Mach 5.74 laminar boundary layer.

Back to Table of Contents

Three-Dimensional Tomographic Studies of Battery Electrodes

Li+ batteries have dominated the portable energy storage market for some time and are increasingly being used in aerospace engineering applications. However current batteries are limited in terms of performance and also constitute extra weight that has to be subtracted from the vehicle payload capacity – a critical constraint especially for lightweight structures. Improving current Li+ batteries could be done by replacing their graphite-based electrodes with Si- or Sn-based ones, which offer higher electrochemical performance. However, their structural performance is limited because of large volume changes experience by Si and Sn upon lithiation.

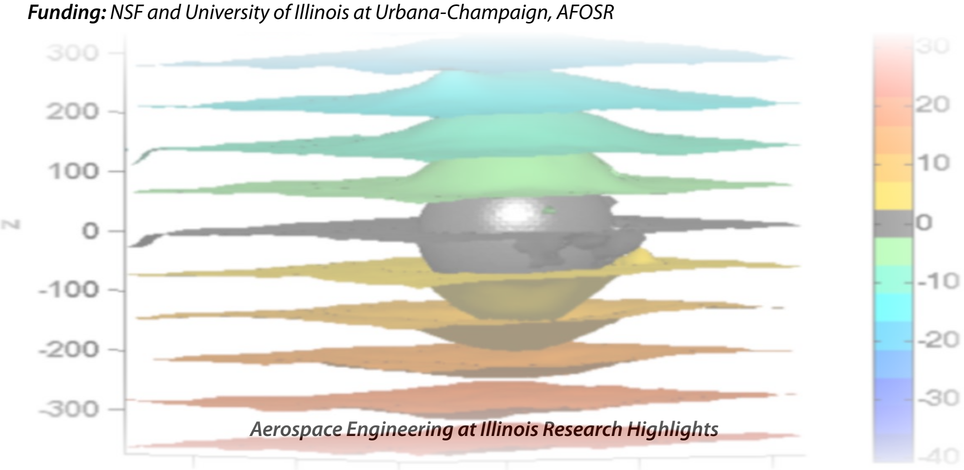
Objective: The objective of this effort is to obtain a 3D understanding of the mechanical and electrochemical performance of functional Si- and Sn-based electrodes, and use the information to design more efficient multifunctional structural batteries by optimizing electrode microstructure.

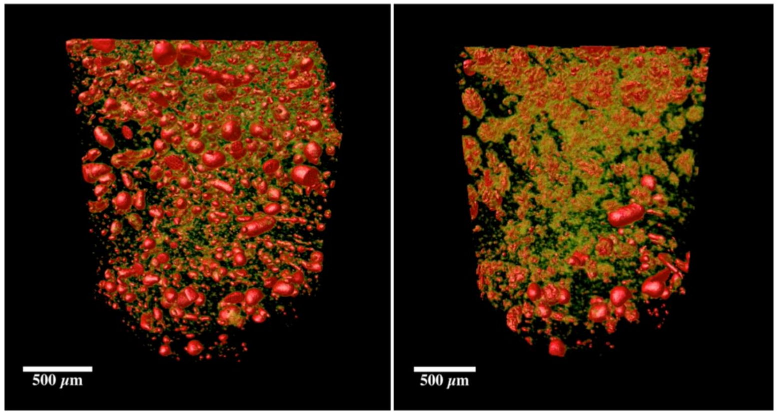
Approach: 3D X-ray microcomputed tomography is combined with the novel metrology technique of Digital Volume Correlation (DVC) to measure the internal deformation of electrodes during lithiation and delithiation. Based on this an understanding of combined electrode electrochemical and mechanical response is obtained.

Significant Results and Potential Impact: To date we have non-destructively measured in situ in the interior of electrodes, particle volume expansions up to 250% of original volume, and have seen differing failure mechanisms for Si- or Sn-based electrodes (matrix cracking and particle cracking respectively). The impact of this work will be to help optimize electrode microstructures for combined structural and electrochemical performance.

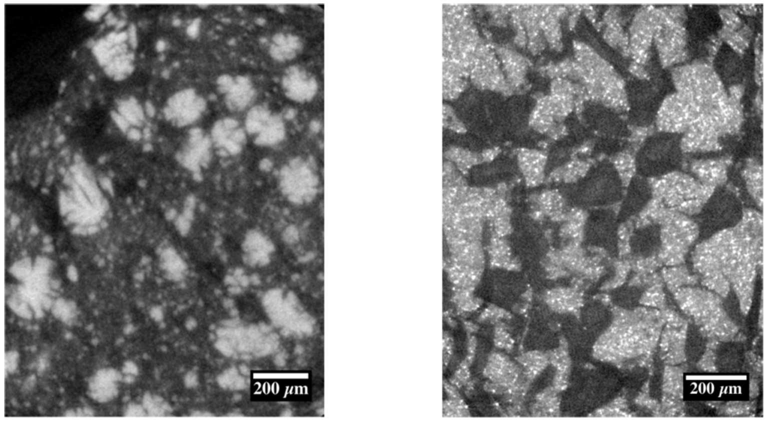
Principal Investigators:
John Lambros, **Ioannis Chasiotis** and **Shen Dillon** **(MatSE)**

Funding: *NSF and University of Illinois at Urbana-Champaign, AFOSR*

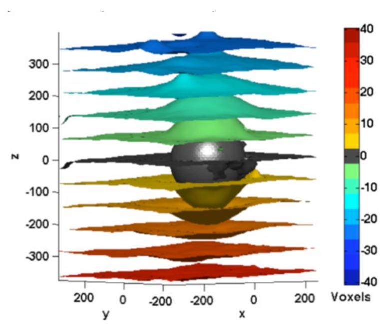




Micro-CT 3D image reconstructions of particles in a Sn-based electrode before lithiation (left) and after lithiation (right). Particles are shown in red and damaged regions are shown in green (arbitrary coloring).



Micro-CT X-ray single image slices after complete lithiation showing massive particle cracking in a Sn-based electrode (left –particles are white, matrix is black) and significant matrix cracking in a Si-based one (right –particles are black, matrix is white). In both cases significant volume expansion of the particles (over 250%) also occurs.



3D contour plot of internal vertical (z-direction) displacement field around a spherical particle in compression measured using DVC.

Back to Table of Contents

Autonomic Protection, Repair, and Shutdown of Lithium-Ion Batteries

Lithium-ion batteries are widely used for powering mobile electronic devices. New strategies for improving battery safety and lifetime are critical for advanced Li-ion battery applications. These strategies include developing a particle-based separator capable of performing thermally-triggered, autonomic shutdown and triggered release of microencapsulated additives to repair damage.

Objective: The objective of this research is to develop a new class of particle-based shutdown and life extension techniques for advanced Li-ion batteries. Particles must survive in battery electrolytes and within the operating voltage window.

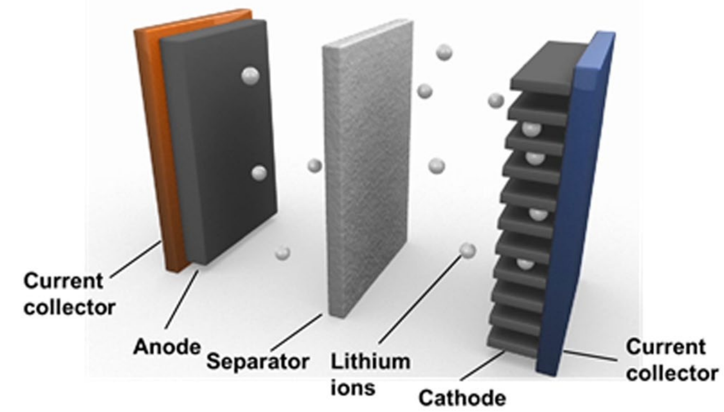
Approach: Autonomic, thermally-induced shutdown of Li-ion batteries is demonstrated by incorporating thermoresponsive polyethylene (PE) microspheres onto battery anodes. When the internal battery environment reaches a critical temperature, the microspheres melt and coat the anode with a non-conductive barrier, halting Li-ion transport permanently. Another approach to improving battery functionality is via the microencapsulation of damage-repairing additives. Several approaches have been developed to restore electric conductivity, including the release of conductive polymers precursors, liquid metal, and conductive particle suspensions. Microencapsulation allows for a high additive loading and release only when and where needed.

Significant Results and Potential Impact: PE microsphere shutdown technology can be used in conjunction with commercial separators for an increased level of battery safety. Further, a wide range of polymer microspheres can be used in order to optimize shutdown response for specific battery designs. Additionally, a wide variety of materials for damage repair of Li-ion batteries have been microencapsulated and tested. During testing, capsule core release leads to the formation of a conductive network in the damage zone. The potential impact of this work is the development of batteries that last longer due to their self-healing capabilities.

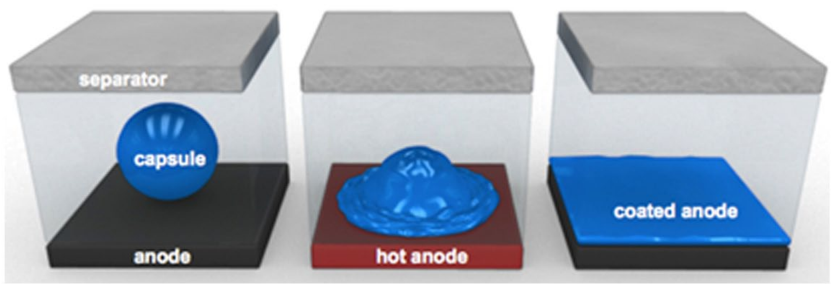
Principal Investigators:
Scott R. White, Nancy R. Sottos, and Jeffrey S. Moore

Funding: *Center for Electrical Energy Storage, an Energy Frontier Research Center funded by the US Department of Energy, Office of Science, Office of Basic Energy Sciences. Marta Baginska is supported by the National Science Foundation Graduate Research Fellowship Program*

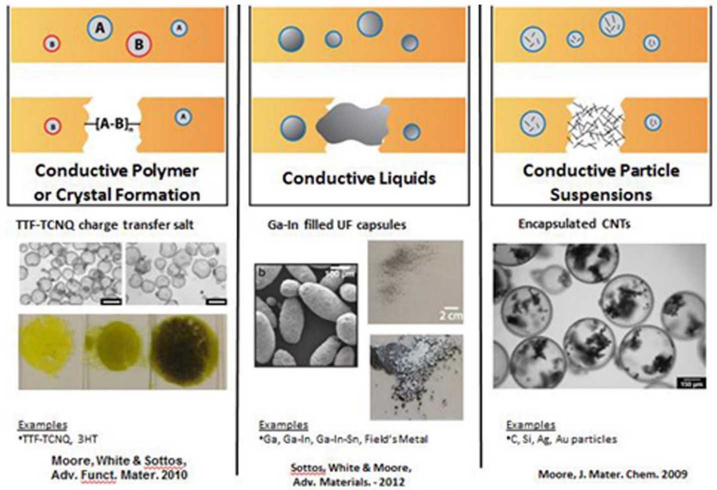
Key Publications: *1) M. Baginska, B.J. Blaiszik, R.J. Merriman, N.R. Sottos, J.S. Moore, and S.R. White, "Autonomic Shutdown of Lithium-Ion Batteries Using Thermoresponsive Microcapsules," Advanced Energy Materials 2(5), 583–590 (2012). 2) Blaiszik, B.J., Kramer, S.L.B., Grady, M.E., McIlroy, D. A., Moore, J.S., Sottos, N.R., White, S.R. "Autonomic Restoration of Electrical Conductivity", Adv. Mater., 24(3), 398-401 (2012).*



Schematic representation of a Lithium-ion battery.



Schematic representation of microsphere-based shutdown concept for Li-ion batteries.



Schematic and pictographic representation of conductivity restoration approaches. These approaches include the release of microencapsulated conductive polymer precursors, conductive liquids, and conductive particle suspensions.

Microvascular Composites for High Temperature Applications

Hypersonic aircraft and reentry vehicles are exposed to high structural, acoustic and thermal loading. As part of hybrid ceramic/metal/composite materials to be used for aircraft skin panels, actively cooled microvascular composites are being considered as potential loading bearing lightweight components.

Objective: Manufacture, assess and optimize a new class of microvascular, actively cooled, 3D composite materials, with the embedded microchannels intimately incorporated in the composite microstructure.

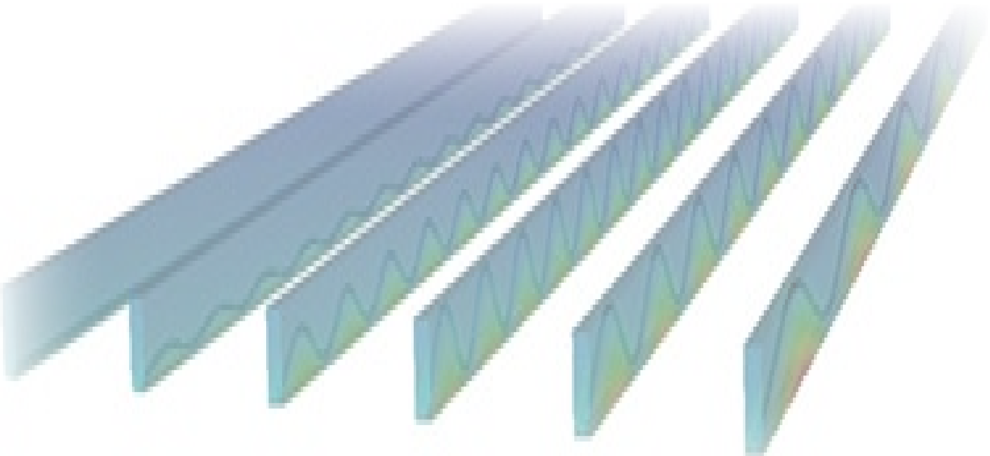
Approach: A new manufacturing technique based on sacrificial PLA fibers has been developed to embed networks of microchannels in 3D composites, with minimal impact on the composite microstructure, and therefore on the structural integrity of the composite panel. A novel interface-enriched generalized finite element method (IGFEM) is used to simulate the thermal impact of the coolant, allowing for the simulation of many configurations with meshes that do not conform to the microchannel geometry.

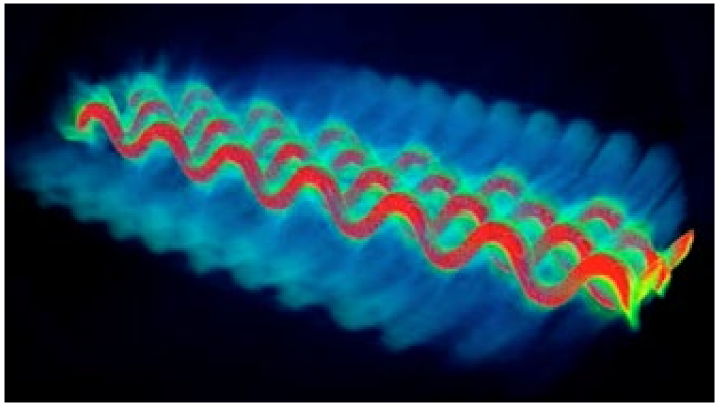
Significant Results and Potential Impact: The ability to create 3D composites with complex microchannel network geometries has been demonstrated. The new IGFEM method offers a lot of potential for the simulation and computational design of a wide range of heterogeneous materials.

Principal Investigators:
Philippe H. Geubelle, **Nancy R. Sottos** and **Scott R. White**

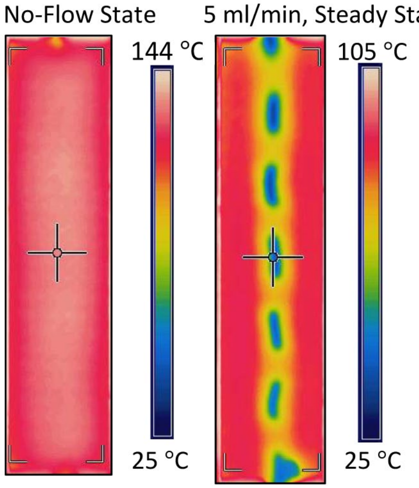
Funding: *Air Force Office of Scientific Research, Multi-University Research Initiative in Collaboration with Texas A&M, U. Michigan, Virginia Tech, U. Dayton and Stanford.*

Key Publications: *1) Esser-kahn A., Thakre P.R., Dong H., Patrick J.F., Sottos N.R., Moore J.S., White S.R., "Three-Dimensional Microvascular Fiber-Reinforced Composites", Advanced Materials, 2011. 2) Soghrati, S., Najafi, A. R., Hughes, K. M., Lin, J. H., White, S. R., Sottos, N. R. and Geubelle, P. H. (2013) "Computational design of actively-cooled 3D woven microvascular composites using a stabilized interface-enriched generalized finite element method." To appear in International Journal of Heat and Mass Transfer.*

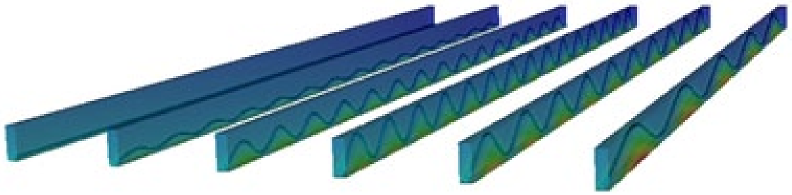




Micro-CT image of 3D microvascular fiber-reinforced composite with four embedded sinusoidal microchannels manufactured using the sacrificial fiber method.



Infrared image of impact of a sinusoidal microchannel on the thermal field in a composite plate. Left: no flow. Right: with 5 ml/min flow of coolant (water).



IGFEM modeling of effect of microchannel configuration on thermal field in a heated microvascular composite plate.

Back to Table of Contents

Deterministic and Probabilistic Viscoelastic Characterizations from One-Dimensional Experiments

The current pervasive use and analysis of composites, high polymers, rubbers, high temperature metals, biological materials, etc., necessitates viscoelastic rather than elastic analyses. Consequently, it is highly imperative that proper accurate high-level experimental and analytical protocols be used in material characterization.

Objective: To achieve as closely as possible precise experimental and analytical protocols to accurately characterize isotropic viscoelastic materials from 1D tension experiments in terms of moduli and/or compliances.

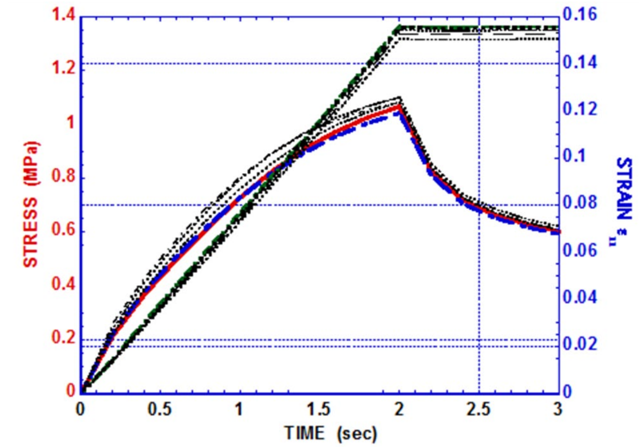
Approach: The experimental equipment consists of testing machines capable of performing creep, relaxation and dynamic experiments. In the first two experiments, load cells, accelerometers, extensometers and two camera photometric equipment are used to determine relaxation moduli and creep compliances without Poisson's ratio manipulations. For the dynamic experiments, impact hammers and accelerometers are employed to measure instantaneous (elastic) moduli from wave front velocities. The accompanying analyses fully take into account the important complete loading histories before and after steady-state conditions are achieved.

Significant Results and Potential Impact: The associated analyses to obtain moduli and compliances are as exact as modeling and computations permit. Both deterministic and stochastic properties are determined from the experiments and analytical expressions for the constitutive relations are derived for all conditions. These results are needed to perform subsequent high fidelity stress analyses.

Principal Investigators:
Eli Altus (Technion), Hagay Grosbein (IMI), Harry H. Hilton, Michael Michaeli (IMI) and Abraham Shtark (IMI)

Funding: *Private Sector Program Division, National Center for Super Computing Applications, and IMI.*
Key Publications: *1) Abraham Shtark, Hagay Grosbein, Guy Sameach and Harry H. Hilton (2013) "An alternate protocol for determining viscoelastic material properties based on tensile tests without use of Poisson ratios," accepted for publication ASME Journal of Applied Mechanics. 2) Michaeli, Michael; Abraham Shtark; Hagay Grosbein; Eli Altus and Harry H. Hilton (2014) "Uncertainty in characterizations of isotropic linear viscoelastic moduli from 1-D experiments," Proceedings AIAA SciTech SDM Conference, Paper ID 1734880.*

Typical experimental measurements for multiple specimens of the same material that show the statistical nature of the harvested data. From this data analytical stochastic moduli and compliance functions are derived to be used in probabilistic stress and strain analyses.



Two-camera set up for strain measurements. The cameras are focused to simultaneously capture the strains in the loading and in the transverse (perpendicular) directions. These two measurements plus the corresponding load and time records are sufficient to construct the viscoelastic stress-strain relations.

Minimal Representation and Decision Making for Networked Autonomous Agents

Envisioned is a heterogeneous group of autonomous ground, underwater, surface, and aerial unmanned vehicles monitoring various national assets and infrastructures. Aerial autonomous surveillance of vessel traffic, current and wave patterns, and ocean weather conditions can enhance the military's ability to coordinate autonomous surveillance agents positioned underwater and on the surface. Proposed is a complex problem of using a large network of decentralized autonomous agents with various sensing capabilities to work together to provide a massive amount of data. Uncertainties, including potential sensor and communication link errors, must be taken into consideration.

Objective: Fundamental issues that arise in information representation architectures for autonomous reasoning and learning, decentralized planning, and decision-making in multiagent systems are addressed. Developing efficient and adaptive strategies to process, represent, exchange, and act upon relevant information from massive data collections, much of which can be irrelevant, imprecise, and contradictory, is desired.

Approach: The technical approach's core is minimalism. Proper identification of the required information is needed to achieve a given task with a desired performance level and provable performance guarantees. Minimal representations involve selection of appropriate models, uncertainty management, and information representation, decomposition and communication. Key role within this framework play set-based approaches in order to perform information decomposition and synchronization for distributed filtering, and representation for meta-reasoning and coordination.

Significant Results and Potential Impact: Fundamental principles, theory, and algorithms should be established to enable distributed teams of autonomous vehicles to coordinate robustly in highly dynamic environments and under information uncertainty to achieve a mission within specified success criteria. Applicability is broad, ranging from sensor coverage and surveillance problems, to formation control and synchronization

Principal Investigators:
Petros G. Voulgaris and **Soon-Jo Chung**

__Funding:__ Air Force Office of Scientific Research
__Key Publications:__ 1) J. Yu, S.-J. Chung, and P. G. Voulgaris, "Target Assignment in Robotic Networks: Distance Optimality Guarantees and Hierarchical Strategies," IEEE Transactions on Automatic Control, under review, 2013. 2) J. Yu, S.-J. Chung, and P. G. Voulgaris, "Distance Optimal Target Assignment in Robotic Networks under Communication and Sensing Constraints," 2014 IEEE International Conference on Robotics and Automation (ICRA), May 31 - June 5, 2014, submitted.

An example of surveillance networks that use multiple video images, where our proposed minimal representation and decision making can be applied.

A complex network comprised of heterogeneous autonomous agents that cover a wide variety of temporal and spatial variations in the scene.

Data-Centric Methods for Inference and Prediction of Large-Scale Complex Systems

An emerging challenge for inference and prediction of large-scale complex systems is to efficiently analyze and assimilate the ever-increasing high dimensional data produced by the vast number of engineered and natural systems. This project aims to develop novel mathematical and statistical methods for (i) discovering fundamental structures and extracting useful information contained in high dimensional data; and (ii) assimilating this information into dynamical models to understand large-scale data-centric problems: health monitoring and vulnerability assessment of electric power systems, and climate predictions and early detection of extreme climate events.

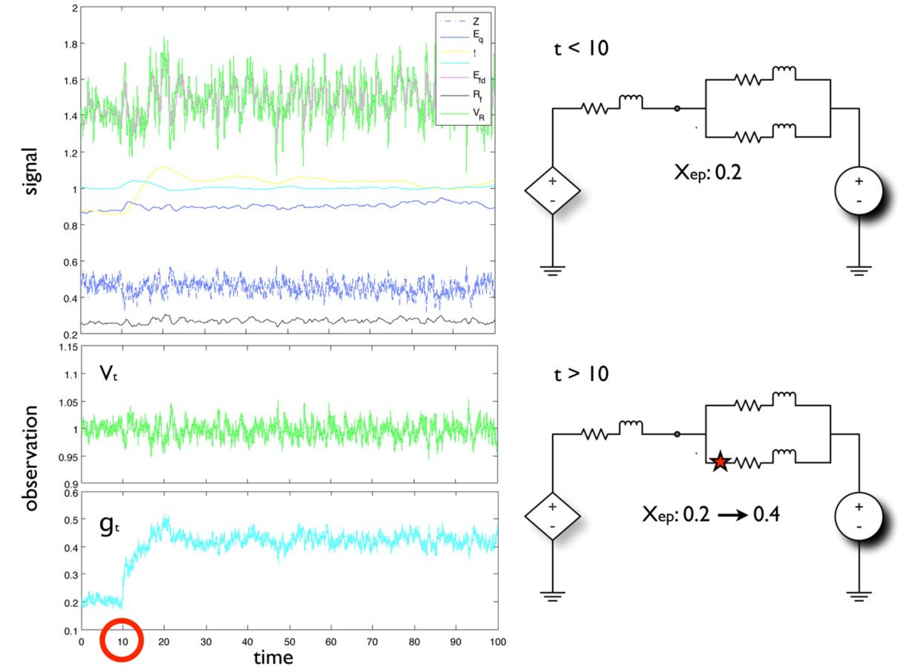
Objectives: 1) Develop efficient and robust methods to produce "data enhanced" reduced order models. 2) Obtain lower-dimensional nonlinear filtering equations driven by observations. 3) Develop a control theoretic framework for optimal collection of sensor-based observations. 4) Develop new approaches for building more flexible graphical models. 5) Evaluate system stability and reliability based on estimated states.

Approach: Weak convergence of Markov processes forms a basis for stochastic dimensional reduction. The theory of nonlinear filtering based on stochastic partial differential equations (SPDE) forms the framework for data assimilation. Methods are developed combining dimensional reduction with nonlinear filtering, revealing how scaling interacts with filtering. Information theoretic measures determine optimal strategies for sensor deployment.

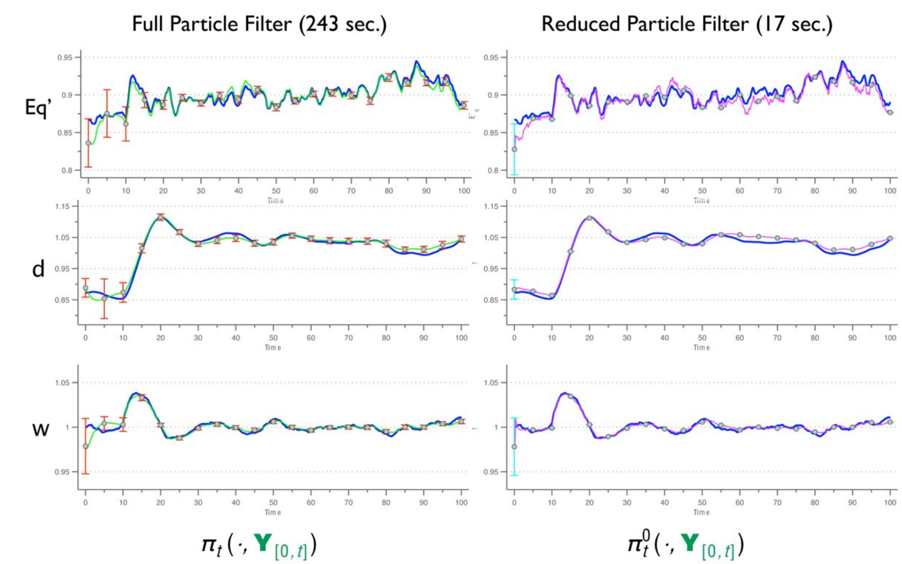
Significant Results and Potential Impact: It is shown with mathematical rigor that the nonlinear filter for the slow component of a multi-scale system will converge to a process governed by a lower dimensional SPDE. These results are used to develop inexpensive lower-dimensional particle filters. Importance sampling and control methods are used as a basic and flexible tool for constructing an efficient particle filtering algorithm adaptable for inherently chaotic systems.

Principal investigators:
N. Sri Namachchivaya and **Peter W. Sauer**

Funding: *National Science Foundation, Air Force Office of Scientific Research.* ***Key Publications:*** *1) P. Imkeller, N, Sri Namachchivaya, N. Perkowski, and H. C. Yeong, Dimensional reduction in nonlinear filtering: A homogenization approach. Accepted in Ann. Appl. Probab., 2013. 2) N. Lingala, N. Sri Namachchivaya, N. Perkowski, and H. C. Yeong, Particle filtering in high-dimensional chaotic systems. Chaos: An Interdisciplinary Journal of Nonlinear Science, 22(4): 18 pages, 2012. 3) J. H. Park, V. Chikkerur, N. Sri Namachchivaya, S. Grijalva, P.W. Sauer, and B. Raczkowski, \Direct Data Driven Electric Power Systems," Accepted in Dynamic Data Driven Applications Systems, eds. Frederica Darema and Craig Douglas, Springer Series. 4) L. Dostal, E. Kreuzer and N. Sri Namachchivaya, Non-standard Stochastic Averaging of Large Amplitude Ship Rolling in Random Seas," Proceedings of the Royal Society, A, Vol. 468, No. 2148, 2012, pp. 4146-4173.*



The simplified circuit diagrams show the situation of a line contingency in which half the transmission lines connecting a generator and the load are cut off at t = 10 sec.



The results show that the reduced order filter tracks the system with minimal error throughout the line contingency. The reduced order filter achieved a near 15-fold reduction in computation time (from 243 sec to 17 sec).

Back to Table of Contents

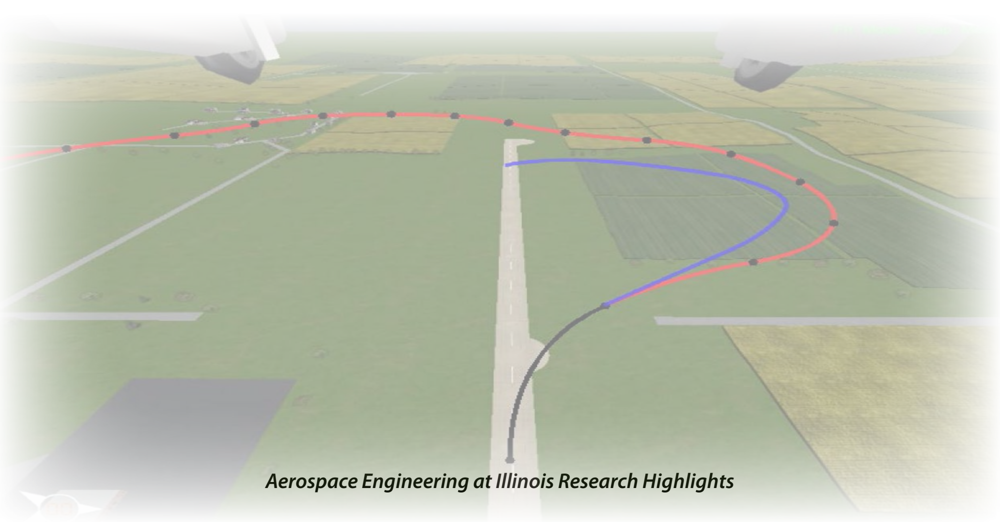
Mechanics and Control of Brain-Machine Interface Systems

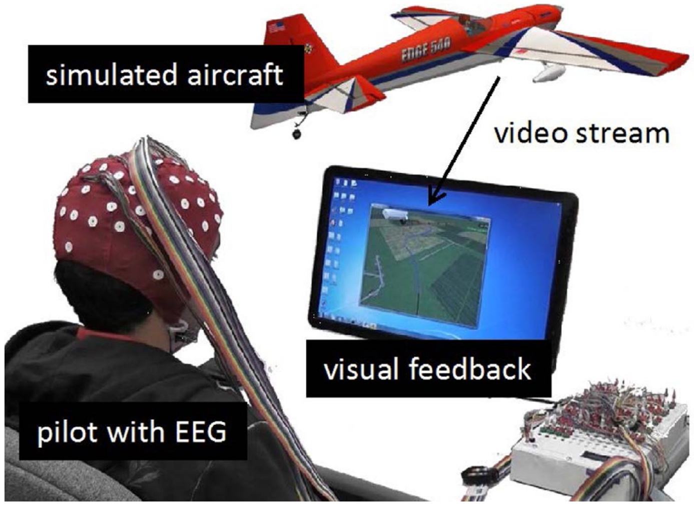
Today's aircraft are flown with a joystick. Tomorrow's aircraft may be flown by thought alone, using brain-machine interface systems to connect the pilot's mind directly to the aircraft. This project provides a theoretical and algorithmic foundation for these future systems.

Objective: Derive models of human motor control and learning that improve the performance of brain-machine interface systems.
Approach: The approach taken is control-theoretic and is based on the premise that human behavior is optimal with respect to some unknown cost function. New methods of inverse optimal control are being developed to identify this cost function from experimental data. The resulting models are used to design brain-machine interface systems in a systematic way, with tools from feedback information theory and stochastic control.
Significant Results and Potential Impact: The ability of a human pilot to fly an unmanned aircraft with input only from an electroencephalograph (EEG) has been demonstrated. The underlying theory is now being applied more broadly to restore sensory-motor function, potentially improving the quality of life for people with disability due to conditions like amputation, spinal cord injury, and stroke.

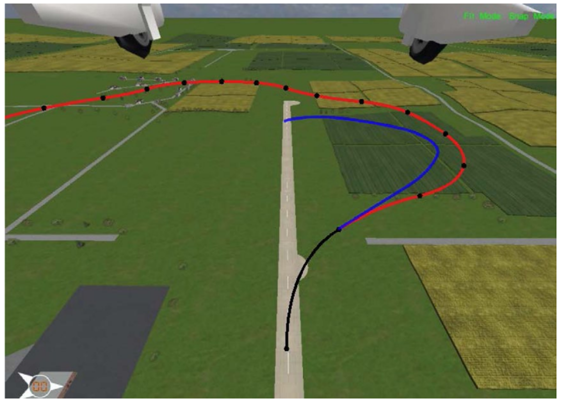
Principal Investigators:
Timothy W. Bretl

Funding: *National Science Foundation (CMMI – CAREER Award).*
Key Publications: *1) A. Akce, M. Johnson, O. Dantsker, and T. Bretl, "A brain-machine interface to navigate a mobile robot in a planar workspace: enabling humans to fly simulated aircraft with EEG," IEEE Trans. Neur. Syst. Rehab. Engr., 21(2):306-318, 2013. 2) R. Ma, N. Aghasadeghi, J. A. Jarzebowski, T. Bretl, and T. P. Coleman, "A Stochastic Control Approach to Optimally Designing Variable-Sized Menus in P300 Communication Prostheses," IEEE Trans. Neur. Syst. Rehab. Engr., 20(1):102-112, 2012. 3) C. Omar, A. Akce, M. Johnson, T. Bretl, R. Ma, E. Maclin, M. McCormick, and T. P. Coleman, "A Feedback Information-Theoretic Approach to the Design of Brain-Computer Interfaces," Int. J. of Human-Computer Interaction, 27(1):5-23, 2011.*

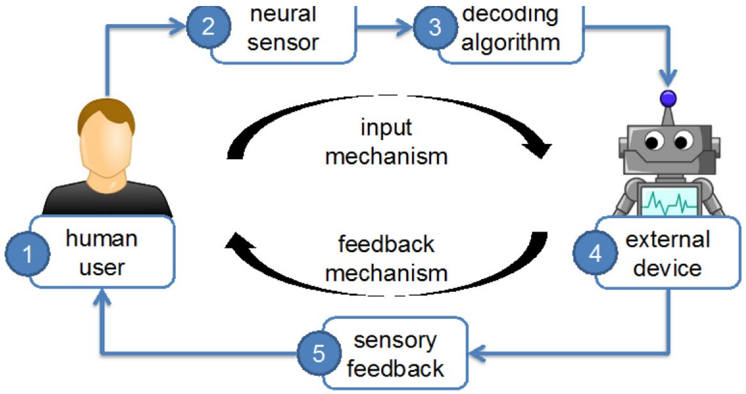




An overview of the brain-machine interface system that allows a human pilot to fly an unmanned aircraft with input only from an electroencephalograph (EEG).



What the pilot sees when flying an aircraft with EEG.



An abstraction of a brain-machine interface system. The external device might be a text speller, a prosthetic limb, or a remotely piloted aircraft.

Back to Table of Contents

A Dynamic Game Theoretic Approach to Cyber-Security of Controlled Systems

CS/IT techniques (cryptography/anonymization, privacy protection, secure multiparty computation, access restriction, fault detection) are necessary to reduce the likelihood and potential harmfulness of an attack on controlled infrastructures, but are unfortunately not sufficient, because they cannot ensure that the plant will perform satisfactorily, if a cyber-attack is actually successful at entering the regulation loop.

Objective: Going beyond point-of-entry security for controlled systems. We want to design control algorithms that can themselves provably guarantee at least some basic level of stability and safety of the closed-loop plant in the face of compromised/ subverted components in the feedback loop.

Approach: Using the theory and tools of dynamic games of incomplete information. Treat the different layers of the network as operated by a strategic attacker with partial knowledge of the controlled system and partial observations. Controller and attacker play a zero-sum game, like in robust control theory. However, attacker is constrained by desire to remain stealthy and information accessible to him. Such stealthiness can be captured, e.g., by a lower bound on the mutual information between the controller observation and a legitimate signal.

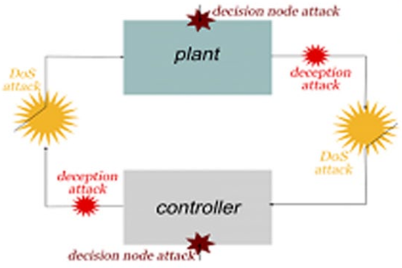
Significant Results and Potential Impact: A new general framework, Adversarial Network Controlled Games (ANC games), which encompasses many known models, is being developed. It gives crisp predictions as to when the jammer randomizes in equilibrium and, more importantly, allows us to answer the question: "what does a 'typical' adversarial channel look like?", with implications for attack signature identification and defense.

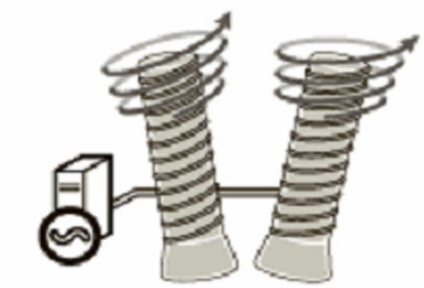
Principal Investigator:
Cedric Langbort

Funding: *NSF Career Award, Australian Research Council Discovery Grant. Air Force Office of Scientific Research, Multi-University Research Initiative (UIUC lead) in Collaboration with U. Maryland, Stanford, UC Berkeley, Georgia Tech*

Key Publications: *1) A. Gupta, A. Nayyar, C. Langbort, T. Basar, A Dynamic Transmitter-Jammer Game with Asymmetric Information. In Proceedings of the 2012 IEEE Conference on Decision and Control (Maui, Hawaii). 2) C. Langbort and V. Ugrinovskii. One-shot control over an AVC-like adversarial channel. In Proceedings of the 2012 American Control Conference (Montreal, CA).*

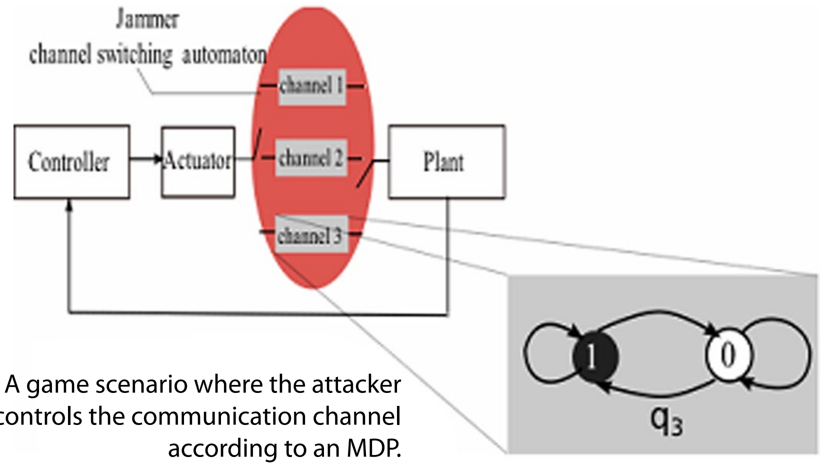
Cyber-attacks can take place at different points of an industrial control loop.





An artist's view of Stuxnet, or how a computer worm can spin turbines out of control...

Adapted from G. Gates' illustration for NYTimes (06-01-2012)



A game scenario where the attacker controls the communication channel according to an MDP.

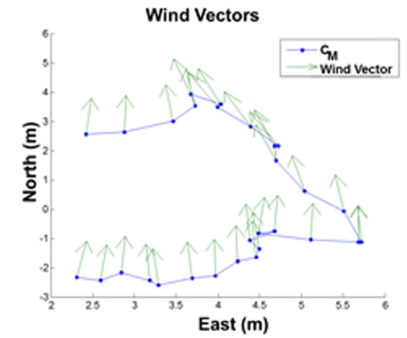
Distributed Array of GPS Receivers for Three-Dimensional Wind Sensing in Wind Farms

Wind energy is currently one of the fastest growing sources of renewable energy. Sensing the wind profile densely, accurately, in three dimensional, and inexpensively is critical for both optimizing the installation of wind turbines on a wind farm, and predicting and optimizing the power generation. Accurate wind profile sensing is critical for predicting wind power generation at existing wind farms and surveying for the installation of new wind farms. Traditional meteorological masts with cup anemometers are costly, especially for offshore wind farms. Therefore, meteorological masts are often sparsely located at fixed positions. There are alternative remote sensing methods to tower-based cup anemometers, such as light detection and ranging (LiDAR) and sound detection and ranging (SoDAR). For offshore wind farms, LiDAR or SoDar will have to be placed on a floating buoy, making it challenging to accurately compensate the buoy motion.

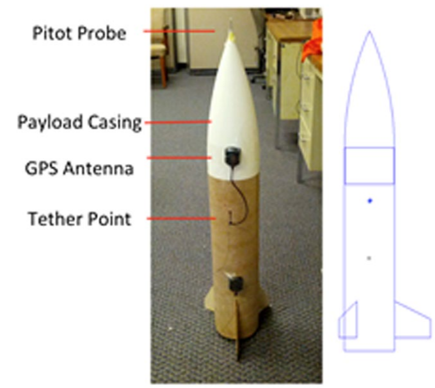
Objective: We propose a new method for dense, 3D, flexible, and inexpensive wind profile sensing.
Approach: The proposed method uses a distributed array of GPS-based sensors carried by aerial carriers. Such aerial carriers can be tethered helikites or Unmanned Aerial Vehicles (UAVs). The sensor payload consists of a GPS receiver, an inertial measurement unit (IMU), a wireless communication transceiver and a Pitot tube. A Pitot tube measures relative air speed, and has been widely used in airplanes. The wind speed is calculated in two ways. First, GPS receivers cooperatively sense the absolute sensing payload speed. Wind speed is calculated by subtracting relative air speed measured by Pitot tubes from absolute wind speed measured by distributed GPS sensors. Second, distributed GPS sensors together sense the shape of the tether. The bending of tether reflects the wind profile.
Significant Results and Potential Impact: Our research provides a cost-efficient method for accurate wind profile sensing for wind farm. It will have a high impact on better integrating wind energy into the power grid by accurately estimating and predicting the wind power.

Principal Investigator: **Grace Xingxin Gao**

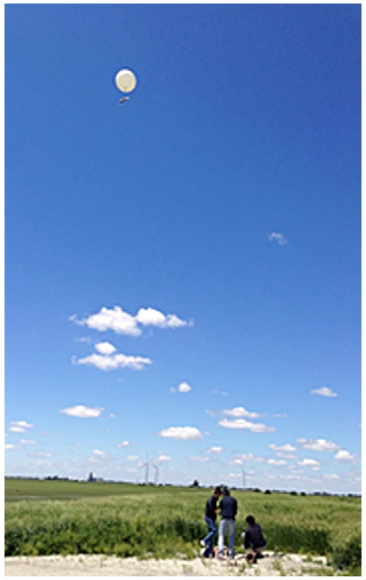
__Funding:__ University of Illinois at Urbana-Champaign
Key Publications: *Derek Chen, Liang Heng, Dan Jia, and Grace Xingxin Gao, Distributed Array of GPS Receivers for 3D Wind Profile Determination in Wind Farms, in Proceedings of the 26th International Technical Meeting of the Satellite Division of the Institute of Navigation (ION GNSS+ 2013), Nashville, TN, Sep 2013. Best presentation of the session award.*



Quiver plot of wind velocities and heading on the payload center of mass



Design and prototype of GPS-based sensing payload shell



Field testing in a wind farm in Paxton, IL

The assembled system in preparation for deployment and sensing

Back to Table of Contents

Real-time Optimal Guidance and Control of Swarms of Spacecraft

Our research team, including graduate student Daniel Morgan, Assistant Prof. Soon-Jo Chung, and Dr. Fred Y. Hadaegh (JPL), have developed and demonstrated a methodology of collision free, optimal path model predictive control (MPC) that guarantees minimal fuel usage for guidance and control of large numbers (tens to thousands) of femtosatellites (100-gram class spacecraft). Guidance and control algorithms are needed for fuel and computationally efficient swarms of spacecraft. The approach enables on–board, real-time implementation of guidance and control software on resource-limited femtosats. The NASA Space Technology Mission Directorate has highlighted this project for contributing to the development of theory and design for guidance and control of swarms of femtosats.

Objective and Approach: Establish the capability for autonomous guidance and control of swarms of 100s-1000s of 100-gram class spacecraft (femtosats). Simultaneously address the technical challenges of swarm formation flight including:

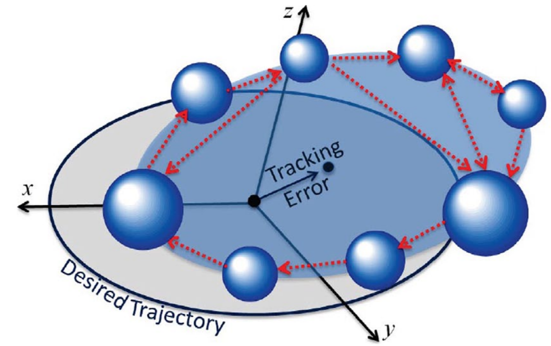
- Large number of femtosats (100s-1000s)
- Control, sensing, and communication capabilities of femtosats
- Complex 6-DOF motions of femtosats in low earth orbit (LEO)

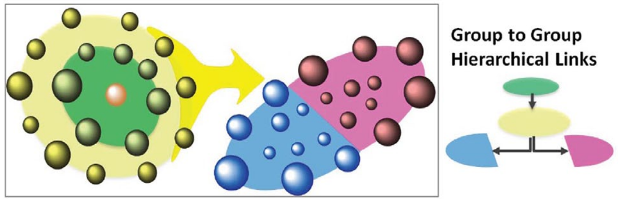
Develop a multi-vehicle, experimental testbed to demonstrate the practicality of swarms flying in a gravity-constrained 3D environment with miniaturized sensing and actuation capabilities. Reduce costs and improve the durability of observational and sensing missions by using swarms of femtosats in the place of monolithic spacecraft.

Significant Results and Potential Impact: This research has established a systematic guidance and control design methodology for controlling thousands of distributed spacecraft with limited onboard resources in LEO as well as in deep space. The realtime optimal control algorithms are scalable to spacecraft of different sizes and to formations of different numbers of spacecraft.

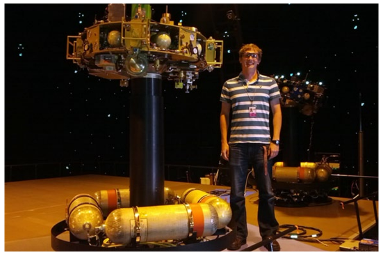
Principal Investigators:
Soon-Jo Chung with Fred Hadaegh (JPL Associate Chief Technologist)

__Funding:__ Jet Propulsion Laboratory Director's Research Development Fund (DRDF). NASA Space Technology Research Fellowship Grant (NNX11AM84H). JPL Summer Faculty Research Fellowship (2011, 2012, 2013).
__Key Publications:__ 1) D. Morgan, S.-J. Chung, and F. Y. Hadaegh, "Model Predictive Control of Swarms of Spacecraft Using Sequential Convex Programming," Journal of Guidance, Control, and Dynamics, under review, 2013. 2) S. Bandyopadhyay, S.-J. Chung and F. Y. Hadaegh, "Probabilistic Swarm Guidance using Inhomogeneous Markov Chains," IEEE Transactions on Control of Network Systems, under review, 2013. 3) S.-J. Chung, et al., "Phase Synchronization Control of Complex Networks of Lagrangian Systems on Adaptive Digraphs," Automatica, vol. 49, no. 5, May 2013.

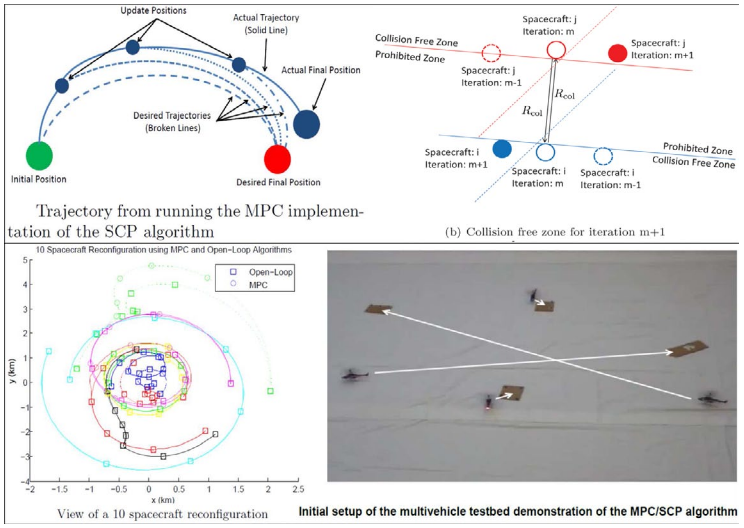




Concurrent synchronization of swarms of spacecraft on adaptive digraph networks (Chung et al., Automatica, 2013).



PhD student Dan Morgan working on the Formation Control Testbed Robots at the Jet Propulsion Laboratory



MPC-Sequential Convex Programming simulation involving hundreds of spacecraft and experimentation

Integrated Launch System Design Using Multi-Objective Optimization

Performance margin allocation strategies with consideration to sensitivities of the propulsion system elements for the Space Launch System are assessed. The allocation problem is a multi-objective optimization problem whereby changes made to the propulsion system to improve performance margin must be traded against possible reductions to the non-functional metrics such as the schedule, cost and risk associated with the changes.

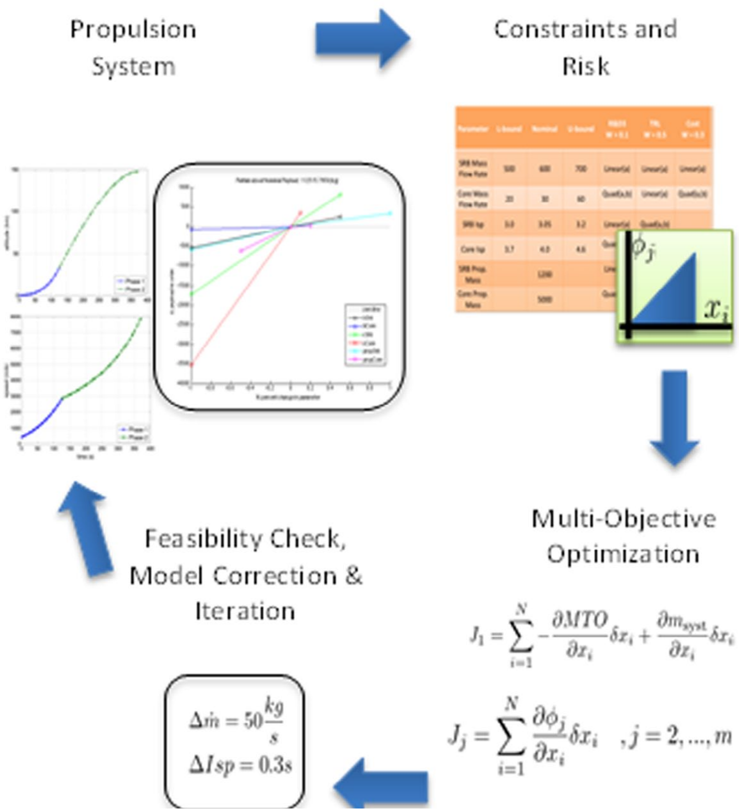
Objective: Aid the decision makers in selecting a single solution from the multi-dimensioned design parameter space.

Approach: Identify the design parameter space. Evaluate the objective functions for assessment of the quality of a design point while applying constraints on the design space. Model the problem using design of experiment and response surface methods, apply evolutionary multi-objective genetic algorithms to generate Pareto optimal sets and apply filters to reduce the Pareto set to a manageable subset to aid the design makers in selecting the final design.

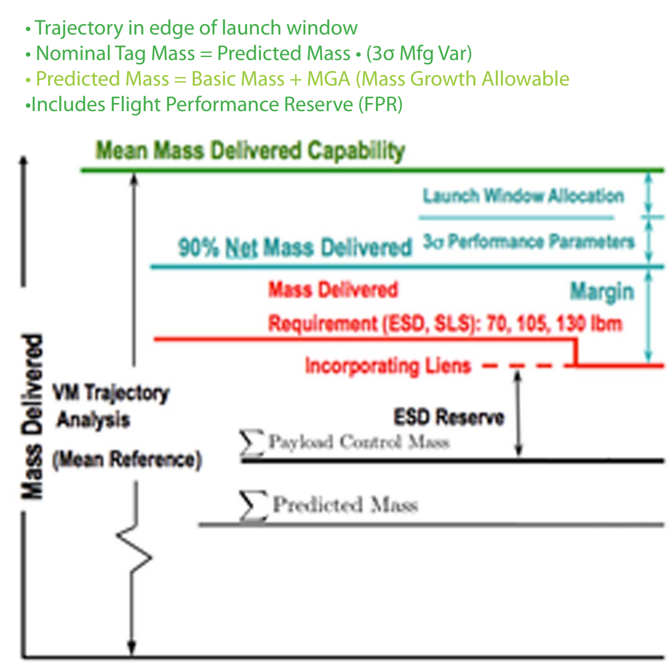
Significant Results and Potential Impact: The described framework was applied to the design of the 1½ stage space launch system and provides the desired aid to the decision makers.

Principal Investigator:
Victoria Coverstone

Funding: *NASA Marshall Space Flight Center, Visiting Investigator Partnership*



Framework for Assessing Performance Margin Allocation



Margin Considerations for an Evolving Launch Vehicle

Back to Table of Contents

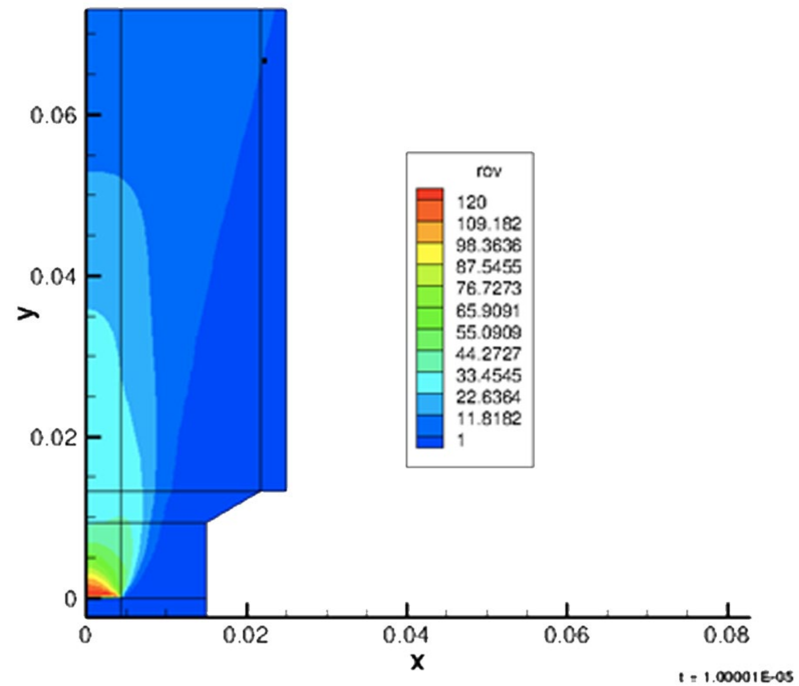
GEM Thruster

Efficient high power electric propulsion is needed for interplanetary missions, such as moving cargo to Mars. Existing thrusters require extremely expensive propellant and large diameter systems. The Gallium Electromagnetic (GEM) thruster uses a relatively inexpensive propellant and promises to result in a compact, low mass system.

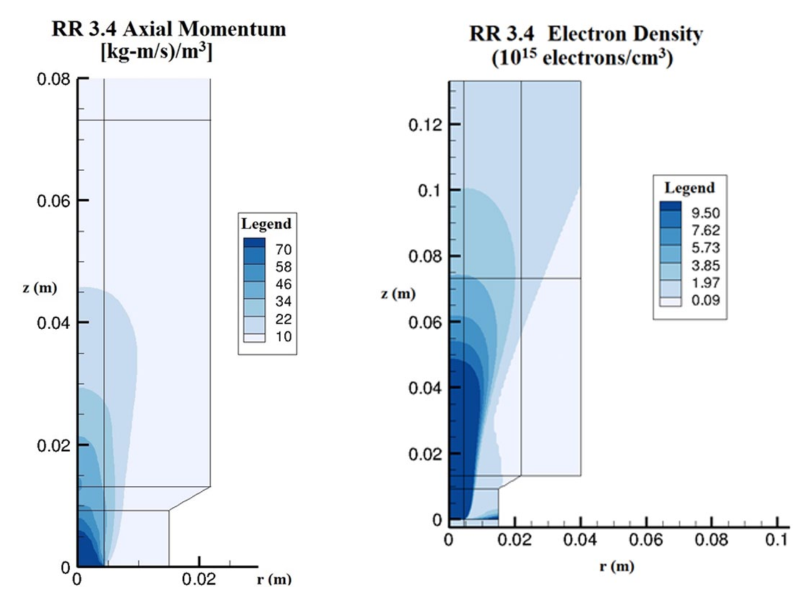
Objective: Use previous experimental results of GEM thruster performance to validate a 2D axisymmetric unsteady GEM numerical model using the MACH2 code
Approach: The GEM thruster is a high-current arc with a strong self-magnetic field, that is self-feeding by evaporating a central gallium cathode. The numerical model assumes a constant cathode evaporation rate, and a rapid ramp-up of current to 22,600 A for a pulse length of 50 microseconds, equivalent to the experimental test conditions. The code tracks a number of plasma and electromagnetic field variables that are plotted on the r-z plane at various times.
Significant Results and Potential Impact: The code predicts thrust results in excess of the pure electromagnetic value, caused by downstream fluid acceleration created from electrothermal plasma heating. This result suggests that actual GEM thrust stand performance may be higher than expected.

Principal Investigator:
Rodney L. Burton

Funding: *NASA Space Grant from State of Alabama.*
Key Publications: *1) Thomas, R. E., Burton, R. L., and Polzin, K. A., "Performance Characteristics of an Ablative Gallium Electromagnetic Accelerator," Journal of Propulsion and Power, Vol. 29, No. 4, 930-937, 2013. 2) Ahern, D., "Investigation of the GEM MPD Thruster Using the MACH2 Magnetohydrodynamics Code," University of Illinois Department of Aerospace Engineering, MS Thesis, 2013*



Mass flux ρV for GEM thruster at 23,000 amperes current.



Axial momentum density and electron density at 23,000 amperes current.

Back to Table of Contents

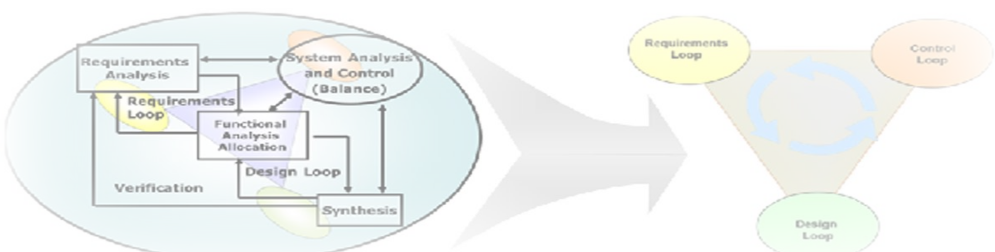
Designer Systems of Systems – A Rational Integrated Approach of System Engineering

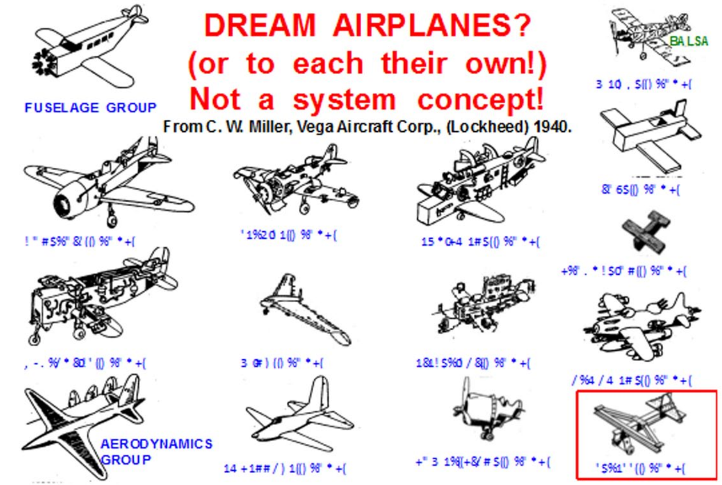
Flight vehicles are complex systems where design/synthesis analysis needs to be applied in toto to the entire unit. Yet the prevailing approach is for each subgroup to “do its own thing” and when their localized endeavors are completed to attempt to integrate with other groups after their localized analyses.

Objective: To achieve optimum tailored total vehicle system analysis and design with provisions for optimized/tailored aerodynamics, stability, control, materials, structures, propulsion, performance, sizing, weight, cost, etc.
Approach: The protocol for these inverse problems is based on a generalized calculus of variations approach. The possibility of achieving such a generalized unified approach has become a reality through the advent of modern computer software and hardware. It is feasible to carry out detailed large-scale analytical enterprises, such as multiple symbolic calculus and matrix algebra. The availability of the UIUC NCSA/NSF Blue WatersTM, the sustained petascale (1015 flops/sec) computing system, will allow efficient solutions of the necessary hundreds of millions of simultaneous algebraic equations describing parameters for an entire flight vehicle.
Significant Results and Potential Impact: The material, structural and sizing analysis has been completed and numerous examples have been published. When adopted by industry as its standard, the developed analysis/synthesis protocol will result in optimal overall system designs with substantial improvement in performance and in weight and cost reduction.

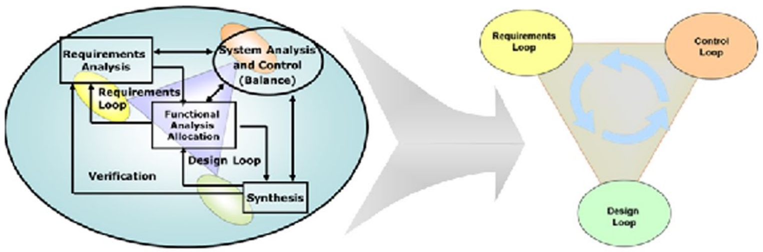
Principal Investigators:
Steven J. D’Urso and **Harry H. Hilton**

__Funding:__ Private Sector Program Division, National Center for Super Computing Applications.
__Key Publications:__ 1) Hilton, Harry H., Daniel H. Lee and Abdul Rahman A. El Fouly (2008) “General analysis of viscoelastic designer functionally graded auxetic materials engineered / tailored for specific task performances,” Mechanics of Time-Dependent Materials, 12:151--178. 2) Hilton, Harry H. and Steven J. D’Urso (2013) “Designer systems of systems – A rational integrated approach of system engineering to tailored aerodynamics, aeroelasticity, stability, control, geometry, materials, structures, propulsion, performance, sizing, weight, cost,” Proceedings Fourth International conference on Inverse Problems, Design and Optimization (IPDO--2013), Paper ID 06290. Albi, France.



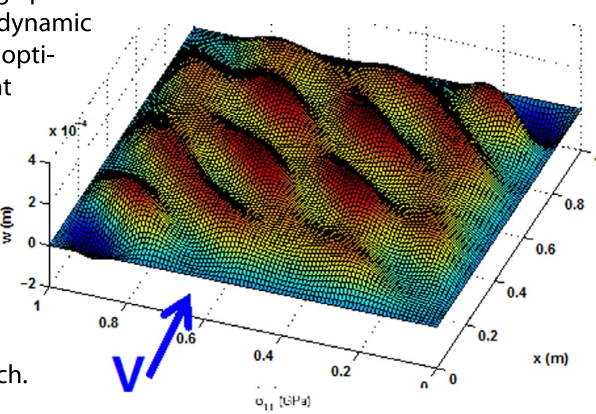


An example of worst-case scenarios where each group is allowed to pursue its own agendas without integration into the best overall system



A schematic representation of the system process from conception to ultimate product

An optimized wing or fuselage panel deflections under aerodynamic loads. While the panel was optimized for minimum weight and best material properties, its deflections were not constrained to enforce minimum drag. Such deflected patterns are also of high importance when electromagnetic considerations impinge on the system engineering approach.



__Back to Table of Contents__

Sponsored Research

We acknowledge the companies and organizations that support the research mission of Aerospace Engineering at Illinois. Following is the list of currently active research projects.

AE Investigator(s)	Funding Agency	Project Title
Joanna M. Austin	NASA	Furrows and Ridges of the Double Layered Ejecta Craters of Mars
Joanna M. Austin	DOE	Simulations of Deflagration-to-Detonation Transition in Reactive Gases
Joanna M. Austin	NSF	CAREER: Dynamics and Damage of Void Collapse in Biological Materials under Stress Wave Loading
Joanna M. Austin, Gregory S. Elliott	AFRL-SBIR	Miniaturized Optical Sensors for Unsteady Pressure and Skin Friction Measurements
Joanna M. Austin	AFOSR	Shock-Boundary Layer and Shock-Shock Interactions in Nonequilibrium Hypervelocity Flow
Lawrence A. Bergman	US-Israel Binational Science Fdn	Multi-Scale Analysis of Strongly Nonlinear Dynamics of Oscillators Exhibiting Targeted Energy Transfer Phenomena
Lawrence A. Bergman	NSF	Collaborative Research: Nonlinear Design and Development of Multi Degree-of-Freedom Broadband Energy Harvesting Systems
Lawrence A. Bergman	DARPA	Structural Logic, Phase II: High Sea-State Adaptive Structures
Lawrence A. Bergman	NSF	Global/Local Identification of Strongly Nonlinear Dynamical Systems
Lawrence A. Bergman	Binational Science Foundation (BSF)	Nonlinear Dynamics of Oscillators Exhibiting Targeted Energy Transfers
Lawrence A. Bergman	NSF	Intrinsically-Nonlinear Broadband Nanoresonator for Ultrahighly Sensitive Sensing of Energy Transfers
Daniel J. Bodony	NASA	Measurement and Modeling of Entropic Noise Sources in a Single Stage Low-Pressure Turbine
Daniel J. Bodony	Rolls-Royce	Parallel Algorithms and Performance Modeling for Aircraft Gas Turbine Engine Prediction Codes
Daniel J. Bodony	NSF	CAREER: Adjoint-Based Control of Human Phonation
Daniel J. Bodony	NASA	Dynamic, Adaptive, and Robust High-Order Numerical Methods for the Prediction and Optimization of High Reynolds Number Turbulent Flows
Daniel J. Bodony	NSF	XSEDE: Prediction and Control of Compressible Turbulent Flows
Daniel J. Bodony	Rolls-Royce	Actuator Selection and Placement for Separation Control in an S-Duct Diffuser
Daniel J. Bodony	Aeroacoustic Research Consortium	Liner Eduction Methodology Using Large-Eddy Simulation
Daniel J. Bodony	ONR	Actuator Type and Placement for Jet Noise Reduction
Daniel J. Bodony, Gregory S. Elliott, Jonathan Freund	DOE	Center for Exascale Simulation of Plasma-Coupled Combustion
Daniel J. Bodony	AFOSR	Direct Numerical Simulation of Compressible Turbulent Flows with Compliant Boundaries
Timothy W. Bretl	NSF	CAREER: Mechanics and Control of Brain-Machine Interface Systems
Timothy W. Bretl	NSF	RI: Small: Mechanics, Manipulation and Perception of Deformable Objects for Robotic Manufacturing
Timothy W. Bretl	US Health & Human Services	Automated Parameter Tuning for Above-Knee Powered Prostheses
Ioannis Chasiotis	NSF	PECASE, CAREER: Nanoscale Confinement in Polymers: Integrated Research and Education in Nanoscale Experimental Mechanics
Ioannis Chasiotis, John Lambros	UI IN3	Mechanism Informed Design of Multifunctional Structural High-Strength Batteries
Ioannis Chasiotis	AFOSR	Glancing Angle Deposition System for Nanostructured Multifunctional Films
Ioannis Chasiotis	ARO	Mechanical and Ferroelectric Response of Highly Textured PZT Films for Low Power MEMS
Ioannis Chasiotis	US ARMY	Failure Mechanisms of Individual High Performance Fibers
Ioannis Chasiotis	AFOSR	Influence of Mechanical Loading on the Integrity and Performance of Energy Harvesting and Storage Materials
Ioannis Chasiotis	AFOSR	Compliant Nanospring Interfaces
Huck Beng Chew	NSF-CMMI	Fracture Toughness of Lithium-Ion Battery Electrodes: An Integrative Experimental and Computational Study
Huck Beng Chew, Marco Panesi	AE Multidisciplinary Innovation Grant	Modeling of Surface Pattern Formation at the Nano-Scale

Huck Beng Chew	TAAC Stampede Cluster	Hierarchical Nanostructured Metals: Revealing the Secrets behind Ultra-Strong and Tough Mechanical Properties with Massively Parallel Computations
Soon-Jo Chung	ONR	Vision-Based Navigation in Riverine Environments
Soon-Jo Chung	ARO	Bio-Inspired Flexible Cellular Actuating Systems
Soon-Jo Chung	NASA	Dynamics and Controls of Swarms of Femtosatellites
Soon-Jo Chung	John Deere	Vision Containment for Robotic Mowing
Soon-Jo Chung, Petros G. Voulgaris	AFOSR	Minimal Representation and Decision Making for Networked Autonomous Agents
Soon-Jo Chung	NSF	CAREER: Control and Sensing Strategies for Robotic Falcons to Prevent Airport Bird Strikes
Soon-Jo Chung	JPL	System Engineering Study of CubeSat Formation Flying
Bruce A. Conway	Missle Defense Agency	Intelligent and Robust Control for Optimal Engage-ment Planning
Bruce A. Conway	NERIO-I	Nuclear Explorations for Realizing Interplanetary Objectives I
Steven J. D'Urso	Rolls-Royce	A Comprehensive Power and Energy Systems Toolset for Air Vehicles
J. Craig Dutton, Gregory S. Elliott	NSF	MRI: Development of a Large-Scale Retractive-Index Matched facility
J. Craig Dutton, Gregory S. Elliott	ARO	Passive and Active Control of Massively Separated High-Speed Flows
J. Craig Dutton, Gregory S. Elliott	AFOSR	Flow Control Using Energy Deposition
J. Craig Dutton, Gregory S. Elliott	NASA SBIR Phase I	Skin Friction and Pressure Measurements in Super-sonic Inlets
Jonathan Freund	NIH	Mechanical Response of Biological Tissue to Shock Wave
Jonathan Freund	NSF	Order and Chaos in the Flow of Red Blood Cells
Jonathan Freund	IN Univ	Strategies for Improved Shock Wave Lithotripsy
Jonathan Freund	AFOSR	Jet Crackle
Jonathan Freund, Joanna M. Austin, Daniel J. Bodony, Gregory S. Elliott	ONR	Adjoint-Based Optimization to Harness LES for Net Noise Control
Grace Xingxin Gao	DOE TCIPG	Understanding and Mitigating the Impacts of GPS/GNSS Vulnerabilities
Grace Xingxin Gao	UI IMSE	Risk Models for Autonomous Vehicle Systems
Grace Xingxin Gao	NSF UI I-Corps	Peer-based GPS Authentication
Philippe H. Geubelle	AFOSR	Center of Excellence of Multiscale Modeling and Experiments
Philippe H. Geubelle	CSE	Computational Modeling and Simulation of Com-posite Materials Based on Tomographic Images
Philippe H. Geubelle	NASA	Illinois Space Grant Consortium
Philippe H. Geubelle	NSF-CMMI	Efficient Energy Release Rate Computations for Cracks with Arbitrary Location and Geometry
Philippe H. Geubelle	NSF	Collaborative Research: Conceptualizing on Insti-tute for Using Inter-Domain Abstractions to Support Interdisciplinary Applications
Philippe H. Geubelle	Boeing-NCSA	Peridynamics Modeling of Fracture
Philippe H. Geubelle	NSF-CMMI	Molecular Tailoring of Interface Fracture
Philippe H. Geubelle, Scott R. White	AFOSR MURI	Synthesis, Characterization and Prognostic Model-ing of Functionally Graded Hybrid Composites for Extreme Environments
John Lambros, Philippe H. Geubelle	ARO	MURI: Design of Adaptive Load Mitigating Materials Using Nonlinear Stress Wave Tailoring
John Lambros	DOE	Dynamic Response of Nanostructured Single and Multilayer Metal
John Lambros	AFOSR	Towards a Multi-Scale Understanding of Thermoa-coustic Fatigue in Aircraft Materials and Structures
Cedric Langbort	AFOSR MURI	Multi-Layer and Multi-Resolution Networks of Inter-acting Agents in Adversarial Environments
Cedric Langbort	Australian Research Council	Consensus-Based Theory of Robust and Resilient Distributed Estimation
Cedric Langbort	NSF	CAREER: A Dynamic Game Theoretic Approach to Cyber-Security of Controlled Systems
Cedric Langbort	ONR	Information Structures, Signaling and Competi-tively Optimal Policies in Decentralized Online Op-timization
Cedric Langbort	UI IN3 Initiative	What Your Infrastructure Wants
Cedric Langbort	NSF	EAGER : Blackout : An Educational Experiment in Gaming the Power Grid
N. Sri Namachchivaya	NSF-DMS	Multiscale Dynamics and Information in Data Col-lection and Assimilation for Complex Systems

N. Sri Namachchivaya	AFOSR-CDS	Multiscale Dynamics and Information in Data Collection and Assimilation for Environmental Applications
Marco Panesi	NASA	Modeling of Ionization Processes in Hypersonic Flows with FIN-S
Marco Panesi	AFOSR STTR Phase I	Non-Equilibrium Plasma-Assisted Combustion-Efficiency Control in Vitiated Air
Marco Panesi	AFOSR STTR Phase I	High Energy Laser Analysis Tool with Experimental Verification of DPAL
Marco Panesi	AFOSR	Advanced Physical Modeling for Hypersonic Applications, Submitted by the von Karman Institute of Fluid Dynamics
Michael S. Selig	Aero Vironment	Low Reynolds Number Airfoil Validation Tests
Michael S. Selig	Northrop Grumman	Improved Efficiency of UAV Propulsion Systems
Michael S. Selig	Private Gifts (Phase II)	Low Reynolds Number Airfoil Design and Wind Tunnel Testing
Michael S. Selig	King Fahd Univeristy of Petroleum and Minerals	Trapped Vortex Low Reynolds Number Airfoil Aerodynamics
Michael S. Selig	DSO National Laboratory Singapore	Airfoil Design and Validation for Application to UAVs
Petros G. Voulgaris	NSF	Distributed Control of Giant Segmented Telescopes
Petros G. Voulgaris	NSF Qatar	Smart Systems for Field Monitoring and Surveillance
Scott R. White	AFOSR	Interfacial Self-Healing in High Performance Composite Materials
Scott R. White	AFOSR	Regeneration and Remodeling of Composite Materials
Scott R. White	Bridgestone	Self-Healing Materials for Automobile Tires: Phase 1 Capsule Survival
Scott R. White	AF	Metastable Packaging for Transient Electronic Devices
Scott R. White	Boeing Co.	Translation of Fiber/Matrix Interface Properties to Composite Tensile and Compressive Strength
Scott R. White	NSF	SusChem/FRG/GOALI: Mechanochemically Based Sustainable Polymers
Scott R. White	Navy	Seeded Reaction Waves in Composites: Fast Structue-Transforming Materials that Respond to Energetic Stimuli
Scott R. White	Army	Self-Healing Composite Armor Substrate
Scott R. White	DOE ANL	EFRC TIES (Tailored Interfaces For Energy Storage)
Scott R. White	Navy	Synthesis Characterization and Modeling of Functionally Graded Multifunctional Hybrid Composites for Extreme Environments

Back to Table of Contents


ILLINOIS