Prof. P.R. Grant
Aircraft Dynamics, Flight Simulation, and Flight Test

Professor Grant's research areas include flight dynamics, flight simulation, the virtual flight test facility, and human control of vehicles. His current research is focused on the development of ground-based simulators for upset prevention and recovery training (UPRT), the impact of structural flexibility on aircraft handling qualities and modeling of human motion perception and control. Professor Grant has also been actively involved in driving simulation research and has written motion drive software for the US National Advanced Driving simulator, as well as for Toyota's state-of-the-art dynamic driving simulator.

Aircraft safety is the primary motivation for Professor Grant's research. First, a large percentage of commercial aircraft accidents are triggered by unexpected aircraft upsets. Due to the fidelity limitations of current flight simulators and safety concerns in real aircraft, pilots have very little training on how to successfully recover from upset conditions. The current upset recovery project is studying ways to improve simulators such that meaningful training can take place. Second, environmental concerns are leading to new aircraft designs that are likely to have: (i) increased structural flexibility compared to previous designs, (ii) unconventional dynamic behavior. The aircraft flexibility project is aimed at understanding how aircraft flexibility will affect the pilot's ability to precisely and safely control the aircraft. Professor Grant's research group is also investigating the handling qualities of unconventional aircraft designs such as the blended-wing body (BWB). Although closed-loop control can modify the BWB dynamic response such that it is similar to a conventional aircraft, it is still important to understand how pilots will interact with the bare-airframe dynamic response of these new aircraft.

The UTIAS Flight Research Simulator is one of a few university owned motion-based flight simulators in the world. It allows the researchers at UTIAS to experimentally validate improvements in simulator fidelity and it can act as a surrogate for new aircraft designs, thereby allowing researchers to measure human control behavior/performance while flying simulations of these new designs in a virtual environment. In addition, the simulator enables the group's ongoing investigation into a basic understanding of human motion perception and control.

Recently an extended B747 flight model that realistically predicts the behavior of the aircraft at and beyond stall was developed and tested. The model includes reduced lateral and directional stability, reduced effectiveness of controls and asymmetric roll-off beyond stall. A new adaptive motion drive algorithm was also developed for UPRT that can produce realistic motion cues during the extreme motions encountered during upsets. A set of experiments using this new algorithm determined that good roll cueing leads to improved pilot control but reduced subjective fidelity due to the increased lateral side force errors. Therefore a careful trade-off between the two motions is required for UPRT. A recent human motion perception study found that translational motion perception tends to follow Weber's law whereby the just-noticeable-difference (JND) is linearly related to the size of the base stimulus. These results are being used to develop Bayesian models of human motion perception.

Prof. H.H-T. Liu
Aircraft Flight Systems and Control

Dr. Hugh H.T. Liu is an Associate Professor at the UTIAS and he currently serves as the Associate Director, Graduate Studies. Dr. Liu is an internationally leading researcher in the area of aircraft systems and control, and he leads the "Flight Systems and Control" (FSC) Research Laboratory. Dr. Liu has published over 100 technical papers in peer reviewed journals and conference proceedings, and he has received one patent (US and Canada) on his work on motion synchronization. He has significant research contributions in autonomous unmanned systems development, cooperative control, and integrated modeling and simulation. He also serves on editorial boards and technical committees of international professional societies. Before his academic appointment, Dr. Liu has several years' industrial experience where he participated and led development projects of aircraft environmental control systems. Dr. Liu is a Fellow of CSME, Associate Fellow of AIAA, and an active member of IEEE, CASI.

The research interests of the "Flight Systems and Control Laboratory" at UTIAS cover the following themes/areas: (1) systems modeling, simulation and control; (2) multi-vehicle systems estimation and control; and (3) autonomous unmanned vehicle systems (UVS) applications. The goal of our research is to bring state-of-art control and integration techniques to improve or optimize aircraft systems performance.

Our recent research projects include:

Systems Modeling, Simulation and Control
- Aeroservoelastic wing and active control
- Landing gear thermo-tribo-mechanical model development
- Aircraft systems simulation and integration
- Fail-safe flight and fault tolerant control

Multi-vehicle Systems Estimation and Control
- Vision-based surveillance and sensing using multi-UAVs
- Quadrotor UAV vision-based target tracking
- Motion synchronization formation control
- Cooperative multi-vehicle forest fire monitoring

Autonomous UVS Applications
- Autonomous localization and mapping
- Autonomous Soaring Surveillance
- Autonomous target interception for border patrol vehicles

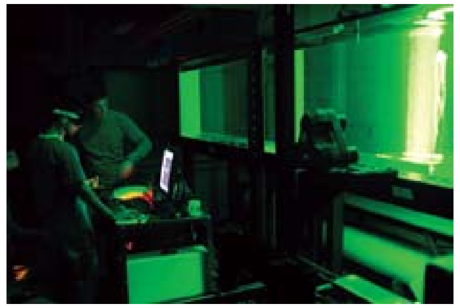
Details of our up-to-date research are available at: www.flight.utias.utoronto.ca

Prof. A. Ekmekci
Experimental Fluid Dynamics

Dr. Alis Ekmekci leads the experimental fluids lab at UTIAS, where she conducts research in flow control, flow-induced noise and vibration, flow-structure interactions, low-Reynolds-number aerodynamics, unsteady separated flows, and vortex dynamics. The main facilities available in this lab include: a re-circulating water channel, a Particle Image Velocimetry (PIV) system, Volumetric 3-Component Velocimetry (V3V) system, hydrogen bubble and dye visualization systems, hot film anemometers, pressure transducers, several motorized linear and rotary traverse systems, and motion control and DAQ systems. This infrastructure leads to a unique capability to conduct several experimental projects in fluid mechanics research. Recent and ongoing projects carried out by her group are as follows:

Passive control of flow past slender structures: This project investigates manipulation of flow past slender structures through various patterns of surface protrusions. We explore the conditions that particularly attain attenuation or enhancement in vortex shedding. In turn, insight into the attenuation aids the development of methods for suppressing vortex-induced structural vibrations, while the enhancement unveils the conditions that exacerbates vibrations for energy harvesting.

Flow structure around landing gear models: This is a collaborative project with Bombardier. Landing gears are known to be a major source of aircraft noise. This noise mainly results from the fluctuating flow structure. Hence, we explore the unsteady flow topology around landing gear models in relation to the components of the model. Knowledge of this, in turn, can reveal the sources of noise and aid the design of next-generation quieter aircraft.



Flow-induced cavity resonance and its control: This project investigates the resonant coupling phenomena in flow past cavity configurations. Flow-induced cavity resonance is encountered, for example, in the cavities located on the fuselage of an aircraft, the hull of marine vessel, and the ballast tank of a submarine, to name a few.

Junction flows, horseshoe vortex dynamics: Horseshoe vortices form in many real scenarios, such as at wing-body junctions in airplanes, turbine blade-hub junctions, cooling flow past computer chips. They often have large effects on skin friction, noise and the local heat transfer in junction regions. This project investigates how the oncoming boundary layer and the geometry of the wing-body affect unsteady dynamics of horseshoe vortices.

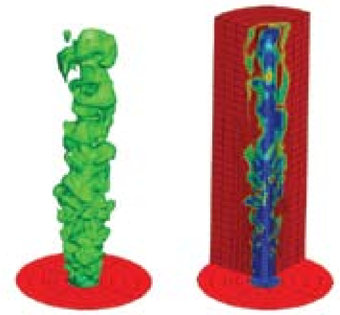
Wake behind a pair of bluff bodies: Understanding of the flow past bundled cylindrical bodies is of great significance for the control of flow-induced vibrations in heat exchanger tubes, adjacent tall buildings, and piles of offshore platforms. In this project, flow past two cylinders in tandem and side-by-side arrangements are investigated. Both stationary and forced oscillating cylinders are tested.

Unsteady vortex dynamics in delta wings: Delta wings are employed in a variety of aerospace vehicles, such as in micro air vehicles and unmanned combat air vehicles. This project explores the unsteady aspects of flow over non-slender delta wings under stationary and manoeuvring conditions.

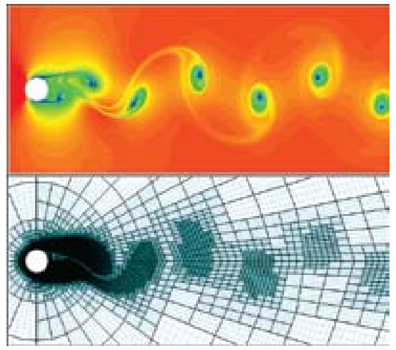
Interfacing of experimental investigations with numerical simulations: We welcome collaborative research with groups conducting numerical simulations. Our experimental work can easily interface the work of numerical simulations in validation efforts.

Prof. C.P.T. Groth
Computational Fluid Dynamics & Propulsion

Prof. Clinton Groth is a theoretical and computational fluid dynamicist with expertise in finite-volume schemes for compressible non-reacting and reacting flows and in the development of parallel adaptive mesh refinement (AMR) methods. He also has expertise in the computation of reactive, non-equilibrium, rarefied, and magnetized flows, and the development of generalized transport models and solution methods following from kinetic theory. His current research focuses primarily on the development of reliable and robust, parallel, high-order, AMR, finite-volume methods mesh for the solution of multi-scale, physically-complex flows and the application of these techniques to numerical combustion modelling, including research on large-eddy simulation (LES) techniques for turbulent premixed, non-premixed, and partially premixed combusting flows, as well as fundamental studies of laminar flames for bio-based fuels under high-pressure gas-turbine-like conditions. Industrial research partners include Rolls-Royce Canada and Pratt & Whitney Canada, two leading manufacturers of gas turbine engines for aviation and power generation applications. He is the author and co-author of nearly fifty journal articles and nearly 120 conference papers, has been involved in organizing both national and international conferences, is currently a member of the Scientific Committee for the International Conference on Computational Fluid Dynamics and University of Toronto SciNet Technical Advisory Committee, and is a past president and member of the Board of Directors of the Computational Fluid Dynamics Society of Canada.



The current and planned research activity of Prof. Groth's CFD and Propulsion group includes: (i) development of AMR and embedded mesh strategies for treatment of complex and possibly moving geometries and interfaces using hybrid multi-block meshes consisting of both body-fitted structured and more generally unstructured grid blocks; (ii) development of high-order finite-volume spatial discretization procedures on structure and unstructured mesh for improved solution accuracy; (iii) development of fully anisotropic mesh refinement techniques with refinement criteria based on dual-weighted reconstruction and residual error estimates; (iv) design of efficient and scalable parallel implementations with two-levels of parallelism - coarse-grain parallelization via domain decomposition and fine-grain parallelization - for more effective use of future petascale and exascale high-performance computing hardware; and (v) and development of improved parallel implicit time-marching schemes based on Newton-Krylov-Schwarz (NKS) approaches. Targeted applications of the new advanced computational tools would include the prediction of high-pressure combustion and pollutant emissions, including soot, for conventional and bio-based fuels, LES of thermo-acoustical phenomena in turbulent premixed flames, and the prediction of non-equilibrium micro-channel and plasma flows.



Aerodynamics, Fluid Dynamics, & Propulsion

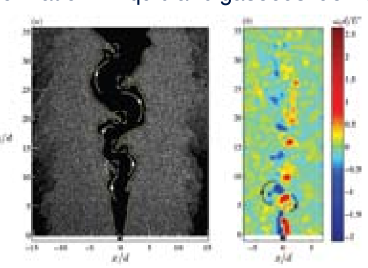
Prof. Ö.L. Gülder
Propulsion & Combustion

Dr. Gülder joined UTIAS in November 2001 and leads an experimental and computational research program in combustion and propulsion. Before coming to UTIAS, he worked at the National Research Council Canada as head of the Combustion Research Laboratory. His research has been in the field of turbulent combustion, premixed flame propagation, soot formation in combustion, development and use of experimental optical diagnostics in combustion systems, combustion in gas turbines and reciprocating engines, and alternative transportation fuels. He is the author and coauthor of more than 250 papers in these areas. He had served on the editorial boards of the journals Combustion and Flame, International Journal of Engine Research, International Journal of Thermal Sciences, and Atomization and Sprays. He served as a Member of the Board of Directors of the Combustion Institute between 2000 and 2012, and was the Chair of the Canadian Section of the Combustion Institute from 1991 to 2001. His current commitments of scientific and technical advisory nature include: Scientific Advisory Committee Member, biennial International Sooting Flame Workshops since 2011; Co-organizer of the biennial International Premixed Turbulent Flames Workshops since 2008.

A key element of many of modern society's critical technologies, combustion accounts for approximately 85 percent of the world's energy usage and is vital to our current way of life. Spacecraft and aircraft propulsion, electric power production, home heating, ground transportation, and materials processing all use combustion to convert chemical energy to thermal energy or propulsive force. Professor Gülder's research aims to improve our understanding of this essential process and paving the way for more efficient and environmentally friendly combustion of both traditional and alternative fuels.

The Combustion and Propulsion group's experimental facilities include several generic burners for laminar and turbulent flames, a high-pressure combustion chamber capable of 100 atm; a unique set up for jet fuel oxidative thermal stability research, and various optical and laser-based combustion and flow field diagnostics such as Rayleigh scattering, soot emission spectroscopy, laser-induced incandescence, two-line atomic fluorescence, particle image velocimetry. The group's recent accomplishments include (a) revealing the flame front structure in turbulent combustion, and (b) pressure dependence of soot formation in gaseous flames.

Current research activities of the Combustion and Propulsion group focus on (a) fundamental combustion properties of biofuels for aviation and ground transportation; (b) soot and particulate formation in liquid and gaseous fuel flames at elevated pressures representative of gas turbines; (c) dynamics and structure of premixed and non-premixed turbulent flames; (d) structure of laminar diffusion flames; (e) thermal oxidative stability of conventional and alternative aviation fuels; (f) laser-induced incandescence technique for soot and particulate diagnostics. These experimental studies are complemented by high-fidelity numerical simulations in collaboration with CFD and Propulsion Group (Prof. Groth). Combustion and Propulsion Group have been collaborating with national and international groups in some of these subject areas.



Current funding of the Combustion and Propulsion Group comes from Rolls Royce Canada – CRIAQ; Biofuel Network; NSERC (Strategic, Discovery, and RTI); Green Aviation Research and Development Network (GARDN); CFI; and Pratt and Whitney Canada.

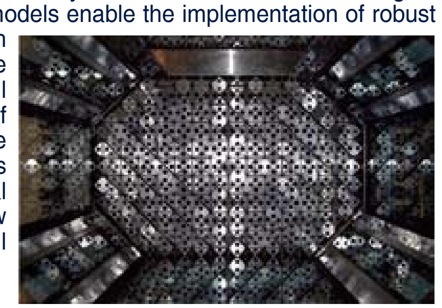
Prof. P.L. Lavoie
Flow Control & Experimental Turbulence

Prof. Lavoie's research interests are in the fields of modern flow control and turbulence, primarily from an experimental perspective. He is particularly concerned with the study of transitional and turbulent flows, as well as the flow structures and instabilities associated with these phenomena. The focus of the FCET group is to investigate the fundamental dynamics of attached and separated shear layers, and how these can be manipulated to improve flow characteristics with respect to specific goals, such as skin-friction drag reduction and mitigating noise emissions. The overarching aim is to develop novel flow control strategies, based on modern approaches, and the instrumentation and tools required to implement passive or active control techniques in an experimental framework and real life applications, such as on the surface of an aircraft. The motivation at the core of this research is the reduction of greenhouse gas emission in commercial transport industries, in particular aviation, through improved fluid system efficiency.

One of the current projects is part of an ongoing international research effort, involving researchers from the US and the UK, aimed at addressing fundamental issues pertinent to the delay of boundary layer transition from laminar to turbulent state via model-based feedback control. This work, which is supported in part by Bombardier Aerospace and Pratt & Whitney Canada, has further significance for the implementation of active control of turbulent boundary layers. For this project, a model-based closed-loop control was developed and implemented to negate the transient growth instabilities, known to trigger early transition to turbulence, in a Blasius boundary layer. Recent tests in the FCET state of the art low-speed wind tunnel (figure 1) have demonstrated reduction of over 90% of the targeted disturbance energy.

Dielectric-barrier-discharge plasma actuators are being developed and utilized for the aforementioned flow control problem. In the context of the transition control problem, the electro-mechanical coupling provided by the plasma actuator is used to negate transient growth due to surface roughness, thus preventing transition (figure 2). Plasma actuators are also used for the control of separated shear layers, such as those found in the wake of a landing gear or blunt trailing edge. The utilization of these actuators is also supplemented by the study of issues relating to the practical implementation of these devices in industry.

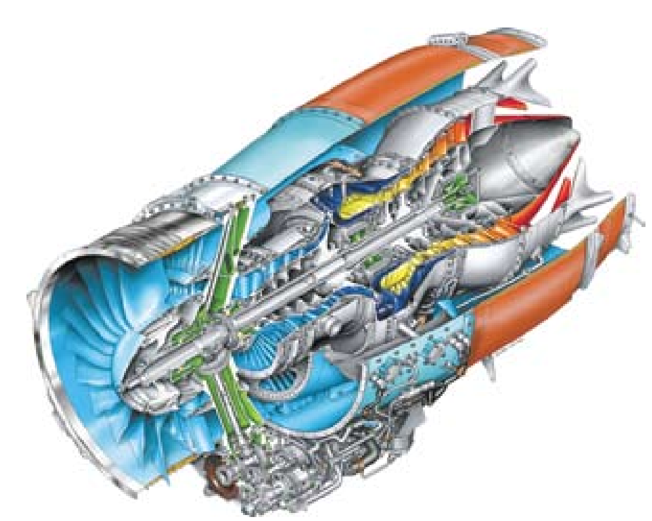
Finally, experimental investigations are presently underway to develop flow state estimators and low-order models for separation control. Estimators are essential tools in modern flow control to allow state estimation of the flow dynamics based on limited sensing. In addition, low-order models enable the implementation of robust control strategies with realistically feasible computational requirements, all of which supports the overarching objectives aimed at the practical implementation of flow control in industrial applications.



Dr. P.S. Sampath
Combustion, Emissions & the Environment

Dr. Sam Sampath is a specialist in combustion and emissions applicable to aviation gas turbine engines. With Pratt and Whitney Canada (P&WC) from 1970 to 2011, Dr. Sampath helped to create the combustion systems of a large number of aviation gas turbine engines currently in field operation, or going through development for application to future aircraft. During his tenure at P&WC, Dr. Sampath played the dual role of manager and Senior Fellow on Combustion. He led several research programs on ultra low emission technologies, alternative and bio fuels. His international research collaborations included US, European, and Indian universities and research institutions. He is author or co-author of over thirty-five papers/publications and innumerable industrial research reports of a proprietary nature. Dr. Sampath also contributed to the latest version of the Handbook of Fluid Dynamics. His environmental impact studies contributed to the 2007 Nobel Peace Prize award to the Inter-governmental Panel for Climate Change (IPCC). Dr. Sampath has been awarded fourteen international patents, a Fellowship of the Canadian Academy of Engineering (FCAE), and a P&WC pioneer award for lifetime achievements.

Over the last sixty years, aviation has evolved in a steady manner with improvements of aircraft/aero-engine efficiency, performance, reliability, range, specific power, etc. This evolution has been facilitated by the availability of engineers and scientists from Canada and abroad including aerodynamicists, structural and other system engineers in many disciplines. New environmental challenges in the future include green engine designs with major reductions of harmful pollutants such as oxides of nitrogen, carbon monoxide, and particulate emissions. The other major demand is the need to reduce the carbon footprint by reducing Green House Gases (GHG). These needs have resulted in the creation of a UTIAS Executive Industrial Research Chair for Dr. Sampath, supported by NSERC and Pratt and Whitney Canada. The focus of Prof. Sampath's efforts is to support specific combustion and emission projects along with three other professors and some graduate students. The aim is to advance the capabilities of UTIAS to become the centre of excellence in the fields of aviation gas turbine combustion and emissions.



**PW300 Engine
(Low Emission Combustor)**

Prof. A.M. Steinberg
Propulsion and Power Thermo-Fluids

Professor Steinberg joined UTIAS in 2011 after spending several years at the German Aerospace Center (DLR) Institute for Combustion Technology. At UTIAS, he heads the Experimental Engines (E^2) laboratory. Research in this laboratory can be broadly classified under three themes:

- Applied research on understanding, predicting, and controlling practical thermo-fluidic processes in aerospace propulsion engines and technologically related power generation systems;
- Fundamental research towards a scientific understanding of 'engine-relevant' turbulent combustion in order to improve prediction and modelling; and
- Development of advanced laser-based measurement techniques for fluid mechanics and combustion.

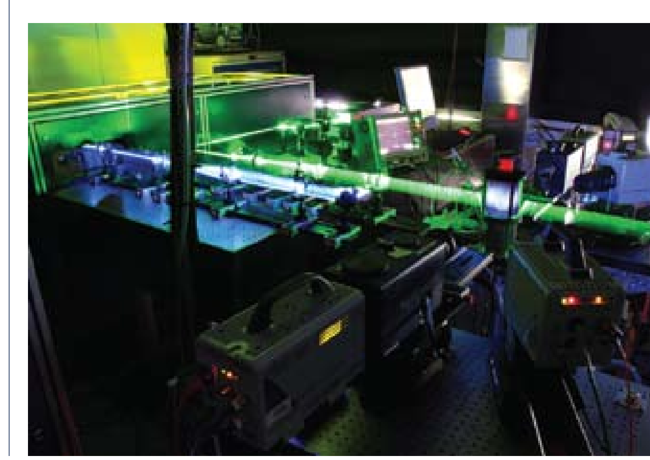
A key principle in Prof. Steinberg's research is the utilization of advanced measurement techniques and data-mining algorithms to quantitatively extract complex data from experiments and thereby reveal underlying causal mechanisms. This often involves the use of 'high-repetition-rate' laser-based techniques that can explicitly resolve dynamic processes occurring at timescales less than a millisecond.

Furthermore, the general philosophy is to replicate conditions that are directly relevant to the engines of interest (as closely as is tractable). To this end, research in the E^2 lab employs a variety of gas turbine model combustors, highly-turbulent flames, and full gas turbine engines that have been modified to allow for optical access. Professor Steinberg also is principle user of the new Advanced Combustion Energy Research (ACER) Facility, which is capable of reaching conditions targeted for future generations of engines (e.g. $p > 50$ atm, $T0 > 800$ K).

Many current projects in the E^2 lab focus on reducing the environmental impact of air travel and power generation through design of low-emission gas turbine engines that can operate with sustainable fuels. Examples of some current topics include:

- Prediction and control of thermo-acoustic oscillations in low-NOx gas turbine combustors;
- Effects of alternative fuels and exhaust gas recirculation on combustion stability;
- Gas turbine-based hybrid electric road vehicles;
- Flame-holding for gas turbines and supersonic engines;
- Complimentary use of high-repetition-rate diagnostics with simulations;
- Rate-controlling processes in extremely turbulent flames;
- Laser-induced phosphorescence diagnostics.

These projects involve extensive collaborations with Canadian industry, as well as laboratories in the US, UK, and Germany.



Aerodynamics, Fluid Dynamics, & Propulsion

Prof. D.W. Zingg
Computational Aerodynamics

Professor Zingg's research areas include aerodynamics, computational fluid dynamics (CFD), aerodynamic shape optimization, and aerostructural optimization. His current research is concentrated on applying high-fidelity aerodynamic and aerostructural optimization to the design of unconventional low-drag aircraft configurations motivated by the need to reduce greenhouse gas emissions from aircraft. Together with colleagues from NASA, he is a co-author of the textbooks Fundamentals of Computational Fluid Dynamics and Fundamental Algorithms in Computational Fluid Dynamics, both published by Springer. He has held the Tier I Canada Research Chair in Computational Aerodynamics and Environmentally Friendly Aircraft Design since 2001 and currently holds the J. Armand Bombardier Foundation Chair in Aerospace Flight. He was awarded a prestigious Guggenheim Fellowship in 2004 for research in the design of environmentally friendly aircraft.

The motivation for the research in the computational aerodynamics group is based on two premises. The first is that we require a substantial reduction in greenhouse gas emissions per passenger-km from the next generation of aircraft. Although the current contribution of civil aviation to climate change is relatively modest, demand for air travel is projected to increase at 3-4% per year, while emissions per passenger-km have historically decreased at a rate of 1-2% per year. This situation is not sustainable, and we need aggressive R&D to obtain larger reductions in emissions. The second premise is that high-fidelity optimization can play an important role in achieving this goal through the design and evaluation of new concepts and unconventional configurations for low-drag aircraft. The specific goals of the computational aerodynamics group are:

1. To advance the state of the art in algorithms for high-fidelity aerodynamic and aerostructural optimization.
2. To apply these algorithms to the design and development of the next generation of aircraft with greatly reduced greenhouse gas emissions per passenger-km.

The group has strong interactions with Bombardier Aerospace, Pratt & Whitney Canada, and the NASA Ames Research Center.

At the core of the research are novel algorithms for CFD and aerodynamic shape optimization developed by the group. The parallel implicit flow solver Diablo combines an efficient Newton-Krylov-Schur algorithm with a higher-order spatial discretization based on summation-by-parts operators and simultaneous approximation terms applicable to multi-block structured grids. This combination provides a unique and powerful algorithm for the numerical solution of the Euler and Reynolds-averaged Navier-Stokes equations as well as large-eddy simulations of turbulent flows. The optimization code Jetstream utilizes this flow solver in conjunction with an adjoint technique for gradient evaluation and a novel integrated approach to mesh movement and geometry parameterization. Jetstream has been applied to the design of various wings and aircraft configurations, including nonplanar wings and blended-wing-body aircraft.

Current projects in the computational aerodynamics group are aimed at the two goals above. Within these general areas, there are numerous exciting thesis topics. Applications from talented students are always welcome. Please see Professor Zingg's web site for more up-to-date information. Several recent papers are posted there.

Recent Faculty Awards

Prof. David Zingg: McCurdy Award, CASI, 2012

Dr. Sam Sampath: GARDN Green Award, 2012

Prof. Ömer Gülder: Fellow of Canadian Academy of Engineering, 2012

Prof. Timothy Barfoot: Canada Research Chair in Autonomous Space Robotics, 2007 – 2012, 2012 – 2017

Prof. David Zingg: Canada Research Chair in Computational Aerodynamics and Environmentally-Friendly Aircraft Design, 2001 – 2008, 2008– 2015

Prof. Timothy Barfoot: Early Researcher Award, 2011

Prof. Prasanth Nair: Canada Research Chair in Computational Modeling and Design Optimization Under Uncertainty, 2011 - 2016

Prof. Peter Stangeby: Fellow of the Royal Society of Canada, 2011

Prof. David Zingg: OSPE/PEO Engineering Medal - Research and Development. 2011

Dr. Robert Zee with the SFL CanX-2 Team: Alouette Award (CASI), 2010

Prof. David Zingg: Fellow of Canadian Academy of Engineering, 2010

Prof. Philippe Lavoie: Early Researcher Award, 2010

Prof. David Zingg: University of Toronto Faculty Award, 2009

Dr. Robert Zee with the SFL MOST Project Team: Alouette Award (CASI), 2008

Prof. Peter Hughes: John H. Chapman Award of Excellence, CSA, 2007

Prof. James DeLaurier: McCurdy Award, CASI, 2007

Prof. Barry French: Member of the Order of Canada, 2007

Prof. Peter Hughes: Alouette Award, 2006

Prof. Lloyd Reid: University of Toronto Engineering Alumni Hall of Distinction, 2005

Prof. David Zingg: Guggenheim Fellowship, 2004

Prof. Ben Etkin: UofT Engineering Alumni Achievement Medal, 2004

Prof. R.C. Tennyson: McCurdy Award, CASI, 2004

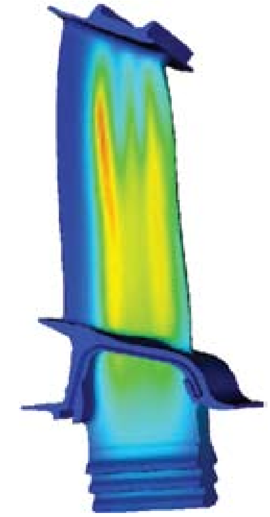
Prof. Ben Etkin: University of Toronto Engineering Alumni Medal, 2004

Prof. Ben Etkin: Member of the Order of Canada, 2003

Design Optimization & Structures

Prof. P.B. Nair
Computational Modeling and Design Optimization

Professor Nair is the Tier II Canada Research Chair in Computational Modeling and Design Optimization Under Uncertainty and an Associate Professor at UTIAS. He received his Ph.D. (2000) from the University of Southampton, and his M.Tech. (1997) and B.Tech. (1995) degrees in Aerospace Engineering from the Indian Institute of Technology, Mumbai. Prior to joining UTIAS in 2011, he was an academic in the School of Engineering Sciences at the University of Southampton.

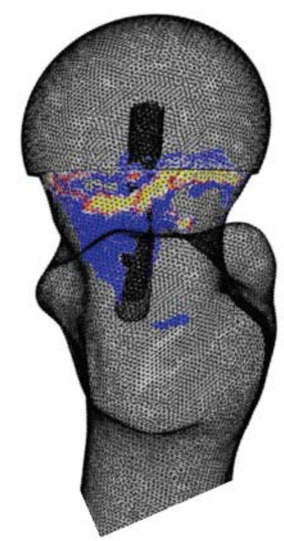


Prof. Nair's research interests lie in three main areas: (i) computational modeling of deterministic and stochastic systems governed by partial differential equations, (ii) optimization algorithms for design, control and parameter estimation, and (iii) generalized function approximation problems. He is the co-author of a book on Aerospace Design (Computational Approaches for Aerospace Design, John-Wiley and Sons, 2005) and over 100 articles in referred journals, edited books and conference proceedings.

Prof. Nair heads the Computational Modeling and Design Optimization Under Uncertainty Group at UTIAS. The research activities of this group are driven by the vision that future computational modelling techniques must not only predict nominal response but also produce a certificate of response variability that rigorously accounts for all sources of uncertainty. Furthermore, this enhanced analysis capability must be highly efficient, parallelizable, and scalable to high-dimensional models. Theoretical and algorithmic advances in these directions are key to realizing the promise of computational models as reliable surrogates of reality as well as enabling robust design optimization of complex real-world systems.

Prof. Nair's research group also works on various aspects of scientific computing, including the implementation of numerical algorithms on multiprocessor hardware and parallel function decomposition schemes for alleviating the curse of dimensionality encountered in high-dimensional function approximation and solution of parameterized operator equations. Ongoing research projects include:

- Numerical methods for stochastic partial differential equations;
- Numerical methods for constructing real-time emulators of high-dimensional engineering systems with applications to robust design optimization and uncertainty analysis;
- Bayesian methods and greedy algorithms for modelling spatio-temporal datasets and operator problems;
- Parsimonious design space parameterization strategies;
- Statistical shape modelling using noisy and sparse measurement data; and
- Computational methods for robust design of total hip and knee replacements and emulators for pre-clinical decision support.



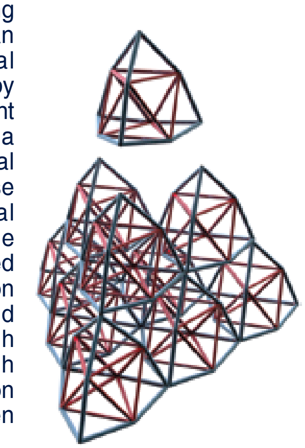
Prof. C.A. Steeves
Multifunctional Structures

Craig Steeves is an assistant professor at the University of Toronto Institute for Aerospace Studies. Dr Steeves has both a Bachelor of Arts degree in International Relations from Trinity College, University of Toronto and a Bachelor of Applied Science in Civil Engineering from the University of British Columbia. He received his Doctor of Philosophy in 2002 from the Cambridge University Engineering Department, studying composite mechanics and minimum-weight design of composite structures in Prof Norman Fleck's Micromechanics Group. Subsequently Dr Steeves joined the Princeton University Department of Mechanical and Aerospace Engineering with Prof Richard Miles on a project examining the use of multifunctional sandwich structures in the context of magnetohydrodynamic power generation on reentering space vehicles. Finally, Dr Steeves worked with Prof Tony Evans at the Materials Department of the University of California, Santa Barbara on topics related to materials and structures enabling airbreathing hypersonic flight.

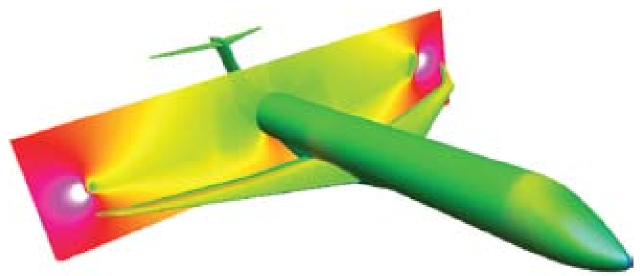
The UTIAS Multifunctional Structures Group conducts research aimed at enhancing aircraft performance by combining complex structural and functional elements in an optimal configuration. Fibre composite materials are key components of this research, because it is possible to exploit the geometric complexity inherent in composites to achieve additional functional capabilities. For example, composites can be structured to be strong, stiff and light, and to have desirable vibrational characteristics. This depends both upon accurate models of the mechanical behaviour of arbitrarily configured composites and upon an ability to choose optimal designs within a very large design space. Modeling and optimal design of complex structured systems are the two interconnected foci of the research group.

Current work is concentrated on complex composite structures and on hybrid nanocrystalline microtrusses. Two specific types of composite structure are under investigation. The first is composite plates with locally variable fibre direction. By varying the fibre direction throughout a structure, it is possible to design additional functional properties into the system, such as novel vibration characteristics, while retaining high strength. Another complex composite structure is the truss-core sandwich, which is a light, stiff beam consisting of two composite face sheets separated by a truss-like composite core. These, because of the geometric complexity of the core truss, enable very precise tailoring of certain properties, such as acoustic transmission behaviour. Hybrid nanocrystalline microtrusses are fabricated by making polymer truss preforms through a rapid-protoyping process, then coating the preforms with high-performance nanocrystalline metal. This produces a very light, strong structure which can be tailored at four length scales, offering a designer wide latitude for optimisation.

Current work also includes research on lattices, which are truss-like structures consisting of repeating unit cells. By using two or more materials and selecting the correct geometry, lattices can be designed to have additional useful properties. For example, by combining two materials with different coefficients of thermal expansion, a lattice with zero effective thermal expansion can be created. These lattices can be used in thermal protection systems or as stable surfaces of mirrors for space-based telescopes. Additional research on lattice materials was associated with wave propagation through three-dimensional lattices, with such lattices to be used as vibration isolators for attachments between aircraft engines and wings.



THE FUTURE NOW

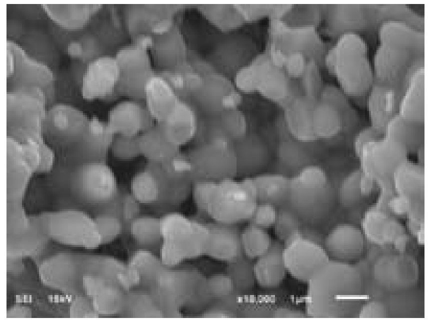


What is the impact of aviation on the environment? How can we reduce greenhouse gas emissions and noise pollution? Is it possible to make airplanes that are both quiet and fuel-efficient? Will biofuels solve the problem of carbon emissions, or does the production of biofuels create still more problems? If we use advanced lightweight materials, can we dispose of them safely when the airplane is retired? Will people want to fly in aerodynamically advanced airplanes? How can we balance the demands of safety, passenger comfort, cost and environmental friendliness? What new technology will help solve these problems? Can aviation truly be made environmentally sustainable? How can these questions be answered?

The Centre for Research in Sustainable Aviation (CRSA) was established in January 2013 to address these questions and the concomitant need for scientists and engineers with the interdisciplinary skills required to develop future generations of environmentally sustainable aircraft.

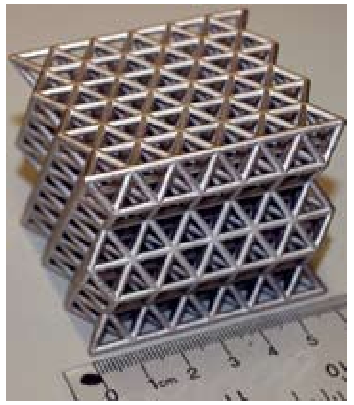
> "We believe that the [UTIAS Sustainable Aviation] program...will produce a new generation of highly qualified engineers [with the] insight, innovation and talent to develop solutions addressing the environmental impact of aviation." - Walter Di Bartolomeo, Vice President, Engineering, Pratt & Whitney Canada

The CRSA brings together technical specialists in key areas for designing airplanes: aerodynamics, propulsion, structures, aeroacoustics and control. To this team are added experts in atmospheric physics, biofuels, life cycle assessment, and aviation policy. This generates a unique opportunity for cutting-edge interdisciplinary research and teaching. The CRSA takes advantage of the technical and professional expertise within UTIAS, its partner institutions, and industry. UTIAS has joined with global leaders in academia including Universite de Sherbrooke, Stanford University, University of Michigan, Imperial College, Cranfield College of Aeronautics, and University of Cambridge. Because of the necessary close cooperation between universities and industry, the CRSA also works directly with the largest employers for aeronautical engineers and researchers in Canada: Bombardier Aerospace and Pratt & Whitney.



Thermographic phosphors (ceramic nano-crystals doped with rare-Earth metals) used to detect phenomena that negatively affect emissions and efficiency inside gas turbine engines

Aerospace companies are seeking employees who possess world-class technical abilities as well as critical non-technical skills, including communication abilities and project management capability. The UTIAS programs in Sustainable Aviation address these needs through strategic professional training opportunities including a Student Research Symposium and a Research Project Management Workshop, supplemented by industrial internships and practical experience in managing undergraduate interns. Students will have networking opportunities with regulatory, governmental, and non-governmental organisations involved in sustainable aviation through the International Workshop on Aviation and Climate Change, the National Colloquium on Sustainable Aviation, and the Summer School on Sustainable Aviation.



3D printed polymer microtrusses coated with nanocrystalline nickel

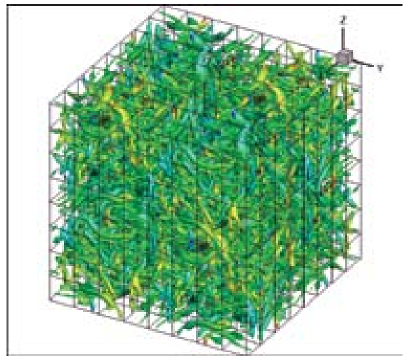
> "It is our belief that students with the breadth of expertise covered by the [UTIAS Sustainable Aviation] program will be in great demand in the aerospace industry." – Farzad Mokhtarian, Manager, Advanced Aerodynamics, Bombardier Aerospace

Carbon black formation at high pressures

With the UTIAS programs in Sustainable Aviation, students work in state-of-the-art facilities with global leaders in their fields, in areas that are in demand and projected to grow. Students will develop technical skills at the top Canadian aerospace department and will be prepared to contribute to future generations of environmentally friendly aircraft. With interdisciplinary training in both sustainable aviation and professional development, the skills that students acquire are, and will continue to be, in exceptionally high demand.

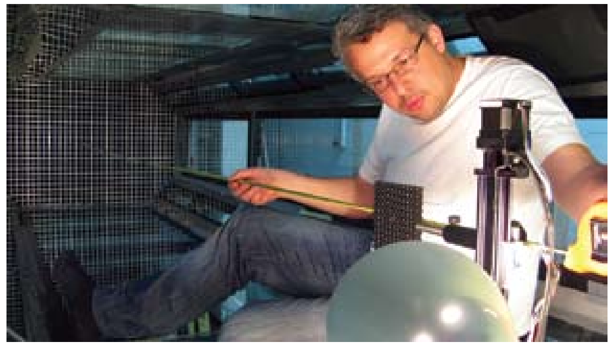
> "My experience at UTIAS has not only helped me significantly in my own research by providing the necessary background in aviation, but has instilled a passion to address the industry's future challenges relating to sustainability. Aside from the proximity to cutting edge research, being a part of the Sustainable Aviation Program allows access to the community-like setting of the UTIAS campus and provides opportunities for professional development." – Katherine Rispoli, M.A.Sc. Candidate – Civil Engineering, CREATE Trainee in Sustainable Aviation, University of Toronto

The CRSA has three initiatives: the industrial-stream NSERC Collaborative Research and Training Experience (CREATE) Program in Environmentally Sustainable Aviation, the Collaborative Research in Sustainable Aviation program, and an Emphasis in Sustainable Aviation for MASc, MEng, and PhD Students. The NSERC CREATE Program in Environmentally Sustainable Aviation was established in April 2012 with $1.65 million in funding from NSERC. The program boasts interdisciplinary technical training and collaborative opportunities with leaders in academia and industry, professional development opportunities, and four-month internships with the largest employers for aeronautical engineers and researchers in Canada.



Taylor-Green vortex flow simplified model of turbulence

The Collaborative Research in Sustainable Aviation Program promotes collaborative research with interdepartmental supervision within the Faculty of Applied Science & Engineering, expanding the breadth and depth of the students' technical knowledge and skills in sustainable aviation.



Prof. Lavoie sets up a calibration target downstream of a turbulence generating grid in a wind tunnel in preparation for tomographic particle image velocimetry measurements

The Emphasis in Sustainable Aviation is a designation on the transcript of a graduating student indicating that they have participated in activities related to sustainable aviation and have completed the relevant academic requirements.

Please visit the admissions page to learn about the application process. If you wish to participate in the UTIAS Sustainable Aviation programs, please indicate this in your statement of intent.

www.utias.utoronto.ca

Prof. T.D. Barfoot

Autonomous Space Robotics

Dr. Tim Barfoot is an Associate Professor and the Principle Investigator of the Autonomous Space Robotic Lab (ASRL) at UTIAS. He began his position in May 2007, after spending four years at MDA Space Missions, where he developed autonomous-vehicle navigation technologies for both space and terrestrial applications. Dr. Barfoot holds a Canada Research Chair (Tier II) in Autonomous Space Robotics, is an Ontario Early Researcher Awardholder, and a Professional Engineer (Ontario).

The purpose of Dr. Barfoot's research program is to enable scientific exploration by creating advanced autonomy for space robotics. Currently, planetary exploration is the primary focus of his work, particularly aspects of estimation and control for planetary rovers. There are currently four research threads at ASRL: (i) localization and mapping, (ii) path planning and path tracking, (iii) novel robotic concepts, and (iv) field testing.

The Localization and Mapping thread examines how to determine where a vehicle is on a planetary surface (either globally or locally) and how to build maps of the environment. These tasks are difficult due to the lack of a Global Positioning System equivalent beyond Earth. For short-range traverses, visual odometry techniques are being developed, which automatically identify and track natural landmarks to infer robot motion using visual sensors such as stereo cameras. For local worksite operations, a set of techniques to build a three-dimensional map using a laser rangefinder is underway. And, for long-range traverses, global localization techniques are being developed including celestial and orbital-image-based navigation.

The Path Planning and Path Tracking thread examines how to find safe passage for a vehicle through outdoor, unstructured, three-dimensional terrain. This can be done by assessing terrain using sensors onboard a robot and then planning to avoid hazards. However, a major challenge in this area is how best to use the limited computational resources available on a rover. A novel concept called a Network of Reusable Paths is under investigation, which allows a robot to explore and establish a network of safe paths, which can be used to revisit locations reliably. This concept builds on the standard visual odometry pipeline and can be thought of as a physical embodiment of a Rapidly-Exploring Random Tree path planner.

The Novel Robotic Concepts thread looks beyond the nominal scenario of having a single wheeled robot carry out planetary exploration. It seeks to develop robotic architectures that simplify the usual approach described in the other research threads. One possibility is to use a team of robots, which could simplify the localization problem by using one another as landmarks. Another is to have a large beach-ball rover blown along by the strong Martian winds, requiring no motors and little in the way of complex sensing or algorithms. Most recently, a tethered cliff-crawling robot concept is under investigation.

Finally, the philosophy of ASRL is that robotics techniques should be proven through realistic field trials. With support from the Canadian Space Agency's analogue program, Dr. Barfoot carried out preliminary robotic explorations of the Haughton Crater on Devon Island in the High Arctic, in the summers of 2008 and 2009. Additional field tests have occurred in the Sudbury (Ontario) and Mistastin Lake (Labrador) Impact Craters as well as the Mars Emulation Terrain at the CSA in Montreal.

Prof. G.M.T. D'Eleuterio

Space Robotics

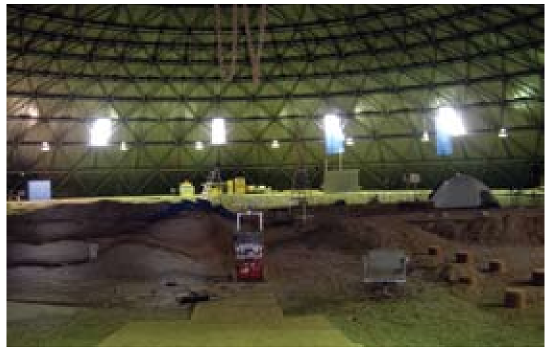
The moon has not been disturbed by human footprints since 1972. But as we gain a purchase on the new century, we are preparing a return to Earth's closest celestial neighbor. This time, however, we plan on staying.

Preparation for a permanent lunar habitat will require robotic missions in advance of humans. Robotics have played a key role in space exploration, from the success of Canadarm on the Space Shuttle to Sojourner which made the first tracks on Mars. They will precede us to the planets and planetoids and will, in a very literal sense, pave the way for our return to the Moon. Robots are currently our surrogate explorers but they will eventually become our companions as we begin to take steps farther into the Solar System. To this end, the UTIAS Space Robotics Group has been working on the concept of network robotics (or collective robotics or group robotics as it is also known); that is, a "swarm" of robots working cooperatively to accomplish a common goal or a form of consensus. Such an approach is necessitated by planetary network science where multiple and distributed measurements have to be made simultaneously as in conducting atmospheric or seismology studies. Even geological exploration and the search for extraterrestrial life will benefit from the network approach. Moreover, robot colonies will be required for resource utilization in situ and to construct habitats on alien soil. But the robots must be robust, autonomous and "intelligent." Herein lies the great challenge not just for space robotics but robotics in general. It is our Group's mission to foster robotic life.

The Space Robotics Group, led by Professor Gabriele D'Eleuterio, has a long history in robotics research for the Canadian space program. Our work dates back to developing general simulation dynamics techniques that were used in the design and development of Canadarm2 for the International Space Station. At present, our Group is participating in the development of a multirobot system for autonomous lunar excavation in support of the planned return to the Moon.

In keeping with its mission, the Group's research is motivated by biology. The notion of "intelligent robotics" is very much in vogue these days. However, our interpretation of "intelligence" in fact derives from observations and knowledge of the natural world. Our robotic control strategies are founded on neural network architectures that mimic the brain. But, ultimately, what has led to the emergence of intelligent creatures in our world has been the natural process of evolution. Accordingly, we are also working with and developing new algorithms of artificial evolution. Our Group is also seeking to understand better the dynamics of evolution and, in this way, not only do we hope these techniques to have a greater impact on the artificial world of robotics but perhaps we can also give back to the field of biology.

As one of our main interests is multiagent systems, we are also turning our attention to flying robots. We have recently begun an effort to build flying robotic "insects." But these too are not without potential space application as small flying robots have been proposed for the exploration of Mars. In the end, we are constantly turning to the natural world for inspiration.



Prof. J.S. Kelly

Pervasive Autonomy

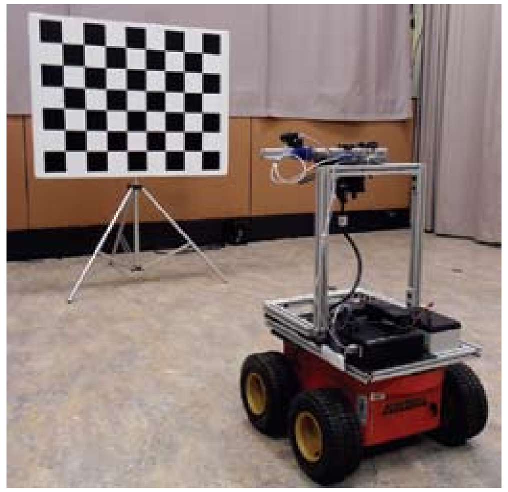
Professor Kelly's research is focused on developing robust autonomous systems that are able to operate independently over long durations and in challenging environments, for example, in space and on remote planetary surfaces. He is also interested in 'bringing space robotics down to Earth,' by emphasizing opportunities for technology transfer from space systems to terrestrial robots.

Professor Kelly received his PhD from the University of Southern California, where he was an Annenberg Fellow and was supported in part by a PGS-D award from NSERC Canada. His doctoral dissertation explored methods for self calibrating hybrid visualinertial navigation systems. Before moving to UTIAS, he held a postdoctoral appointment in the Robust Robotics Group at the Massachusetts Institute of Technology. Prior to graduate school, he was a Software Engineer in the Space Technologies division of the Canadian Space Agency.

The work in Kelly's group is motivated by the desire to implement effective autonomy solutions across a broad spectrum of application domains. Specifically, the group seeks to build robots that are:

1. persistent — able to function reliably and safely for days to weeks, or longer, with little or no human intervention, and
2. pervasive — efficient and cost-effective enough to be widely deployable.

Towards these goals, Kelly's group develops algorithms for an array of sensing devices and robotic platforms. Examples of current research topics include: robust, selfcorrecting sensing; low-fidelity sensor fusion for high-fidelity observation; long-term navigation, mapping and change detection; and autonomous science discovery. Theoretical results are verified through rigorous experimental trials, to ensure that the group's research can be successfully applied in the field.



Applications from talented and enthusiastic students are always welcome. Please visit Professor Kelly's web site for more information http://arrow.utias.utoronto.ca/~jkelly/

Prof. A.P. Schoellig

Dynamic Systems

The Dynamic Systems Lab headed by Prof. Angela Schoellig envisions a new generation of robots that have the ability to sense their environment and intelligently interpret information about it in order to improve their performance. Learning algorithms that can process large amounts of previously collected experience data will allow these robots to operate robustly and reliably in changing and challenging environments.

By conducting research at the interface of robotics, controls and learning, Prof. Schoellig's ultimate research goal is to extend the performance and autonomy of robots, and of dynamic systems in general. To this end, the Dynamics Systems Lab focuses on learning algorithms that combine prior knowledge about a system (such as dynamics models) with experimental data. Specifically, the Lab seeks to (i) advance the field of learning and data based control by combining concepts from dynamics, controls, optimization and machine learning, (ii) develop the theoretical foundations of new learning algorithms and apply them to state-of-the-art robotic platforms, and (iii) design computationally efficient algorithms that can later be extended to multi-robot applications such as coordinated, cooperative tasks of multiple agents, and human robot learning scenarios.

Prof. Schoellig engages her students in challenging, cutting-edge research projects that are self-contained, have a clear vision and the potential for high impact. Outreach activities such as lab demonstrations, events and online dissemination are an important facet of her work, and are used to communicate research results to the scientific community and beyond.

Prof. Schoellig aims to build a dynamic, creative and passionate research environment. Applications from self-motivated, talented students are welcome. Exchange and collaborations with researchers who work in complimentary fields and applications are also sought.

Prof. Schoellig received her Ph.D. in control engineering from ETH Zurich, and holds both a M.Sc. in Engineering Science and Mechanics from the Georgia Institute of Technology and a Masters degree in Engineering Cybernetics from the University of Stuttgart. Previously, she has worked on iterative learning algorithms for aerial quadrotor vehicles, and on new concepts for multi-vehicle coordination and motion synchronization. Her past research has been funded by the Swiss National Science Foundation and she was a finalist for the 2008 IEEE Fellowship in Robotics and Automation, which supports prospective leaders in this field. Her work has been published in robotics and controls journals such as Springer's Autonomous Robots and the Asian Journal of Control, and has received coverage worldwide on mainstream TV, and in print and online media.

Videos demonstrating her recent work can be found at: http://www.youtube.com/user/angelaschoe, and more information about her research is available at: http://schoellig.name.

Prof. C.J. Damaren
Spacecraft Dynamics/ Control & Microsatellites

Professor Chris Damaren obtained his doctorate at UTIAS in 1990 in the area of control systems for flexible spacecraft. In the 1990s most of his research concentrated on control system design for large structurally flexible robot manipulator systems such as the Space Station robotic systems developed by Canada. Most of this work was performed at Royal Roads Military College in Victoria, BC and the University of Canterbury in Christchurch, New Zealand. Since joining the faculty of UTIAS in 1999, his research group has been involved in the dynamics and control of spacecraft including the orbital, attitude, and structural motions of these systems.

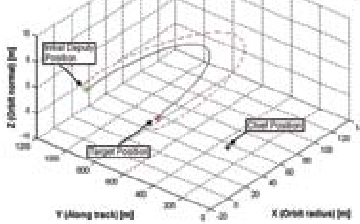
Previously completed research theses have included topics such as nonlinear filtering for spacecraft attitude determination, direct methods for low thrust optimization of interplanetary transfers, control of a flexible beam using a tip-mounted control moment gyro, control strategies for stable orbits around Phobos, position accommodation and compliance control for robotic excavation, and optimization of strictly positive real controllers for large flexible space structures.

A current research thrust is the development of control systems for formation flying spacecraft. The goal here is to control the relative motion between multiple spacecraft. Our research group has examined many aspects of the control problem including the development of suitable reference trajectories, optimal maneuvers for transitioning between different formation types, and the design of feedback controllers and state estimation methods. Current research focuses on combining impulsive control via thrusters with the Lorentz force produced by the geomagnetic field acting on spacecraft charge.

Another major research area centres on the use of the Earth's magnetic field and the torques it produces on current loops to provide control torques for spacecraft attitude control. This is fundamentally a time-varying problem because the field changes as the spacecraft moves around in its orbit. Our group has developed special methods for developing stabilizing feedback controllers which control the currents in the loops on board the spacecraft and hence the torques that are experienced. This work has been recently extended to attitude control for structurally flexible spacecraft.

More fundamental research has included the development of robust controllers for (possibly) nonlinear systems using two celebrated results in feedback control theory: the passivity theorem and small gain theorem. The idea is to use the stability properties predicted by the latter theorem to deal with systems which have passive characteristics at low frequency but exhibit passivity violations at high frequency. Applications included flexible space structures with collocated sensors and actuators. Other work has applied nonlinear robust control theory for the control of aerospace problems such as formation flying and attitude control. The bottleneck here is the Hamilton-Jacobi equation. Special algorithms have been developed for constructing approximate solutions to it.

Recently our group has embarked on the development of control systems for solar sails: large gossamer structures that use solar radiation pressure acting on a thin sail as a source of propulsion. Current projects include the study of control-structure interaction when tip vanes are used for pointing the sail and trajectory optimization using numerical approaches to optimal control theory.



Dr. M.R. Emami
Space Mechatronics

The goal of the Aerospace Mechatronics research thrust is to develop systematic frameworks and modular architectures for the concurrent, detail-level engineering of aerospace systems, from conception to configuration and integration, to realization and implementation.

Some of the group's current research activities include:

a) Holistic Mechatronics: a new concurrent design methodology is developed through introducing the universal notion of satisfaction and expressing the holistic behaviour of multidisciplinary systems using the concept of energy. The application of the methodology to an industrial robot manipulator has shown promising results.

b) Reconfigurable Mechatronics: the research focuses on the development of concurrent design frameworks for autonomously reconfigurable mechatronic systems. The merits of the research are shown through its applications to reconfigurable robotic rovers as well as a newly-designed 18 d.o.f. autonomously reconfigurable serial manipulator.

c) Mechatronics by Analogy: the research postulates that by establishing a similarity relation between a complex system and a number of simpler systems it is possible to design the former using the analysis and synthesis means developed for the simpler systems. The methodology is successfully applied to the design of a robotic leg.

d) Heterogeneous Robotic Team: The new approach of Control ad Libitum is introduced for developing control architectures that allow a team of non-uniform (both software and hardware) rover platforms to perform collectively, while adapting to changing hardware and tasks in real-time without the intervention of a central server or operator.

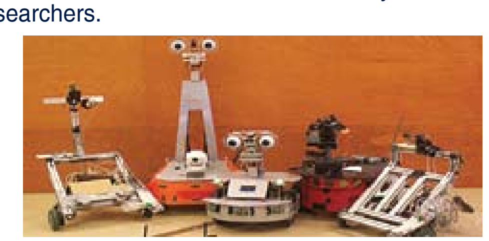
e) Robotics Social Learning: The research studies interactions between collective, cooperative and collaborative behaviours of a robotic team, and attempts to develop hybrid multi-agent learning algorithms for enhancing such social behaviours concurrently.

f) Free-base Robot Manipulation: the research aims at reformulating the kinematic and dynamic equations of free-base manipulators, based on symplectic geometry, in order to obtain suitable laws for the concurrent base-manipulator motion control. The goal is to develop a new generation of free-flying manipulators that can be released from the base station for reaching larger workspaces.

g) Aerospace Remote Experimentation: the research attempts to establish a transformative vision of remotely accessible aerospace laboratories for both pedagogical and research purposes. The goal is to enable students and researchers to reliably operate remote devices (such as manipulators) in space and also conduct from Earth future experiments on the moon.

h) Robotic Hardware-in-the-loop Simulation: a practical framework for the concurrent engineering of reconfigurable robot manipulators is constructed through the development of a hardware-in-the-loop design and simulation platform.

i) Mechatronics Pedagogy: the research attempts to define a hybrid framework for teaching mechatronics that synergistically utilizes various learning theories. The premise is that teaching mechatronics requires both direct instruction and learner-controlled knowledge construction. One key outcome of the research is the invention of an affordable, comprehensive, and transparent Personal Mechatronics Laboratory toolkit for students and researchers.

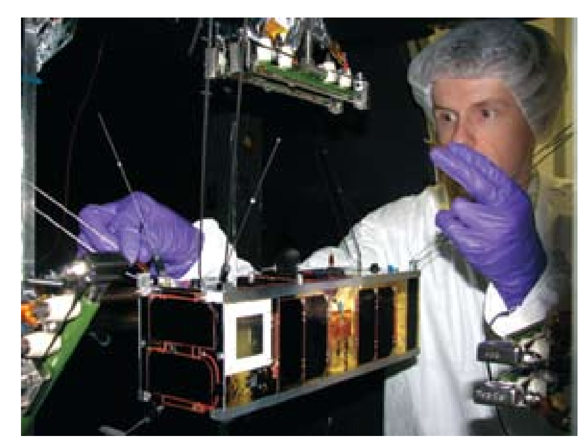


Dr. R.E. Zee
Space Flight Laboratory

The Space Flight Laboratory (SFL) is Canada's premier microspace organization. SFL builds low-cost microsatellites and nanosatellites that continually push the performance envelope. Missions are typically developed with stringent attitude control and data requirements that are striking relative to the budget available. SFL must be innovative while adopting a highly focused approach to development in order to achieve costs as low as 1/100th the price of similar satellites developed elsewhere. SFL's credits include: MOST, Canada's first space telescope; CanX-2, a technology demonstrator and atmospheric science satellite; and NTS, a ship-tracking satellite developed in only six months and launched in the seventh. SFL arranges launches through its Nanosatellite Launch Service (NLS) and provides customizable separation systems called "XPODs" for those launches. As part of its complete end-to-end mission capabilities, SFL maintains a mission control centre consisting of multiple ground stations.

In addition to developing next generation missions and conducting research and development in disruptive space technologies, SFL trains graduate students through hands-on, practical experience in developing real space missions. Students are able to obtain experience they wouldn't otherwise receive this early in their careers, giving them a unique advantage when they graduate and move on to industry or academia. Within the time it takes to complete a Master's degree, students receive complete development cycle training, from mission conception through to launch and on-orbit operations, working side-by-side with SFL's professional staff. The experience is multi-disciplinary, resulting in versatile engineering graduates that are always in high demand.

At present, SFL operates three satellites from its mission control center: MOST, CanX-2, and NTS. Each satellite represents an advance in the field and has broken barriers relative to what small satellites can do. The 53-kilogram MOST satellite was launched in June 2003 and has been operating for six years despite being designed for a one-year mission. It is a space astronomy satellite that has made numerous scientific discoveries related to solar-type stars and exoplanets. When MOST was launched, it was the first microsatellite in the world to have arcsecond attitude control capability and the ability to accomplish a challenging scientific mission. CanX-2 is Canada's smallest operational satellite and is the size of a milk carton. Its technologies push the state of the art in low-power, miniature satellite components. It is also among the smallest scientific satellites in the world and features three-axis attitude stabilization. Nanosatellite Tracking of Ships (NTS), a 6.5-kilogram satellite, was launched together with CanX-2 in April 2008 to demonstrate leading edge ship detection technology from space. NTS was developed on an incredibly fast timeline of only six months, a first for a satellite of this class in Canada and perhaps the world.



From the Archives
UTIAS and the Rescue of Apollo 13

GRUMMAN AEROSPACE CORPORATION
BETHPAGE, NEW YORK 11714

CABLE ADDRESS
GRUMAIR

Research Department
4 May 1970

Professor J. B. French
University of Toronto Institute of Aerospace Studies
Toronto 5, Ontario
Canada

Dear Barry:

Grant Hedrick, our Senior Vice President for Technical Operations, has asked me to add his personal thanks to my own for the vital aid you, Prof. Glass, Prof. Sullivan, and others of your staff gave us during the late stages of Apollo 13's flight. We will probably never know exactly how dangerous the LM proposed separation maneuver would have been, but your estimates were the main quantitative criterion for confidence in the procedure that was finally established for separating the LM and the Command Module.

The astronauts were instructed to vent the tunnel to between 2 and 2.5 psia, and several different real-time derivations at Houston and Bethpage showed that a sufficient relative velocity would be achieved at that pressure. We knew that the Apollo 10 CM had survived a 5.5 psia tunnel pressure when the shaped charge was fired, but your estimating calculations were our only guide for determining how close to collapse that case had been.

It has been very satisfying to all of us at Grumman to have played our parts in the successful outcome of this drama,

GRUMMAN AEROSPACE CORPORATION PAGE 2

Research Department
4 May 1970

and I want you to know how grateful we are for your help. Sometimes the years of research on basic problems have strange (and sudden) ways of becoming relevant.

Best regards,

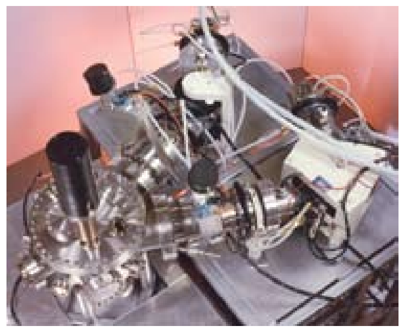
Dick Oman

Richard A. Oman
Head, Gas Dynamics Research Group

Preamble & International Collaborations

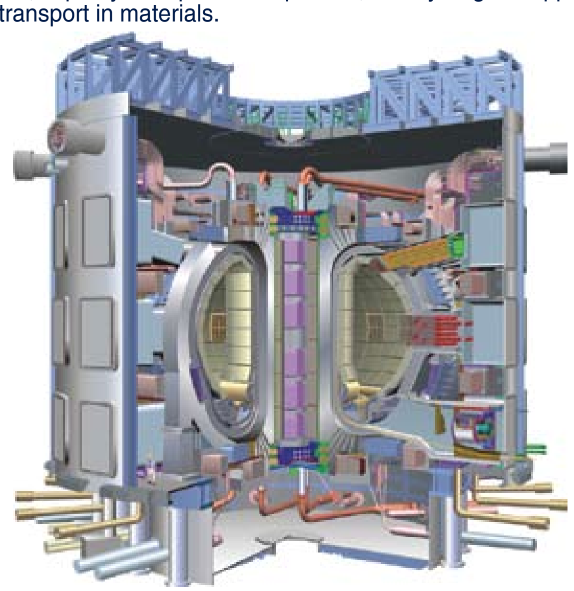
Preamble

Fusion has the potential of providing an environmentally attractive, practically inexhaustible, safe and reliable source of energy. Fusion energy is produced by 'burning' deuterium and tritium – the heavy isotopes of hydrogen. Deuterium can be extracted from the vast bodies of water on our planet and tritium will be produced in the reactor, where it will also be burned. Fundamental features of fusion energy are the absence of greenhouse gases, no run-away chain reactions, and no leftover radioactive fuel. Scientific demonstration of controlled fusion, using deuterium and tritium, has been achieved during the 1990s in TFTR (US) and JET (EU), the latter being the world's largest fusion device. The latest major international undertaking in fusion power R&D is the International Thermonuclear Experimental Reactor (ITER), whose objective is to produce ignited, self-sustaining fusion reactions. ITER participants are the EU, US, Japan, Russia, China, South Korea, and India. Construction is currently underway in France. Although at present Canada is not formally involved in ITER, our fusion group at UTIAS participates in international collaborations focusing on critical materials issues for ITER, and for eventual demonstration reactors.



International Collaborations

Over the years we have been involved in many international research collaborations related to materials issues for current and future fusion reactors, the latest being ITER. Some of these collaborations occur through coordinated research projects of the International Atomic Energy Agency (IAEA). At present we work with GA-San Diego, the ITER Organization, MIT, JET-UK, Labs in Garching and Juelich in Germany, and TEKES-Finland. Our work primarily addresses issues related to material modification and erosion, impurity transport in the plasma, and hydrogen trapping and transport in materials.



ITER, The people at the bottom show the scale.

Drs. A.A. Haasz & J.W. Davis
Plasma-Materials Interactions

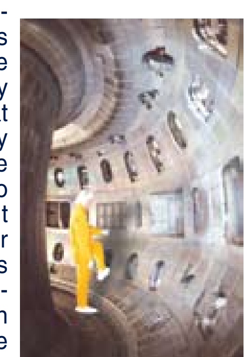
The fuel in fusion reactors is a mixture of deuterium and tritium – the heavy isotopes of hydrogen. Fusion reactions occur at about 100 million degrees. At this temperature the fuel is in the plasma state. While magnetic fields confine the hot core plasma to the centre of the reactor vessel, the cooler edge plasma will contact the reactor walls, resulting in physical and chemical phenomena with potential engineering implications. Research at UTIAS focuses on the study of plasma-materials interactions with ITER-specific materials, namely, carbon, tungsten and beryllium. Current research includes studies of (i) materials erosion, in particular, chemical erosion and high temperature erosion processes, (ii) diffusion, trapping. and retention of hydrogen isotopes in carbon, tungsten, and mixed materials, (iii) the recovery of deuterium (in the case of ITER it will be deuterium and tritium) from layers of D-containing deposits formed in tokamaks. Using our dual-beam ion accelerator, we also study surface modification and composition dynamics during simultaneous irradiation of surfaces by two plasma species, e.g., D and He, D and C, D and O, where D is the fuel and He, C and O are impurities in the plasma.

One of the main technological challenges associated with fusion reactor R&D is the development of new materials capable of existing in the fusion plasma environment. We study plasma-materials-interaction processes using plasma simulation facilities where candidate reactor materials are tested under controlled conditions. These facilities consist of ultrahigh vacuum systems and plasma particle beams, including sub-eV hydrogen, electrons, and energetic hydrogen and other ions. Diagnostics include quadrupole mass spectrometers, residual gas analyzers and a laser-thermal-desorption apparatus for hydrogen retention measurements. We also have access to surface analysis facilities elsewhere at the University of Toronto.

Prof. P.C. Stangeby
Impurity Transport Modelling in Tokamak Plasmas

Various types of "magnetic bottle", such as the tokamak, have been built to contain fusion plasmas, and must be capable of retaining the deuterium and tritium ions at temperatures exceeding 100 million K. No magnetic bottle yet built achieves perfect plasma confinement and when the leaking plasma particles strike the solid walls, Plasma Surface Interactions, PSI result. The UTIAS Fusion Computer Impurity Transport Modelling Group carries out PSI studies under contract for the DIII-D (San Diego), and ITER (France) tokamak projects.

The Group's principal experimental research focus is on DIII-D, specifically aimed at understanding the behaviour of carbon impurities released from the protective tiles on the divertor targets and the walls. The most pressing issue is the substantial tritium retention due to co-deposition with carbon predicted for ITER. In order to achieve the most readily interpreted plasma conditions, dedicated "Simple-as-Possible Plasma", SAPP, shots are run on DIII-D for our Group. These SAPP shots are particularly heavily (edge) diagnosed and numerous repeat shots are used to maximize the quantity and quality of edge data. All of the experimental data are then brought into simultaneous comparison with output of the Group's OEDGE code in order to adequately constrain the numerous unknowns (adjustables) in the code-model. Modelling of ITER focuses on the behaviour of beryllium, which is the material to be used to armour the main walls of ITER.



DIII-D

Undergraduate Studies

Students who wish to study Aerospace Science and Engineering at the University of Toronto enroll in the four-year undergraduate Engineering Science program. In the first two years, this program places strong emphasis on mathematics, chemistry, physics and computing. Towards the end of the second year of Engineering Science, students must select an option for their third and fourth years of study. One of the most exciting options offered is Aerospace Engineering, taught, on the most part, by UTIAS professors.

The Aerospace Engineering option of the Engineering Science program focuses on aeronautical engineering and space-systems engineering, featuring courses in flight dynamics, mechanics of structures, aerodynamics, materials, stability, control and design of aircraft and spacecraft. Since aerospace engineering is a high-tech and multi-disciplinary field, the curriculum also includes elective courses to accommodate students' interests.

Students have the opportunity to apply their knowledge and innovative ability to the solution of practical problems of their own selection. To do so, students have access to a well-equipped aerospace laboratory for the design, fabrication and testing of prototype devices.

All Aero Option Students are required to complete two capstone design courses. Aircraft Design provides students with the opportunity to design, construct and fly radio-controlled aircraft, while the Space Systems Design course gives students further experience in the design of complex aerospace systems.

In their fourth year, undergraduate aerospace students are required to complete a thesis. Students work under the supervision of professors on related research projects. The submission of a thesis document at the end of the term is a major requirement.

For more information, please visit our website: www.utias.utoronto.ca.

Master of Engineering Program

The Institute for Aerospace Studies may accept candidates for the M.Eng. degree under the general regulations of the School of Graduate Studies.

Candidates for the M.Eng. degree shall hold the degree of Bachelor of Applied Science of this University or an equivalent degree from a 4-year engineering undergraduate program.

Under the guidance of the graduate coordinator or a staff supervisor, a candidate selects a program of study that consists of at least 10 courses. Individual programs will be arranged to make up for background deficiency. The program may be pursued on a full-time or part-time basis. On a full-time basis, completion is possible in three terms. On a part-time basis, the program must be completed within 6 calendar years.

A minimum of 5 technical courses are required that are offered by the Institute (AER courses). One of them may be an M.Eng. project course that can be taken in any of the three terms. A maximum of 3 500-level courses are allowed. Nontechnical courses are sometimes offered in the summer as 2-week intensive courses.

G.N. PATTERSON AWARD

Established in 1974 to honour
Prof. Patterson, The Founding
Director of UTIAS
Presented Annually In Recognition
Of Excellence In A Ph.D. Program
At UTIAS

2000	W. Fundamenski	2001	S. DeRango
2002	T. Barfoot	2003	M. Nemec
2004	J. Etele	2005	A. de Ruiter
2006	I. Guiamatsia	2007	D. Elder
2008	M. Rumpfkeil	2009	J. Hicken
2010	F. Yuen	2011	J. Forbes
2012	P. Furgale	2013	R. Hanson

ETKIN MEDAL

Established through a donation by
Prof. B. Etkin
Presented Annually In Recognition
Of Excellence In A MASc Program
At UTIAS

2003	M. Naylor	2004	R. Perez
2005	A. de Ruiter	2006	A. Naseri
2007	T. Reichert	2008	C. Mader
2009	R. Henderson	2010	S. Haghighat
2011	O. Wong	2011	S. Liu
2012	C. McManus	2013	G. Lau

2014 N. Houser

Recent Ph.D. Thesis Titles

Tayfun Besim Aydin (2014)
Controlling the Near-Wake of a Circular Cylinder With a Single, Large-Scale Tripwire
Supervisor: **Prof. A. Ekmekci**

Lana Osusky (2013)
A Novel Numerical Tool for Aerodynamic Shape Optimization in Turbulent Flow
Supervisor: **Prof. D.W. Zingg**

Robin Chhabra (2013)
A Unified Geometric Framework for Kinematics, Dynamics and Concurrent Control of Free-Base, Open-Chain Multi-Body Systems with Holonomic and Nonholonomic Constraints
Supervisor: **Dr. M.R. Emami**

Scott Northrup (2013)
A Parallel Implicit Adaptive Mesh Refinement Algorithm for Predicting Unsteady Fully-Compressible Reactive Flows
Supervisor: **Prof. C.P.T. Groth**

Stefan LeBel (2013)
Nonlinear Robust Control Synthesis Methods for Spacecraft Applications
Supervisor: **Prof. C.J. Damaren**

Minfeng Zhang (2013)
Vision-Based Estimation and Tracking Using Multiple Unmanned Aerial Vehicles
Supervisor: **Prof. H.T. Liu**

Michal Osusky (2013)
A Parallel Newton-Krylov-Schur Algorithm for the Reynolds-Averaged Navier-Stokes Equations
Supervisor: **Prof. D.W. Zingg**

Chi Hay Tong (2013)
Laser-Based 3D Mapping and Navigation in Planetary Worksite Environments
Supervisor: **Prof. T.D. Barfoot**

John Gatsis (2013)
Preconditioning Techniques for a Newton-Krylov Algorithm for the Compressible Navier-Stokes Equations
Supervisor: **Prof. D.W. Zingg**

Ronald Hanson (2013)
Control of Transient Growth Induced Transition in a Zero-Pressure Gradient Boundary Layer Using Plasma Actuators
Supervisor: **Prof. P. Lavoie**

Gaetan Kenway (2013)
A Scalable Parallel Approach for Multi-Point High-Fidelity Aerostructural Optimization of Aircraft Configurations
Supervisor: **Prof. J.R.R. Martins**

Adrian Martin (2012)
A Framework for the Development of Scalable Heterogeneous Robot Teams with Dynamically Distributed Processing
Supervisor: **Dr. M.R. Emami**

Braden Stenning (2012)
Path/Action Planning for a Mobile Robot
Supervisor: **Prof. T.D. Barfoot**

Arman Azad (2012)
A Multi-Criteria Framework for Optimal Design of Structures in the Presence of Uncertain Loads
Supervisor: **Prof. J.S. Hansen**

Graeme Kennedy (2012)
Aerostructural Analysis and Design Optimization of Composite Aircraft
Supervisor: **Prof. J.R.R. Martins**

John Roszell (2012)
The Effect of Ion Energy and Substrate Temperature on Deuterium Trapping in Tungsten
Supervisors: **Prof. A.A. Haasz, Dr. J.W. Davis**

Kai James (2012)
Aerostructural Shape and Topology Optimization of Aircraft Wings
Supervisor: **Prof. J.R.R. Martins**

Sohrab Haghighat (2012)
Multidisciplinary Design Optimization of a Highly Flexible Aeroservoelastic Wing
Supervisors: **Prof. H.T. Liu, Prof. J.R.R. Martins**

Charles (Sandy) Mader (2012)
Stability-Constrained Aerodynamic Shape Optimization with Applications to Flying Wings
Supervisor: **Prof. J.R.R. Martins**

Keith Leung (2011)
Cooperative Localization and Mapping in Sparsely-Communicating Robot Networks
Supervisor: **Prof. T.D. Barfoot**

Pradeep Jha (2011)
Modelling Detailed-Chemistry Effects on Turbulent Diffusion Flames Using a Parallel Solution-Adaptive Scheme
Supervisor: **Prof. C.P.T. Groth**

Todd Reichert (2011)
Kinematic Optimization in Birds, Bats, and Ornithopters
Supervisor: **Prof. J.D. DeLaurier**

James Forbes (2011)
Extensions of Input-Output Stability Theory and the Control of Aerospcae Systems
Supervisor: **Prof. C.J. Damaren**

Francisco Hernandez-Perez (2011)
Subfilter Scale Modelling for Large Eddy Simulation of Lean Hydrogen-Enriched Turbulent Premixed Combustion
Supervisors: **Prof. C.P.T. Groth, Prof. Ö.L. Gülder**

Wen Lin (2010)
Large-Eddy Simulation of Premixed Turbulent Combustion Using Flame Surface Density Approach
Supervisors: **Prof. C.P.T. Groth, Prof. Ö.L. Gülder**

Peter Joo (2010)
Soot Formation in Non-Premixed Laminar Flames at Subcritical and Supercritical Pressures
Supervisor: **Prof. Ö.L. Gülder**

Stephen Guzik (2010)
Accurate Residual-Distribution Schemes for Accelerated Parallel Architectures
Supervisor: **Prof. C.P.T. Groth**

Tim Leung (2010)
A Newton-Krylov Approach to Aerodynamic Shape Optimization in Three Dimensions
Supervisor: **Prof. D.W. Zingg**

Research Partners

Institutional Partners

Air Force Research Laboratory, Wright-Patterson Air Force Base
Beijing Institute of Technology, China
California Institute of Technology, USA
Carnegie Mellon University, USA
Catalonia Polytechnic University, Spain
Charles Stark Draper Laboratory, USA
CNRS Orleans, France
Cranfield University,
DLR, Germany
EADS/Airbus, EU
ETH Zurich, Switzerland
Federal Aviation Administration (FAA), USA
GE Global Research, USA
George Washington University
Georgia Institute of Technology
German Aerospace Center
Graz University of Technology, Austria
Imperial College of London
Indian Space Research Organization, India
Keck Institute for Space Studies, USA
Leibniz University Hannover, Germany
Massachusetts Institute of Technology, USA
McGill University
Michigan State University
NASA Ames Research Center
Norwegian Space Center, Norway
Princeton University
Queen's University
Queensland University of Technology, Australia
Ryerson University
Sandia National Laboratory, USA
Space Research Center, Polish Academy of Sciences,Poland
SPACE-SI, Slovenia
Stanford University
Université de Sherbrooke
University of Adelaide, Australia
University of British Columbia
University of Calgary
University of Cambridge
University of Flinders, Australia
University of Klagenfurt, Austria
University of Lethbridge
University of Michigan
University of New Brunswick
University of Newcastle, Australia
University of Oxford
University of Southampton, UK
University of Vienna, Austria
University of Warwick, UK
University of Waterloo
University of Winnipeg
University of Wyoming, USA
Western University
York University

Industry Partners

Airbus
Anemoi Technologies Inc.
Apex Composites Inc.
Bell Helicopter Textron Inc.
Bennett-Jones LLP
Bombardier Aerospace
Brican Automated Systems Inc
CAE
CMC Electronics
Canadian Space Agency
Clearpath Robotics
COM DEV Ltd.
DRDC Suffield
exactEarth Inc.
Flight Safety International
Indian Oil Company
Integran Technologies
Kevin Quan Studios
MDA
Magellan Aerospace Ltd.
Messier-Bugatti-Dowty
Pratt and Whitney Canada
Rolls Royce Canada
Solar Ship
Xiphos Technologies Inc.

UTIAS Advisory Board

Mr. Dan Breitman
Retired Vice President, Engine Development Programs at Pratt & Whitney Canada

Dr. Allan Carswell
Founder and Chairman of the Board, Optech, Inc.

Dr. Barry French
Co-Founder, Chief Scientist, Gedex, & UTIAS Professor Emeritus

Mr. Scott Goobie
Vice President, Engineering, Bombardier Aerospace

Dr. Rocco Martino
Founder and Chairman of the Board, Cyber Technology Group, Inc. and of CyberFone Technologies, Inc.

Dr. Cameron Ower
Director, Research and Development, MDA Corp.

Dr. Christian Sallaberger
President & CEO, Canadensys Aerospace,

Mr. Francis Shen
Member of the Board of Directors & Chief Strategy Officer, Mitel

Mr. Rod Williams
President, Wheels Up Aviation Canada