# Department of Aeronautics and Astronautics

The MIT Department of Aeronautics and Astronautics (Aero-Astro) students, faculty, and staff share a passion for air and space vehicles, the technologies that enable them, and the missions they fulfill. Aerospace is an intellectually challenging, economically important, and exciting field, offering unique opportunities for students and researchers to contribute to the future of exploration, transportation, communication, and security.

Aero-Astro has a 94-year tradition of strong scholarship and of contributing to the solution of "industrial-strength" problems. The Department's reach within aerospace extends to the highest levels of policy and practice. The Aero-Astro community includes a former space shuttle astronaut, a former secretary of the Air Force, two former NASA associate administrators, three former Air Force chief scientists, 12 members of the National Academy of Engineering, and 16 fellows of the American Institute of Aeronautics and Astronautics (AIAA). Department members are executives in the aerospace industry and founders of companies.

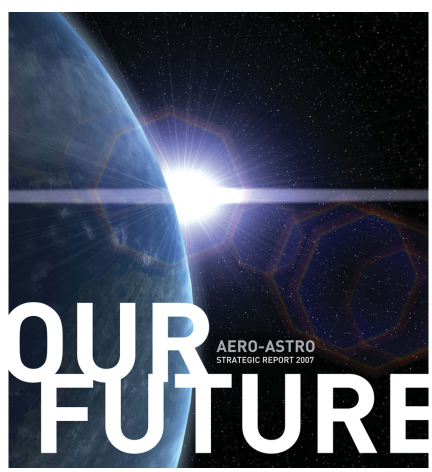
This report, which covers Aero-Astro initiatives and activities for the 2007–2008 year, is divided into five main sections: Strategic Report, Plans for Success and Achievement, 2007–2008 Personnel Achievement, Research, and Education.

## Strategic Report

In 2007, we completed a strategic report, Aero-Astro: Our Future, which defines our mission and values and identifies eight areas that represent grand challenges and grand opportunities for the Department and for aerospace. We also studied the collaborations that our faculty have with others inside and outside MIT in order to better understand our strategic position. The full report can be downloaded at http://web.mit.edu/aeroastro/about/stratrept-08.pdf. The elements of the strategic report are briefly reviewed below.

### Mission

MIT Aero-Astro prepares engineers for success and leadership in the conception, design, implementation, and operation of aerospace and related engineering systems. The Department is committed to excellence and to the creation, development, and application of the technologies critical to aerospace vehicle and information engineering and to the architecture and engineering of complex high-performance systems.




*Aero-Astro's document* Our Future: Aero-Astro Strategic Report *defines the Department's mission and values. It identifies grand challenges and opportunities for the Aero-Astro Department and for aerospace.*

### Goals

- Educate tomorrow's leaders through innovative educational programs and pedagogies, which have as their context the conception, design, implementation, and operation of systems and processes.

- Create research opportunities that generate inventions, technologies, and solutions to aerospace problems in cooperation with colleagues at MIT and other universities, industry, and government throughout the world.
- Provide leadership to the Institute and to the national and international aerospace communities.

### Values

Aero-Astro:

- is committed to excellence and leadership in research and teaching
- is united by a passion for air and space vehicles, the technologies that enable them, and the missions they fulfill
- is committed to personal and professional development of students, faculty, and staff
- has a deep sense of responsibility to profession and society and leads through service at Institute, national, and international levels
- has a mutual respect for its colleagues and a strong sense of community

### Grand Challenges and the Future

Aero-Astro has identified eight areas that present grand challenges and opportunities for aerospace, the nation, and the world: space exploration; autonomous systems; environment; communications and networks; computation, design, and simulation; air transportation; large-scale complex systems; and advancing engineering education.

### Connections

Aero-Astro students, faculty, and staff work with each other, with colleagues across MIT, and with colleagues from institutions throughout the world. Our linkages enable the Department to tackle challenging multidisciplinary problems. These linkages also amplify our contributions. Aero-Astro faculty members and senior researchers reported more than 900 substantive collaborations that have occurred in the last four years. Substantive collaboration is defined as working together to solve a research problem or to produce an educational advance. The linkages offer unique capabilities: the whole is greater than the sum of the parts.

This type of collaboration is inherent in the world of aerospace, where systems are designed and developed multiorganizationally and multinationally. These collaborations enhance the ability of the overall enterprise to solve problems and introduce students to the development of critical teaming skills.

## Plans for Success and Achievement

We have defined eight areas that represent grand challenges and grand opportunities. As described in the Research section of this report, we already have considerable strength in these areas. We plan to build our capabilities to contribute further to them. We will do this by striving for excellence in the core disciplines that underlie these areas, but also by continuing to emphasize and promote the collaborative problem solving that is required for tackling the complex, multidisciplinary problems that characterize our industry. By doing so, we will be well positioned to pursue the opportunities of today and the opportunities that will arise in our future.

Our strategy has four elements:

1. We will hire and mentor superb faculty members who will work collaboratively to pursue the grand challenges and opportunities identified in our strategic report.
2. We will advance our excellence in undergraduate education.
3. We will launch an initiative to advance graduate education, graduate student mentoring, and graduate student professional development.
4. We will improve the financial structure and competitiveness of our Department by increasing our endowment for graduate student fellowships.

## 2007–2008 Personnel Achievement

### Faculty Highlights

Professor Hamsa Balakrishnan received a National Science Foundation CAREER award for her proposal "Practical Algorithms for Next Generation Air Transportation Systems."

Professor Mary "Missy" Cummings was promoted to associate professor without tenure.

Professors Mary "Missy" Cummings, Annalisa Weigel, and Karen Willcox were elected AIAA Associate Fellows—reportedly the first time three women from a single institution were elected in the same year.

Professor David Darmofal became associate department head.

A paper coauthored by Professor Olivier de Weck titled "Assessing Risks and Opportunities of Technology Infusion in System Design" was selected as the 2007 Best Paper of the Year to appear in the journal *Systems Engineering*, the scientific journal of the International Council on Systems Engineering.

Professor Olivier de Weck was named associate director of the MIT Engineering Systems Division.

The Executive Committee of the MIT Corporation awarded tenure to Aero-Astro professors Olivier de Weck, Raul Radovitzky, Zoltan Spakovszky, and Karen Willcox.

Professor Wesley L. Harris moved from serving as department head to the position of associate provost for faculty equity.

A patent application by Professor Jonathan How and others, emanating from the Boeing/MIT Alliance, for a lab facility was one of 35 selected from a field of 235 applications for a Boeing Special Invention Award.

The MIT DARPA Urban Challenge team was one of six teams to successfully complete the Challenge. Aero-Astro people involved with the autonomous vehicle include professors Jon How and Emilio Frazzoli, students Gaston Fiore and Justin Teo, and postdoc Yoshi Kuwata.

Professor Nancy Leveson was named to the Federal 100 by Federal Computer Week/ FCM.com.

Professor emeritus Earll Murman was named to present the SAE International/American Institute of Aeronautics and Astronautics William Littlewood Memorial Lecture.

*Time* magazine's Best Innovations of 2007 included Professor Dava Newman's space biosuit and Aero-Astro professor of the practice Robert Liebeck's X-48B blended wing body aircraft.

Professor Raul Radovitzky was named associate director of the MIT Institute for Soldier Nanotechnologies.

Professor Raul Radovitzky was given the position of invited professor ad honorem by the Faculty of Engineering at the University of Buenos Aires.

Aero-Astro professors Nicholas Roy, Ruijie "RJ" He, and Sam Prentice received the Best Paper Award at the International Conference on Robotics and Information in Phoenix.

An MIT team, under the leadership of professor Nicholas Roy, tied for first place in the first US–Asian Demonstration and Assessment of Micro-aerial and Unmanned Ground Vehicle Technology Conference, held March 10–15 in Agra, India. The MIT team was also awarded Best Rotorcraft and was recognized for special achievement by the U.S. Army Aviation and Missile Research, Development, and Engineering Center.

Professor Zoltan Spakovzsky, was named the new director of Aero-Astro's Gas Turbine Laboratory. He was also named the American Society of Mechanical Engineers International Gas Turbine Institute's turbomachinery committee vice-chair and received that committee's Best Paper Award.

Professor Ian A. Waitz, who became department head in February, was named by the Federal Aviation Administration as recipient of its 2007 Excellence in Aviation Research Award.

Professor Annalisa Weigel was presented the MIT Alumni Association Henry B. Kane '24 Award for her fundraising volunteer work.

*Under the leadership of professor Nicholas Roy (back row, left), an MIT team tied for first place in the in the First US–Asian Demonstration and Assessment of Micro-aerial and Unmanned Ground Vehicle Technology Conference, held March 10–15 in Agra, India.*

MIT Institute Professor and professor of Aeronautics and Astronautics Sheila Widnall received three honorary degrees: the University of Oxford in England, Claremont Graduate University in California, and Northwestern University in Illinois each presented her with an honorary doctor of science degree.

Professor Brian Williams was elected a fellow of the Association for the Advancement of Artificial Intelligence for his "significant contributions to model-based reasoning and control and the innovative application of AI to space exploration."

Professor Moe Win was presented with the Best Paper Award at the International Conference on Communications in Beijing.

## Other Accomplishments

Engineering postdoc Hiro Aoki won the Aerospace Medical Association Space Medicine Branch's Young Investigator's Award.

Aerospace Computational Design Laboratory students Garrett Barter and Krzysztof Fidkowski received first and second place in the student paper competition at the AIAA Computational Fluid Dynamics Conference.

Aero-Astro graduate students Elza Brunelle-Yeung and Chris Sequeira were first and second place winners, respectively, in the Partnership for AiR Transportation Noise and Emissions Reduction's 2008 Joseph A. Hartman Student Paper Competition.

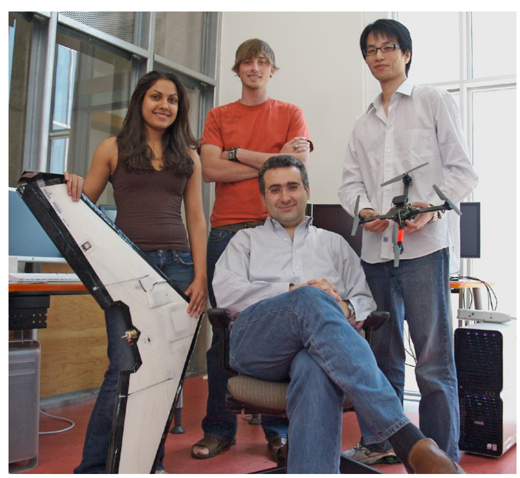
Aero-Astro postdoc Simon Nolet won first prize for his research paper "The SPHERES Navigation System: from Early Development to On-Orbit Testing" at the AIAA Guidance, Navigation and Control Conference and Exhibit.

The European Geosciences Union Lewis Fry Richardson Medal was to be presented to research fellow Akiva Yaglom. Sadly, Professor Yaglom passed away before the award could be presented.

The Revolutionary Aerospace Concepts–Academic Linkage (RASC-AL) team won a first place graduate level award for its "Living on the Lunar Surface: A Minimalist Approach" concept at a competition in Florida.

## Research

Aero-Astro faculty and students are engaged in hundreds of research projects under the auspices of our Department's laboratories and centers. Many of the Department's research projects are open to undergraduates through the Undergraduate Research Opportunities Program. In addition, research activities in other MIT laboratories and centers are open to students registered in Aero-Astro.



*Professor Emilio Frazzoli and grad students (from left) Sameera Ponda, Joshua Bialkowski, and Byunghoon Kim in his lab with some of the vehicles they fly in their research of robotic and autonomous aerial systems.*

## Aerospace Computational Design Laboratory

The mission of the Aerospace Computational Design Laboratory (ACDL, http://acdl.mit.edu/) is to lead the advancement and application of computational engineering for aerospace system design and optimization. ACDL research addresses a comprehensive range of topics in advanced computational fluid dynamics, methods for uncertainty quantification and control, and simulation-based design techniques.

The use of advanced computational fluid dynamics for complex three-dimensional configurations allows for significant reductions in time from geometry to solution. Specific research interests include aerodynamics, aeroacoustics, flow and process control, fluid–structure interactions, hypersonic flows, high-order methods, multilevel solution techniques, large eddy simulation, and scientific visualization.

Uncertainty quantification and control are aimed at improving the efficiency and reliability of simulation-based analysis. Research focuses on error estimation and adaptive methods as well as certification of computer simulations.

The creation of computational decision-aiding tools in support of the design process is the objective of a number of methodologies the lab pursues, which include PDE-constrained optimization, real-time simulation and optimization of systems governed by PDEs, multiscale optimization, model order reduction, geometry management, and fidelity management. ACDL is applying these methodologies to aircraft design and to the development of tools for assessing aviation environmental impact.

ACDL faculty and staff include Jaime Peraire (director), David Darmofal, Mark Drela, Robert Haimes, Cuong Nguyen, Per-Olof Persson, Karen Willcox, and David Willis.

## Aerospace Controls Laboratory

The Aerospace Controls Laboratory (ACL, http://acl.mit.edu/) researches topics related to autonomous systems and control design for aircraft, spacecraft, and ground vehicles. Theoretical research is pursued in areas such as decision making under uncertainty; path planning, activity, and task assignment; estimation and navigation; sensor network design; and robust, adaptive, and model predictive control. A key part of ACL is RAVEN (real-time indoor autonomous vehicle test environment), a unique experimental facility that uses a Vicon motion capture system to enable rapid prototyping of aerobatic flight controllers for helicopters and aircraft, robust coordination algorithms for multiple helicopters, and vision-based sensing algorithms for indoor flight.

ACL was also involved in the 2007 DARPA URBAN Challenge and designed and developed the rapidly exploring random tree-based motion planner and vehicle controller, which was integral to MIT's fourth-place finish in the competition.

ACL faculty are Jonathan How and Steven Hall.

### Communications and Networking Research Group

The primary goal of the Communications and Networking Research Group (http://web.mit.edu/aeroastro/labs/cnrg/)is to design network architectures that are cost-effective, scalable, and meet emerging needs for high data rate and reliable communications. To meet emerging critical needs for military communications, space exploration, and Internet access for remote and mobile users, future aerospace networks will depend on satellite, wireless, and optical components. Satellite networks are essential for providing access to remote locations lacking in communications infrastructure, wireless networks are needed for communication between untethered nodes (such as autonomous air vehicles), and optical networks are critical to the network backbone and in high-performance local area networks.

The group is working on a wide range of projects in data communication and networks with application to satellite, wireless, and optical networks. Over the past year, the group started work on a new project designing highly robust telecommunication networks that can survive massive disruption resulting from natural disasters or intentional attack. The project examines the impact of large-scale, geographically correlated failures on network survivability and design. The group also started work on a new project designing architectures and algorithms for dynamically reconfigurable optical networks. This novel architecture enables network topology to dynamically change based on changes in traffic patterns, significantly increasing the traffic capacity of core optical networks. The group's research crosses disciplinary boundaries by combining techniques from network optimization, queuing theory, graph theory, network protocols and algorithms, hardware design, and physical layer communications.

Eytan Modiano directs the Communications and Networking Research Group.

### Complex Systems Research Laboratory

Increasing complexity and coupling, and the introduction of digital technology, present challenges for engineering, operations, and sustainment. The Complex Systems Research Laboratory (CSRL, http://sunnyday.mit.edu/csrl.html) designs system modeling, analysis, and visualization theory and tools to assist in the design and operation of safer systems with greater capability. To accomplish these goals, the lab applies a systems approach to engineering that includes building technical foundations and knowledge and integrating them with the organizational, political, and cultural aspects of system construction and operation.

While CSRL's main emphasis is aerospace systems and applications, research results apply to complex systems in domains such as transportation, energy, and health. Current research projects include accident modeling and design for safety; model-based system and software engineering; reusable, component-based system architectures; interactive visualization; human-centered system design; system diagnosis and fault tolerance; system sustainment; and organizational factors in engineering and project management.

CSRL faculty include Nancy Leveson (director), Mary Cummings, and Paul Lagacé.

### Gas Turbine Laboratory

The MIT Gas Turbine Laboratory (GTL, http://web.mit.edu/aeroastro/www/labs/GTL/index.html) has had a worldwide reputation for research and teaching at the forefront of gas turbine technology for more than 50 years. GTL's mission is to advance the state-of-the-art in gas turbines for power and propulsion. The research focuses on advanced propulsion systems and turbomachinery, with activities in computational, theoretical, and experimental study of loss mechanisms and unsteady flows in turbomachines; compression system stability and active control; heat transfer in turbine blading; gas turbine engine noise reduction and aeroacoustics; pollutant emissions and community noise; and MEMS-based high-power-density engines.

Examples of past research include the first implementation of a three-dimensional computation transonic compressor flow and the concept of blowdown testing of transonic compressors and turbines, thereby enabling these machines to be used for university-scale experiments. Recent examples are the work on turbomachine instabilities and "smart engines"; the research project on microengine, which involves extensive collaboration with the MIT Department of Electrical Engineering and Computer Science; and the Silent Aircraft Initiative, which is a collaborative project with Cambridge University, Boeing, Rolls Royce, and other industrial partners to dramatically reduce aircraft noise below the background noise level in well-populated areas.

Zoltan Spakovszky is GTL director. Faculty, research staff, and frequent visitors include John Adamczyk, Nick Cumpsty, Fredric Ehrich, Alan Epstein, Edward Greitzer, Gerald Guenette, Stuart Jacobson, Bob Liebeck, Jack Kerrebrock, Choon Tan, and Ian Waitz.

### Humans and Automation Laboratory

Research in the Humans and Automation Laboratory (HAL, http://mit.edu/aeroastro/www/labs/halab/index.html) focuses on the multifaceted interactions of human and computer decision making in complex sociotechnical systems. With the explosion of automated technology, the need for humans as supervisors of complex automatic control systems has replaced the need for humans in direct manual control. A consequence of complex, highly automated domains in which the human decision maker is more on-the-loop than in-the-loop is that the level of required cognition has moved from that of well-rehearsed skill execution and rule following to higher, more abstract levels of knowledge synthesis, judgment, and reasoning. Employing human-centered design principles to human supervisory control problems and identifying ways human and computer can leverage the strengths of the other to achieve superior decisions together is HAL's central focus.

Current research projects include investigation of human understanding of complex optimization algorithms and visualization of cost functions, collaborative human–computer decision making in time-pressured scenarios (for both individuals and teams), human supervisory control of multiple unmanned vehicles, and designing decision support displays for direct-perception interaction as well as assistive collaboration technologies, including activity awareness interface technologies and interruption assistance technologies. Lab equipment includes an experimental test bed for future command and control decision support systems intended to aid in the development of human–computer interface design recommendations for future unmanned vehicle systems. In addition, the lab hosts a state-of-the-art multiworkstation collaborative teaming operations center as well as a mobile command-and-control experimental test bed mounted in a Dodge Sprint van awarded through the Office of Naval Research.

HAL faculty include Mary L. Cummings (director), Nicholas Roy, and Thomas Sheridan.

### International Center for Air Transportation

The International Center for Air Transportation (ICAT, http://web.mit.edu/aeroastro/www/labs/ICAT/) undertakes research and educational programs that discover and disseminate the knowledge and tools underlying a global air transportation industry driven by technologies. Global information systems are central to future operation of international air transportation. Modern information technology systems of interest to ICAT include global communication and positioning; international air traffic management; scheduling, dispatch, and maintenance support; vehicle management; passenger information and communication; and real-time vehicle diagnostics.

Airline operations are also undergoing major transformations. Airline management, airport security, air transportation economics, fleet scheduling, traffic flow management, and airport facilities development, represent areas of great interest to the MIT faculty and they are vitally important to international air transportation. ICAT is a physical and intellectual home for these activities. ICAT and its predecessors, the Aeronautical Systems Laboratory and Flight Transportation Laboratory, pioneered concepts in air traffic management and flight deck automation and displays that are now in common use.

ICAT faculty include R. John Hansman (director), Cynthia Barnhart, Peter Belobaba, and Amedeo Odoni.

### Laboratory for Information and Decision Systems

The Laboratory for Information and Decision Systems (LIDS, http://lids.mit.edu/) is an interdepartmental research laboratory that began in 1939 as the Servomechanisms Laboratory, focusing on guided missile control, radar, and flight-trainer technology. Today, LIDS conducts theoretical studies in communication and control and is committed to advancing the state of knowledge of technologically important areas such as atmospheric optical communications and multivariable robust control. In April 2004, LIDS moved to MIT's Stata Center, a dynamic space that promotes increased interaction within the lab and with the larger community. Laboratory research volume is approximately $6.5 million, and the size of the faculty and student body has tripled in recent years. LIDS continues to host events, notably weekly colloquia that feature leading scholars from the laboratory's research areas. The 12th annual LIDS Student Conference took place in January 2007, showcasing current student work and including keynote speakers. These, and other events reflect LIDS' commitment to building a vibrant, interdisciplinary community. In addition to a full-time staff of faculty, support personnel, and graduate assistants, scientists from around the globe visit LIDS to participate in its research program. Currently, 17 faculty members and approximately 100 graduate students are associated with the laboratory.

Aero-Astro/LIDS faculty includes Emilio Frazzoli and Moe Win. Vincent Chan directs the laboratory.

### Lean Advancement Initiative

The Lean Advancement Initiative (LAI, http://lean.mit.edu/) is a unique learning and research consortium focused on enterprise transformation; its members include key stakeholders from industry, government, and academia. LAI is headquartered in Aero-Astro, works in close collaboration with the Sloan School of Management, and is managed under the auspices of the Center for Technology, Policy and Industrial Development, an MIT-wide interdisciplinary research center.

LAI began in 1993 as the Lean Aircraft Initiative when leaders from the U.S. Air Force, MIT, labor unions, and defense aerospace businesses created a partnership to transform the U.S. aerospace industry using an operational philosophy known as "lean." Now in its fifth and most important phase, LAI has moved beyond a focus on business-unit-level change toward a holistic approach to transforming entire enterprises. Through collaborative stakeholder engagement, along with the development and promulgation of knowledge, practices, and tools, LAI enables enterprises to effectively, efficiently, and reliably create value in complex and rapidly changing environments. Consortium members work collaboratively through the neutral LAI forum toward enterprise excellence, and the results are radical improvements, life-cycle cost savings, and increased stakeholder value.

LAI's educational network includes 37 educational institutions in the United States, England, and Mexico and provides LAI members with unmatched educational outreach and training capabilities.

Aero-Astro LAI participants include Deborah Nightingale (codirector), Earll Murman, Daniel Hastings, Annalisa Weigel, and Sheila Widnall. John Carroll (codirector) joins LAI from the Sloan School of Management, and Warren Seering and Joe Sussman represent the Engineering Systems Division.

### Man Vehicle Laboratory

The Man Vehicle Laboratory (MVL, http://mvl.mit.edu/) optimizes human-vehicle system safety and effectiveness by improving understanding of human physiological and cognitive capabilities and developing countermeasures and evidence-based engineering design criteria. Research is interdisciplinary and uses techniques from manual and supervisory control, signal processing, estimation, sensory-motor physiology, sensory and cognitive psychology, biomechanics, human factors engineering, artificial intelligence, and biostatistics. MVL has flown experiments on Space Shuttle missions, the Mir Space Station, and on many parabolic flights and is developing experiments for the International Space Station (ISS). Research sponsors include NASA, the National Space Biomedical Institute, the Office of Naval Research, the Department of Transportation's Federal Aviation Administration (FAA) and Federal Railroad Administration, the Center for Integration of Medicine and Innovative Technology, the Deshpande Center, and the MIT Portugal Program. Projects focus on advanced space suit design and dynamics of astronaut motion, adaptation to rotating artificial gravity environments, spatial disorientation and navigation, teleoperation, design of aircraft and spacecraft displays, and controls and cockpit human factors. MVL students have been active in developing the Mars gravity biosatellite. Some of MVL's newest research projects deal with the astronaut's role in semiautomatic lunar landing, mathematical modeling of spatial disorientation, ensuring the effectiveness of astronaut lunar exploration sorties, planetary mission planning, microgravity teleoperation, fatigue detection, and advanced helmet designs for brain protection in sports and against explosive blasts. MVL collaborates closely with the Harvard–MIT Division of Health Sciences and Technology, the Charles Stark Draper Laboratory, the Volpe Transportation Research Center, and the Jenks Vestibular Physiology Laboratory of the Massachusetts Eye and Ear Infirmary. Annual MVL MIT Independent Activities Period activities include a course on Boeing 767 systems and automation.

MVL faculty include Charles Oman (director), Jeffrey Hoffman, Dava Newman, and Laurence Young. They teach subjects in human factors engineering, space systems engineering, space policy, flight simulation, space physiology, aerospace biomedical engineering, the physiology of human spatial orientation, and leadership. MVL also serves as the office of the Director for the NSBRI-sponsored Graduate Program in Bioastronautics, the Massachusetts Space Grant Consortium, NSBRI Sensory-Motor Adaptation Team, the MIT-Volpe Program in Transportation Human Factors, and the MIT Portugal Program's Bioengineering Systems focus area.

### The Partnership for AiR Transportation Noise and Emissions Reduction

The Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER, http://www.partner.aero/) is an MIT-led FAA/NASA/Transport Canada–sponsored Center of Excellence. PARTNER fosters breakthrough technological, operational, policy, and workforce advances for the betterment of mobility, economy, national security, and the environment. PARTNER combines the talents of nine universities, three federal agencies, and 53 advisory board members, the latter spanning a range of interests from local government, to industry, to citizens' community groups. During 2007–2008, PARTNER continued to expand its research portfolio and added advisory board members. New research projects include health effects of aircraft noise, emissions characteristics of alternative aviation fuels, airport surface movement optimization, and network restructuring scenarios for Air Traffic Organization forecasts. New advisory board members are the Air Line Pilots Association, Commercial Aviation Alternative Fuels Initiative, International Airline Passengers Association, Opportunities for Meeting the Environmental Challenge of Growth in Aviation, and the Federal Interagency Committee on Aviation Noise. Several new research reports were released including a low-frequency noise impact study, a land-use and noise complaint study, a passive sound insulation report, and a vibration and rattle mitigation report.

MIT's most prominent role within PARTNER is developing research tools that provide rigorous guidance to policy makers who must decide among alternatives to address aviation's environmental impact. The MIT researchers collaborate with an international team in developing aircraft-level and aviation-system-level tools to assess the costs and benefits of different policies and research and development investment strategies.

Other PARTNER initiatives in which MIT participates include exploring mitigating aviation environmental impacts via the use of alternative fuels for aircraft; studies of aircraft particulate matter microphysics and chemistry; and a study of reducing vertical separations required between commercial aircraft, which may enhance operating efficiency by making available more fuel- and time-efficient flight levels and enhancing air traffic control flexibility and airspace capacity.

PARTNER MIT personnel include Ian Waitz, who directs the organization, Stuart Jacobson (associate director), Hamsa Balakrishnan, John Hansman, James Hileman, Karen Willcox, Malcolm Weiss, Stephen Connors, William Litant (communications director), Jennifer Leith (program coordinator), and 10–15 graduate students.

### Space Propulsion Laboratory

The Space Propulsion Laboratory (SPL, http://web.mit.edu/dept/aeroastro/www/labs/SPL/home.htm), part of the Space Systems Lab, studies and develops systems for increasing performance and reducing costs of space propulsion. A major area of interest to the lab is electric propulsion, in which electrical, rather than chemical, energy propels spacecraft. The benefits are numerous, hence the reason electric propulsion systems are increasingly applied to communication satellites and scientific space missions. In the future, these efficient engines will allow exploration in more detail of the structure of the universe, increase the lifetime of commercial payloads, and look for signs of life in faraway places. Areas of research include Hall thrusters; plasma plumes and their interaction with spacecraft; electrospray physics, mainly as it relates to propulsion; microfabrication of electrospray thruster arrays; Helicon and other radio frequency plasma devices; and space electrodynamic tethers.

As part of his M.S. thesis, SPL student Daniel Courtney designed and built a new type of space plasma thruster dubbed "DCF" for divergent field cusped thruster. Professor Paulo Lozano participated in the effort. This device has a unique magnetic configuration designed to contain electrons while they ionize the xenon propellant, and it has some similarities to existing Hall thrusters and to devices being investigated in Germany and at Princeton. Dan's thruster performed so impressively the first time around that we have been selected by the Air Force Office of Scientific Research, together with groups at Stanford and Princeton to further study and develop the concept.

Manuel Martinez-Sanchez directs the SPL research group, and Paulo Lozano and Oleg Batishchev are key participants.

### Space Systems Laboratory

Space Systems Laboratory (SSL, http://ssl.mit.edu/) research contributes to the exploration and development of space. SSL's mission is to explore innovative space systems concepts while training researchers to be conversant in this field. The major programs include systems analysis studies and tool development, precision optical systems for space telescopes, microgravity experiments operated aboard the ISS, and robotic operations for Mars and beyond. Research encompasses a wide array of topics that together compose a majority of space systems: systems architecting, dynamics and control, active structural control, thermal analysis, space power and propulsion, microelectromechanical systems, modular space systems design, microsatellite design, real-time embedded systems, and software development.

*Astronaut and MIT alumnus Dan Tani (BSc 1984, MSc 1988) tests a Space Systems Laboratory SPHERES microsatellite aboard the International Space Station. SPHERES started as an Aero-Astro student project.*

Major SSL initiatives study the development of formation flight technology. The SPHERES facility, which began operations aboard the ISS in May 2006, enables research of algorithms for distributed satellite systems, including telescope formation flight, docking, and stack reconfiguration. The electromagnetic formation flight test bed is a proof-of-concept demonstration for a formation flight system that has no consumables; a space-qualified version is under study. The MOST project studies multiple architectures for lightweight segmented mirror space telescopes using active structural control; its final product will be a ground prototype demonstrator. Multiple programs research the synthesis and analysis of architectural options for future manned and robotic exploration of the Earth-Moon-Mars system, as well as real options analysis for earth-to-orbit launch and assembly. SSL continues to lead the development of methodologies and tools for space logistics. In 2007, SpaceNet 1.4 was accredited by the NASA Constellation Program as an approved software tool for modeling lunar exploration missions and campaigns. SSL contributed several important studies to the Constellation Program Integrated Design and Analysis Cycles. Together with the Jet Propulsion Laboratory, SSL is editing a new *AIAA Progress in Aeronautics and Astronautics* volume on space logistics that summarizes the current state of the art and future directions in the field. Jointly with Aurora Flight Sciences, SSL is developing prototypes for automated asset tracking and management systems for ISS based on radio frequency identification technology. Innovative exploration logistics container concepts were tested at the Mars Desert Research Station in Utah in February 2008.

SSL personnel include David W. Miller (director), John Keesee, Olivier de Weck, Edward F. Crawley, Daniel Hastings, Annalisa Weigel, Manuel Martinez-Sanchez, Paulo Lozano, Oleg Batishchev, Alvar Saenz-Otero, Paul Bauer, SharonLeah Brown (administrator and outreach coordinator), Brian O'Conaill (fiscal officer), and Marilyn E. Good (administrative assistant).

### Technology Laboratory for Advanced Materials and Structures

A dedicated and multidisciplinary group of researchers constitute the Technology Laboratory for Advanced Materials and Structures (TELAMS, http://web.mit.edu/telams/index.html). They work cooperatively to advance the knowledge base and understanding that will help facilitate and accelerate the advanced materials systems development and use in various advanced structural applications and devices.

The laboratory has broadened its interests from a strong historical background in composite materials, and this is reflected in the name change from the former Technology Laboratory for Advanced Composites. A new initiative involves engineering materials systems at the nanoscale level, particularly focusing on aligned carbon nanotubes as a significant constitutent in new materials and structures. This initiative is in partnership with industry through the Nano-Engineered Composite aerospace STructures (NECST, http://necst.mit.edu/) Consortium. The research interests and ongoing work in the laboratory thus represent a diverse and growing set of areas and associations. Areas of interest include the following:

- Nano-engineered hybrid advanced composite design, fabrication, and testing
- Characterization of carbon nanotube bulk engineering properties
- Composite tubular structural and laminate failures
- MEMS-scale mechanical energy harvesting modeling, design, and testing
- Curability testing of structural health monitoring systems
- Thermostructural design, manufacture, and testing of composite thin films and associated fundamental mechanical and microstructural characterization
- Continued efforts on addressing the roles of lengthscale in the failure of composite structures
- Numerical and analytical solid modeling to inform, and be informed by, experiments
- Continued engagement in the overall issues of the design of composite structures with a focus on failure and durability, particularly within the context of safety

In supporting this work, TELAMS has complete facilities for fabricating structural specimens such as coupons, shells, shafts, stiffened panels, and pressurized cylinders made of composites, active, and other materials. A recent addition includes several reactors for synthesizing carbon nanotubes. TELAMS testing capabilities include a battery of servohydraulic machines for cyclic and static testing, a unit for the catastrophic burst testing of pressure vessels, and an impact testing facility. TELAMS maintains capabilities for environmental conditioning, testing at low and high temperature, and testing in hostile and other controlled environments. There are facilities for nano- and microscopic inspection, nondestructive inspection, high-fidelity characterization of MEMS materials and devices, and a laser vibrometer for dynamic device and structural characterization.

With its linked and coordinated efforts, both internal and external, the laboratory continues its commitment to leadership in the advancement of the knowledge and capabilities of the composites and structures community through education of students, original research, and interactions with the community. There has been a broadening of this commitment consistent with the broadening of the interest areas in the laboratory. This commitment is exemplified in the newly formed NECST Consortium, an industry-supported center for developing hybrid advanced polymeric composites. In all these efforts, the laboratory and its members continue their extensive collaborations with industry, government organizations, other academic institutions, and other groups and faculty within the MIT community.

TELAMS faculty include Paul A. Lagacé (director), Brian L. Wardle, and visitors Antonio Miravete and Leonard Daniel.

### Wright Brothers Wind Tunnel

Since its opening in September 1938, The Wright Brothers Wind Tunnel (WBWT, http://web.mit.edu/aeroastro/www/labs/WBWT/wbwt.html) has played a major role in the development of aerospace, civil engineering, and architectural systems. In recent years, faculty research interests generated long-range studies of unsteady airfoil flow fields, jet engine inlet-vortex behavior, aeroelastic tests of unducted propeller fans, and panel methods for tunnel wall interaction effects. Industrial testing has ranged over auxiliary propulsion burner units, helicopter antenna pods, and in-flight trailing cables as well as concepts for roofing attachments; a variety of stationary and vehicle-mounted ground antenna configurations; the aeroelastic dynamics of airport control tower configurations for the FAA; and the less anticipated live tests in Olympic ski gear, space suits for tare evaluations related to underwater simulations of weightless space activity, racing bicycles, subway station entrances, and Olympic rowing shells for oarlock system drag comparisons.

In its nearly 70 years of operations, WBWT work has been recorded in hundreds of theses and more than 1,000 technical reports.

WBWT faculty and staff include Mark Drela and Richard Perdichizzi.

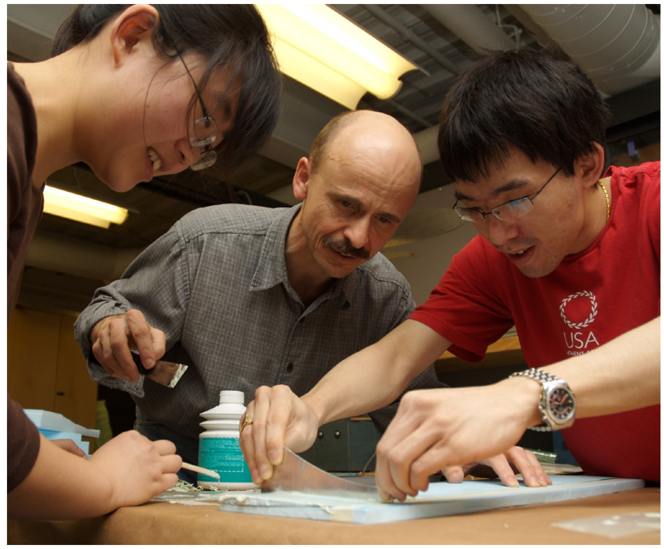
## Education

### Undergraduate Program

Several years ago, working closely with student, alumni, industry, government, and academic stakeholders around the world, the Aero-Astro Department developed and implemented a landmark educational initiative for our degree programs. It was determined that graduates must be knowledgeable in all phases of the aerospace system life cycle: conceiving, designing, implementing, and operating (CDIO). A new form of undergraduate engineering education was adopted, motivating students to master a deep working knowledge of the technical fundamentals while giving them the skills, knowledge, and attitudes necessary to lead in the creation and operation products, processes, and systems. The Department reformed the way it teaches, redesigned its curriculum, and performed a $20 million state-of-the-art reconstruction of its teaching laboratories. The academic program and its facilities now serve as models for 33 engineering schools on four continents (see http://www.cdio.org/).

### Learning Lab

The Aero-Astro Learning Laboratory for Complex Systems complements the Department's curriculum by providing spaces where students conceive, design, implement, and operate engineering systems in modern, team-based environments.



*Professor Mark Drela oversees Eleanor Yang Lin and Eric Liu as they laminate a wing structure in the Aero-Astro Learning Lab's Gelb Laboratory.*

The Learning Lab comprises four main areas. The **Arthur and Linda Gelb Laboratory** includes the Gelb Machine Shop, Instrumentation Laboratory, Mechanical Projects Area, Projects Space, and the Composite Fabrication-Design Shop. The Gelb Laboratory provides facilities for students to conduct hands-on experiential learning through diverse engineering projects starting as first-year students and continuing through their last year. The Gelb facilities are designed to foster teamwork with a variety of resources (e.g., machining tools, electrical instrumentation, composites) to meet the needs of curricular and extracurricular projects. The **Gerhard Neumann Hangar** lets students work on large-scale projects that take considerable floor and table space. Typical of these projects are planetary rovers, a human-powered zero-*g* centrifuge, and unmanned air vehicles. The structure also houses low-speed and supersonic wind tunnels. The **Robert C. Seamans Jr. Laboratory** includes a multipurpose room for meetings, presentations, lectures, videoconferences, and distance learning. Two project offices support team study, group design work, online work, and telecommunications. A network operations area supports learning about the operations and management of networks. The Seamans Aerospace Library offers a collection of aerospace engineering resources with extensive digital information storage and retrieval capability. And the Al Shaw Student Lounge provides a large space for social interaction and operations. The Digital Design Studio offers multiple computer stations arranged around reconfigurable conference tables. Here, students conduct engineering evaluations and design work and exchange computerized databases as system and subsystem trades are conducted during the development cycle. Adjacent to the studio are the AA Department Design Room, and the Arthur W. Vogeley Design Room, which are reserved for student design teams.

Since its completion in 2001, the Learning Lab has spawned some of the Department's most interesting projects, including the Mars Biosatellite Project, a car competing for a 200 mpg X Prize, a successful competitor in the DARPA Urban Challenge, a legged planetary rover, and a flying automobile.

The Experimental Projects course (Course 16.62x) is a major user of the teaching labs, from experiments using the Neumann Hangar's low-speed wind tunnel to the workspaces in the Gelb Laboratory, with a number of excellent projects as outcomes. Two examples of work done in this hands-on environment are the investigation of reconfigurable wheels for planetary rovers and a study of bats' wing cilia enabling these creatures' highly maneuverable flight. The Neumann and Gelb facilities were also much used by the Robotics: Science and Systems I class (Course 16.415/6.14), which has participation from both Aero-Astro and Electrical Engineering and Computer Science faculty.

The Space Systems Engineering capstone class (Course 16.83x) is using the Gelb Lab to build a high delta V (~2–3 km/s) microsatellite. The motivation is to provide a low-cost orbital transfer vehicle capability for maneuvering throughout the Earth-Moon system. The goal of the class is to deliver, in May 2009, a flight-qualified vehicle for launch as an ESPA-Ring (a device that permits up to six small satellites to be carried along with a larger satellite) secondary payload. The project offers approximately 45 undergraduates hands-on experience in designing, building, and testing actual flight hardware.

### Graduate Program

While the dramatic advancements we have made in our undergraduate program are being studied and replicated by schools throughout the world, our graduate program has remained largely unchanged. It is time for us to look deeply at it, to assess its strengths and weaknesses, and to promote and innovate in areas that most contribute to excellence in our students when they are here at MIT and, more importantly, during their professional lives when they make their greatest contributions to society. In this regard, we have begun to work with our faculty, our graduate students, and our graduate student alumni to develop an initiative to significantly advance graduate education, graduate student mentoring, and graduate student professional development.

During the past year, the Department has developed a semester research evaluation for all graduate students. At the end of each fall and spring semester, graduate students and advisors meet to reflect on student progress; to discuss short- and long-term research objectives; and to consider other issues such as professional development, funding, and plans after graduation. This evaluation is based on a best practice from Materials Science and Engineering that we have evolved to include a web interface to streamline the process and reduce paperwork (funding provided by the dean of graduate students).

The Department has also made major changes in the doctoral program. This change process (which involved faculty, current and former graduate students, and staff) began by clearly defining the objectives we have for graduates of our doctoral program. Specifically, we desire our doctoral graduates to have a strong foundation in analytical skills and reasoning; the ability to solve challenging, engineering problems; an understanding of the importance and strategic value of their research; and the ability to communicate their research with context and clarity. We then identified a variety of changes to better align the requirements of our doctoral program (e.g., doctoral qualifying exams) with these objectives. The past year marked the first year of our revised program. While we still have much to do, these changes represent a significant first step.

## Degrees

The bachelor of science degree is a four-year program preparing the graduate for an entry-level position in the aerospace field and for further education at the master's level. Two degrees are available: one that emphasizes the disciplines that relate to the engineering of aerospace vehicles and one that defines a specialization in aerospace information technology. Both degrees retain an emphasis on the fundamentals and provide strong integration with the overarching CDIO context. The program includes an opportunity for a year abroad.

The master of science (SM) degree is a one- to two-year graduate program with a beginning research or design experience represented by the SM thesis. This degree prepares the graduate for an advanced position in the aerospace field, and it forms a solid foundation for future doctoral study.

Aero-Astro offers doctoral degrees (PhD and ScD) that emphasize in-depth study with a significant research project in a focused area. Admission to the doctoral program requires students to pass a graduate-level examination in a field of aerospace engineering and to demonstrate an ability to conduct research in the field. The doctoral degree is awarded after completion of an individual course of study, submission and defense of a thesis proposal, and submission and defense of a thesis embodying an original research contribution. In addition, the Department participates in a variety of interdisciplinary graduate programs.

## Undergraduate Enrollment

**Undergraduate Enrollment Statistics, Academic Years 1999–2008***

| | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|---|---|---|---|
| Sophomores | 48 | 59 | 68 | 56 | 64 | 72 | 64 | 65 | 65 | 57 |
| Juniors | 37 | 40 | 53 | 69 | 51 | 59 | 59 | 52 | 60 | 66 |
| Seniors | 35 | 37 | 45 | 53 | 70 | 61 | 65 | 76 | 56 | 66 |
| **Total** | **120** | **136** | **166** | **178** | **185** | **192** | **188** | **196** | **181** | **189** |
| Women (%) | 33 | 30 | 32 | 33 | 35 | 34 | 30 | 26 | 31 | 30 |
| Underrepresented minorities (%) | 15 | 12 | 21 | 22 | 30 | 30 | 27 | 25 | 19 | 14 |

*Data based on fifth-week enrollment.

### Undergraduate Student Prizes

Awards presented at the Aero-Astro Class of 2006 Recognition Dinner on Monday, May 12, 2008:

The Andrew Morsa Prize—given to undergraduate students for demonstration of ingenuity and initiative in the application of computers to the field of aeronautics and astronautics: Gerardo E. Cruz and Christopher K. Hoffman.

The Apollo Award—given to an Aero-Astro student who conducts the best undergraduate research project on the topic of humans in space: Joy M. Dunn and Corinne E. Vannatta.

The David J. Shapiro Award—given to Aero-Astro undergraduate students to pursue special aeronautical projects that are student initiated and/or to support foreign travel for the enhancement of scientific/technical studies and research opportunities: Robyn Allen, Ruijie He, Bruce T. Vest, and Louis E. Perna.

The AIAA Undergraduate Advising Award—given by the AIAA Student Chapter to a faculty or staff member who has demonstrated excellence in serving as an academic or Course 16.621/16.622 advisor and has had a real positive impact on a student's time in the Aero-Astro Department: Zoltan Spakovszky.

The Leaders for Manufacturing Prize—awarded to a team that uses its project to directly deal with issues related to the interaction between manufacturing and engineering through demonstration of modern manufacturing processes: Brittany Baker and Noelle Steber.

The Lockheed Martin Prize for Excellence in Systems Engineering—awarded to an undergraduate team that has exhibited a superior level of accomplishment in engineering innovation, product development, and team organization: the Mars Gravity Biosatellite Team.

The United Technologies Corp. Prize—given to an Aero-Astro student for outstanding achievement in the design, construction, execution, and reporting of an undergraduate experimental project: Warren (Woody) Hoburg and James P. Houghton.

The Admiral Luis De Florez Prize—given for "original thinking or ingenuity" as demonstrated by the individual effort of the student, not the ideas and suggestions of his/her advisor, instructors, or an advisory team: Katrina M. Sorensen and Joseph Yurko.

The James Means Award for Excellence in Space Systems Engineering: Zachary J. Bailey, Katherine A. Ingle, James P. Houghton.

The James Means Award for Excellence in Flight Vehicle Engineering: David A. Sanchez.

## Graduate Enrollment

**Graduate Enrollment Statistics, Academic Years 2004–2008***

| | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|
| Total | 245 | 231 | 223 | 223 | 226 |
| SM** | 166 | 137 | 124 | 135 | 146 |
| PhD*** | 67 | 94 | 99 | 88 | 80 |
| Minority | | | | | |
| SM | 10 | 7 | 7 | 9 | 8 |
| PhD | 3 | 6 | 4 | 3 | 5 |
| Female | | | | | |
| SM | 38 | 34 | 31 | 26 | 29 |
| PhD | 21 | 19 | 25 | 19 | 19 |

*Numbers based on fifth-week enrollment data.
** Includes students pursuing only a master's degree and students who have not yet passed the doctoral qualifying exam.
***Students who have passed the doctoral qualifying exam.

**Ian A. Waitz**
**Department Head**
**Jerome C. Hunsaker Professor of Aeronautics and Astronautics**

**William T. G. Litant**
**Communications Director**

*More information about the Department of Aeronautics and Astronautics can be found at http://web.mit.edu/aeroastro/.*