Department of Aeronautics and Astronautics

MIT's Department of Aeronautics and Astronautics (AeroAstro) has long been one of the world's leading centers of aerospace research and education. With 220 graduate students, 190 undergraduate students, 35 faculty members, and top-ranked graduate and undergraduate educational programs, our community includes a former space shuttle astronaut, a former fighter pilot, former leaders of industry, a former secretary and three chief scientists of the Air Force, two former NASA associate administrators, 14 National Academy of Engineering members, and 15 American Institute of Aeronautics and Astronautics members.

AeroAstro is a vibrant department with a strong sense of community. We value collaboration—within the department, across MIT, and with colleagues around the world. Our environment is connected, busy, global, hectic, open, collegial, and fun.

Two years ago we completed a strategic report, *Aero-Astro: Our Future* (http://web.mit.edu/aeroastro/about/stratrpt.html). It defines our mission and values and identifies eight areas that represent grand challenges and grand opportunities for the department and for aerospace. Those areas are:

- space exploration
- autonomous, real-time humans-in-the-loop systems
- aviation environment and energy
- aerospace communications and networks
- aerospace computation, design, and simulation
- air transportation
- fielding large-scale complex systems
- advancing engineering education

Through making advances in these and related areas MIT AeroAstro is shaping the future of air and space transportation, exploration, communication, and national security.

Mission and Strategy

As defined in our Strategic Report, AeroAstro's mission is to prepare engineers for success and leadership in the conception, design, implementation, and operation of high-performance 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.

Our strategy has four elements:

1. We are building a stronger faculty by hiring for excellence, mentoring, and promoting collaboration.

2. We are attracting more top-quality graduate students (not more students) through increasing our graduate student fellowship endowment and improving our financial structure.
3. We are improving the short-term and lifelong value of the graduate student experience to both the student and the Institute research enterprise by pursuing an initiative to advance graduate education, graduate student mentoring, and graduate student professional development.
4. We are enhancing excellence in undergraduate education by reinvigorating our commitment to the development, assessment, and continuous improvement of our pedagogy and of our student learning.

Progress in 2008–2009

Promoting Faculty Excellence

- The department head and associate head met every two to three weeks with junior faculty members throughout the year as part of an expanded mentoring program.
- More frequent faculty research talks were used to build connection among faculty.
- We continued the faculty awards and recognition committee.
- We strategically repositioned space allocations for several research groups to enable stronger collaborations among and within research groups.
- All promotion cases were successful (professors Nicholas Roy and Brian Wardle to associate professor without tenure, professor Emilio Frazzoli to associate professor with tenure) following rigorous faculty promotion and performance review processes.
- Our hiring process was successful, leading to one new faculty member from our department general search (to be announced) and one from the School of Engineering–wide computational engineering search (professor QiQi Wang)
- Two retiring faculty members (professors John Deyst and Alan Epstein) will be missed but will promote opportunities for renewal.
- We participated in significant ways in major School and Institute initiatives (computation for Design and Optimization Program, MIT Energy Initiative, Transportation@MIT, and the Institute-wide Planning Task Force).

Attracting More Top-Quality Graduate Students

Despite a difficult financial year, in parallel with our Giant Leaps events, we announced two new endowed fellowship funds (the Jack and Vicki Kerrebrock Fellowship and the David and Patricia Vos Foundation Fellowship) and one industrially funded fellowship program (Aurora Flight Sciences Fellows Program). We significantly increased our competitiveness for top graduate program applicants through the explicit formation of a risk pool to underwrite research funding offers; this pool enabled us to provide funding guarantees to 90% of the applicants before the April 15 decision deadline (compared with 40% last year).

Promoting Excellence in Graduate Education

- Our second year of a new PhD qualifier and general exam structure for the doctoral program was successful.
- We required formal end-of-semester progress reviews whereby graduate students and faculty meet at the end of each semester to enhance professional development, feedback, and mentoring.
- We implemented a web-based graduate application review system.
- We significantly improved our graduate admissions process, moving from a selectivity of 38% last year to 19% this year (percent of applicants admitted).
- The department head and associate head met informally with the graduate students every other week throughout the year to promote feedback and stronger involvement in department business.
- We held the first Women in Aerospace Symposium (with Department of Earth, Atmospheric, and Planetary Sciences) to foster a network among top women doctoral students in aerospace from around the United States.

Promoting Excellence in Undergraduate Education

- We welcomed our largest entering sophomore class in 18 years (74 students), composed of 30% women and 32% underrepresented minorities.
- The department head and associate head met informally with the undergraduates every other week throughout the year to promote feedback and a stronger sense of community.
- We continued to require reflective memos of all undergraduate instructors as a means for promoting continuous improvement in faculty teaching performance.
- We initiated a review of 16-II, our aerospace information degree program.

In addition to the progress listed above, the department research volume remained strong, with the two largest areas being research related to air transportation and environment and to autonomous systems. Financial challenges in FY2009 were addressed through a variety of measures, such that we are able to carry forward a significant balance into the next fiscal year in anticipation of more significant cuts in coming fiscal years. As a result of financial constraints within the MIT libraries, the AeroAstro library was closed and the collection was moved to the Barker Engineering Library.

Giant Leaps

The department played a major role in the Apollo Program, designing the guidance, navigation, control, and computer system and educating five Apollo astronauts, including four of the 12 people who have walked on the moon.

Last year, when we began planning our recognition of the moon-landing anniversary, we decided from the onset that it would be more than a social event and a historical retrospective. We would use the opportunity to reflect on the legacy of human space exploration and discuss how lessons learned can be applied to future space exploration and future air transportation as well as to other critical engineering and social needs here on Earth.

Our events began in February with the launch of a SEED Academy aerospace course and other local outreach activities. In April we invited women doctoral candidates from leading academic programs around the United States to the first of what will become an annual event: the Women in Aerospace Symposium. The symposium was also the venue for our annual Lester D. Gardner Lecture, featuring speaker Yvonne Brill, a veteran of 60 years in aerospace engineering and a pioneer in space propulsion. In May we sponsored the Sally Ride Science Festival on campus as part of the Cambridge Science Festival.

On June 10, 11, and 12, AeroAstro held a once-in-a-lifetime event, which we named Giant Leaps. Among Giant Leaps' features were a symposium with many of the engineers, astronauts, and managers who were part of Apollo; a memorial to Apollo program principal architect and former MIT School of Engineering dean Robert C. Seamans, Jr.; production of two videos—one celebrating the life of Bob Seamans and another examining the Apollo adventure and posing questions about how we can apply its lessons to the future; an MIT Museum exhibit of Apollo artifacts; a traveling display encouraging young people to consider aerospace careers; and a Boston Pops concert with Buzz Aldrin narrating selections from Gustav Holst's "The Planets." More than 700 people attended the seminar, and more than 2,000 attended Pops.

Figure 1. The Giant Leaps Apollo Symposium begins as President Kennedy's special advisor Theodore Sorenson takes the lectern to offer reflections on Apollo. Also on the dais are (from left) AeroAstro professor and former Shuttle astronaut Jeffrey Hoffman; Apollo director of guidance, navigation, and control systems Richard Battin; Apollo command and service module manager Aaron Cohen; lunar module program director Joseph Gavin, Jr.; Apollo 17 astronaut Harrison "Jack" Schmitt; and Apollo flight operations director Christopher Kraft, Jr.

Celebration of the Life of Robert C. Seamans, Jr.

The commemoration of the life of Robert C. Seamans included opening comments from Ian Waitz, president Susan Hockfield, and Louis Padulo, president emeritus, University City Science Center, Philadelphia, president emeritus, University of Alabama, Huntsville.

The speakers included Richard Battin, Apollo guidance, navigation, and control system director and MIT senior lecturer; Laurence R. Young, Apollo MIT program professor of aeronautics and astronautics; Edward F. Crawley, AeroAstro Ford professor of engineering; Sheila Widnall, AeroAstro Institute professor; George Mueller, chief executive officer of Kistler Aerospace and former NASA Office of Manned Space Flight associate administrator; Neil Armstrong, former astronaut and former University of Cincinnati professor of aerospace engineering; Richard Meserve, Carnegie Institution for Science president; John Bullard, Sea Education Association president; Paul Gray, MIT president emeritus; Anne Meyer, Center for Applied Special Technology founder and chief of education design; Joel Moses, Electrical Engineering and Computer Science and Engineering Systems Division Institute professor; Brian Tucker, GeoHazards International president; Ernest L. Godshalk, ELGIN Management Group managing director. Excerpts from Robert Seamans's autobiography *Aiming at Targets* were read by AeroAstro graduate students Holly Jeffrey, Hemant Chaurasia, Chelsea He, Allie Anderson, Justin Kaderka, and Phillip Cunio.

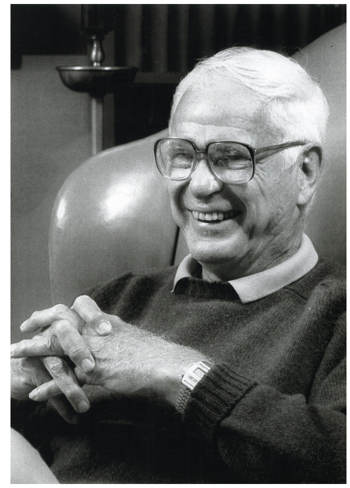

Figure 2. As part of the Giant Leaps celebration of the 40th anniversary of the moon landing, AeroAstro hosted a memorial gathering to celebrate the life and accomplishments of Robert C. Seamans, Jr., a principal architect of the Apollo Program, an AeroAstro professor, and former MIT dean of engineering.

The Giant Leaps Symposium

The Giant Leaps Symposium was led by opening remarks from Ian Waitz, president Susan Hockfield, and Mr. James D. Shields, president and chief executive officer of Draper Laboratory. Speakers included:

Session 1. Apollo: Reflections and Lessons, moderator: Jeffrey A. Hoffman, former Space Shuttle astronaut and AeroAstro professor of the practice. Panel: Richard Battin, Apollo guidance director, AeroAstro senior lecturer; Aaron Cohen, Apollo command and service module manager, former NASA Johnson Space Center director; Joseph G. Gavin, Jr., Lunar Module Program director, retired Grumman president; Christopher C. Kraft, Jr., Apollo flight operations director; Harrison Schmitt, Apollo astronaut, scientist, former US Senator; Theodore Sorensen Esq., President Kennedy's special counsel and adviser and primary speechwriter.

Session 2. The Next Giant Leaps in Energy, Environment, and Air Transportation, keynote: John P. Holdren, director, Office of Science and Technology Policy, Executive Office of the President; moderator: Dr. Ian A. Waitz, Jerome C. Hunsaker professor and AeroAstro Department head. Panel: Michael B. Bair, Boeing Commercial Airplanes vice president, business strategy and marketing; David Danielson, US Department of Energy's Advanced Research Projects Agency program manager, MIT Energy Club founder; Alan H. Epstein, United Technologies Pratt & Whitney vice president for technology and environment, R.C. MacLaurin professor, AeroAstro; Lourdes Q. Maurice, Federal Aviation Administration (FAA) chief scientific and technical advisor.

Session 3. The Next Giant Leaps in Space Exploration, keynote: Maria Zuber, E.A. Griswold professor of geophysics, Department of Earth, Atmospheric, and Planetary

Sciences head; moderator: Edward F. Crawley, Ford professor of engineering, AeroAstro. Panel: James Crocker, Lockheed Martin Space Systems Sensing & Exploration Systems, vice president and general manager; Richard Garriott, private astronaut, Space Adventures vice chairman; James Garvin, Goddard Space Flight Center chief scientist; David W. Thompson, Orbital Sciences Corporation chairman and chief executive officer; Erika Wagner, AeroAstro lecturer.

Figure 3. AeroAstro grad student volunteers Allie Anderson (left) and Brad Holschuh help a young visitor experience a "space suit" at the Cambridge Science Festival. (Michael Fein/Cambridge Science Festival photo)

We have produced both a video of seminar highlights and a special edition of our department annual publication, *AeroAstro*, which focuses on our Giant Leaps events. Videos and transcripts of the seminar will also be made available for scholarly purposes.

2008–2009 Personnel Achievement

Faculty Highlights

Professor Ed Crawley has been named a member of NASA's Review of US Human Space Flight Plans Committee.

Professors Olivier de Weck and Dava Newman are featured in the June issue of *IEEE Spectrum*: Professor Newman in the article "What to Wear on Mars" and Professor deWeck in "What to Pack for Mars."

Professor Weck received a special commendation for his contribution to the International Council on Systems Engineering's Space Systems Working Group. The group received an Outstanding Achievement Award at the INCOSE 2009 Workshop. Professor de Weck was also named associate director of the Engineering Systems Division.

Professor Mark Drela was elected to be a member of the National Academy of Engineering (NAE).

The MIT Corporation Executive Committee awarded tenure to professor Emilio Frazzoli. Professor Frazzoli was also invited to present his work at the NAE 2009 German–American Frontiers of Engineering Symposium in Potsdam, Germany, this past April and at the National Science Foundation Briefing and Research Expo on Cyber-Physical Systems on Capitol Hill in July.

Professor Edward Greitzer was elected an international fellow of the British Royal Academy of Engineering and appointed an honorary professor at the Beijing Institute of Aeronautics and Astronautics. He is principal investigator of a multifaculty, multiorganization program to define an N+3 civil aircraft for the 2035+ time frame—the only university-led team that was selected.

Professor Steven R. Hall is a member of the Smart Rotor Team that was awarded the Howard Hughes Award from the American Helicopter Society. The award is given in recognition of an outstanding improvement in fundamental helicopter technology brought to fruition in the previous year. He also received the American Institute of Aeronautics and Astronautics (AIAA) Undergraduate Teaching Award, given by the AIAA student chapter to a faculty or staff member who has exemplified the role of a "great teacher."

Professor Jonathan How and his student Brett Bethke received a Boeing Special Invention award for their work in developing the RAVEN test facility at Boeing.

In January, professor Nancy Leveson presented the MITSUI lecture in Japan. This lecture brings nationally and internally prominent speakers to address issues of concern to China, Korea, and Japan.

Professor Paulo Lozano received a grant through the US Air Force Young Investigator Research Program to research fully scalable porous metal electrospray propulsion.

Professor emeritus Earll Murman was named an AIAA honorary fellow "for significant contributions to transonic flow and delta wing CFD, aerospace engineering education, industrial application of lean aerospace principles, and for leadership in aeronautics and astronautics."

Professor of the practice Deborah Nightingale was appointed to the executive advisory board of the Veterans Administration Virtual Engineering Research Center.

In June, the Global Airline Industry Program celebrated the completion and publication of their new textbook, *The Global Airline Industry*, edited by professor Amedeo Odoni and principal research scientist Peter Belobaba and associate dean Cynthia Barnhart.

Professor Raul Radovitzky has been appointed by the Argentinean Government to the International Advisory Board of that country's Center for Multi-Physics Simulations and Technical Applications. He also was named an invited professor at the Computational Solid Mechanics Laboratory at the Swiss Federal Institute of Technology of Lausanne.

Professors Nicholas Roy and Brian Wardle were promoted to associate professor without tenure. Professor Roy received an IEEE Robotics and Automation Society Early Career Award "for fundamental contributions to planning, machine learning and the development of indoor unmanned air vehicle flight."

Professor Zoltan Spakovszky was named a recipient of MIT's Ruth and Joel Spira Award for Distinguished Teaching. The award, which acknowledges the tradition of high-quality engineering education at MIT, honors junior faculty members who have balanced their research agenda with excellent, enthusiastic, and creative teaching.

At a September 11 hearing in Washington, DC, professor Ian Waitz, AeroAstro head and Partnership for AiR Transportation Noise and Emission Reduction director, testified before the House Committee on Science and Technology on the two most critical needs for the Next Generation Air Transportation System.

Professor Brian Wardle gave the keynote address at the 2009 Conference of the Society of Plastics Engineers. In May, he received USpatent 7,537,825 for a hybrid nanocomposite architecture. His research was featured in the article "A Stitch in Time—Nanotechnology: A New Way to Prevent Flaws in Composite Materials," in the *Economist* on June 4.

Professor Sheila E. Widnall received the AIAA Undergraduate Advising Award, given by the AIAA student chapter to a faculty or staff who has demonstrated excellence in serving as an academic or Course 16.621/16.622 advisor and has made a real positive impact on a student's time in the AeroAstro Department.

Professor Karen Willcox was named codirector of the Center for Computational Engineering.

Professor Moe Win received the Best Paper Award at both the 2008 IEEE International Conference on Communications and the IEEE 67th Vehicular Technology Conference. Additionally, he received the 2008 Guglielmo Marconi Best Paper Award from the IEEE Communications Society for "an original paper in the field of Wireless Communications published in the *IEEE Transactions on Wireless Communications*." He also received the Technical Recognition Award from the IEEE ComSoc Radio Communications Committee for "exceptional technical contributions to radio communications."

Other Accomplishments

Abraham Bachrach, Ruijie He, Samuel Prentice, Garrett Hemann, and Anton de Winter took both the First Prize Award and the Systems Integration Award at the 19th International Aerial Robotics Competition.

PhD student Fabio Fachin received a Fulbright fellowship.

AeroAstro student team Arthur Guest, Phillip Cunio, Wilfried Hofstetter, and SeungBum Hong won the Pacific International Space Center for Exploration Systems annual design competition, which focused on developing an outpost for the moon.

Dr. James Hileman was named associate director of the Partnership for AiR Transportation Noise and Emissions Reduction and promoted to principal research engineer.

Senior Jeremy McGee received the Albert G. Hill Prize, which is awarded to a minority undergraduate junior or senior who has maintained high academic standards and made continued contributions to improving the quality of life for minorities at MIT.

Three students were awarded AIAA undergraduate scholarships. The E.C. "Pete" Aldridge scholarship went to Ryan McLinko. The Dr. James Rankin Digital Avionics scholarship was awarded to Christopher Han, and Eric Dow received the Digital Avionic Technical Activities Committee award.

Figure 4. Aboard the Zero-G aircraft, conducted in conjunction with AeroAstro's Giant Leaps Apollo anniversary events, Tina Srivastava (left) and Jillian James test microgravity deployment of a solar panel for an undergrad satellite project. (Steve Boxal/Zero Gravity Corp. photo)

Graduate student Dan Kwon received a Boeing Engineering Student of the Year honorable mention for research he performed in the Space Systems Lab. The award recognized research likely to "impact the future of aerospace engineering in areas such as new or enhanced capabilities, systems, processes or tools; new levels of performance; and improved lifecycle costs."

Dan Kwon also received a first place in the Frank J. Redd student scholarship competition at the Annual AIAA/USU Conference on Small Satellites for his paper "Cryogenic Thermal Design of Small Electromagnetic Formation Flight Satellites."

Dr. Charles Oman was reappointed team leader for sensorimotor research, National Space Biomedical Research Institute. In February, he was awarded the Laurence R. Young Space Biomedical Research Award.

Lecturer George T. Schmidt was reappointed as editor-in-chief of the *AIAA Journal of Guidance, Control and Dynamics*.

Graduate student Julie Shah received the best paper prize at the International Conference on Automated Planning and Scheduling (Sydney, Australia) for her work on mixed human/robot task coordination. The title of her paper was "Fast Dynamic Scheduling of Disjunctive Temporal Constraint Networks through Incremental Compilation."

AeroAstro/Technology and Policy Program master's degree candidate Ioannis Simaiakis was selected by the Transportation Research Board for its graduate research award for his paper "Airport Ground Operations Planning for Surface Emissions Reduction."

PhD candidate Alejandra Uranga received the Graduate Student Council Teaching Award for the School of Engineering.

PhD candidate Namiko Yamamoto was honored with a JAXA Fellowship to IAC in Korea.

Research

AeroAstro 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 aeronautics and astronautics.

Aerospace Computational Design Laboratory

The mission of the Aerospace Computational Design Laboratory (ACDL) (http://acdl.mit.edu/) is 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 and reacting flow, 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. Research interests also extend to chemical kinetics, transport–chemistry interactions, and other reacting flow phenomena.

Uncertainty quantification and control is aimed at improving the efficiency and reliability of simulation-based analysis as well as supporting decision under uncertainty. Research is focused on error estimation, adaptive methods, ordinary differential equations/partial differential equations (PDEs) with random inputs, certification of computer simulations, and robust statistical frameworks for estimating and improving physical models from observational data.

The creation of computational decision-aiding tools in support of the design process is the objective of a number of methodologies the lab pursues. They 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), Doug Allaire, Marcelo Buffoni, David Darmofal, Mark Drela, Michalis Frangos, Robert Haimes, Youssef Marzouk, Cuong Nguyen, 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 nonlinear control. A key part of ACL is RAVEN (Real-time indoor Autonomous Vehicle test ENvironment), a unique experimental facility that uses a 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. Recent research includes the following:

Robust Planning: ACL developed a distributed task-planning algorithm that provides provably good conflict-free task allocations that are robust to poor network connectivity and inconsistencies in the situational awareness over the team. Recent work demonstrated key theoretical properties of this consensus-based bundle algorithm and extended the algorithm to enable tight linkages with a human operator.

Sensor Networks: ACL also addressed planning of mobile sensor networks (e.g., unmanned air vehicles (UAVs)) to extract the maximal information from a complex dynamic environment such as a weather system. The primary challenge in this planning is the significant computational complexity due to the large size of the decision space and the cost of propagating the influence of sensing into the future. ACL developed a new set of methodologies that correctly and efficiently quantify the value of information in large information spaces, thus leading to a systematic architecture for planning information-gathering paths for mobile sensors in a dynamic environment.

Approximate Dynamic Programming: Markov decision processes are a natural framework for formulating many of the decision problems of interest to ACL, but the curse of dimensionality prevents the exact solution of problems of practical size. ACL has developed new approximate policy iteration algorithms that exploit flexible, kernel-based cost approximation architectures to quickly compute an approximate policy by minimizing the error incurred in solving Bellman's equation over a set of sample states. Experimental results demonstrate the applicability of this approach to several applications, including a multi-UAV coordination and planning problem.

Autonomous Vehicles: Working with Professor Frazzoli and team as part of the Agile Robotics for Logistics program, ACL has developed a planning and control framework capable of autonomous forklift operations in an unstructured, outdoor warehouse setting. The framework implemented uses closed-loop rapidly exploring random trees for navigation and a steering controller coupled with pallet and truck perception filters for manipulation of pallet loads. In a presentation at Fort Belvoir, VA, in June 2009, the team's robotic forklift demonstrated robust path-planning capabilities in a complex environment with uncertain terrain, dynamic obstacles (including humans), and unreliable GPS data.

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 the design of 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 the area of data communication and networks with application to satellite, wireless, and optical networks. Over the past year, the group continued to work on a Department of Defense–funded project toward the design of highly robust telecommunication networks that can survive a massive disruption that may result from natural disasters or intentional attack. The project examines the impact of large-scale, geographically correlated failures on network survivability and design. In a related project, recently funded by the National Science Foundation, the group is studying survivability in layered networks, with the goal of preventing failures from propagating across layers.

The group also started work on a new Army MURI (Multidisciplinary University Research Initiative) project titled "MAASCOM: Modeling, Analysis, and Algorithms for Stochastic Control of Multi-Scale Networks." The project deals with control of communication networks at multiple timescales and is a collaboration between MIT, Ohio State University, University of Maryland, University of Illinois, Purdue University, and Cornell University.

The Communications and Networking Research Group 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 as well as the introduction of new digital technology are posing new challenges for engineering, operations, and sustainment. The Complex Systems Research Laboratory (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 system's 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 the main emphasis of the Complex Systems Research Laboratory is aerospace systems and applications, its research results are applicable 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.

Nancy Leveson directs the Complex Systems Research Laboratory.

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 60 years. GTL's mission is to advance the state-of-the-art in fluid machinery for power and propulsion. The research is focused on advanced

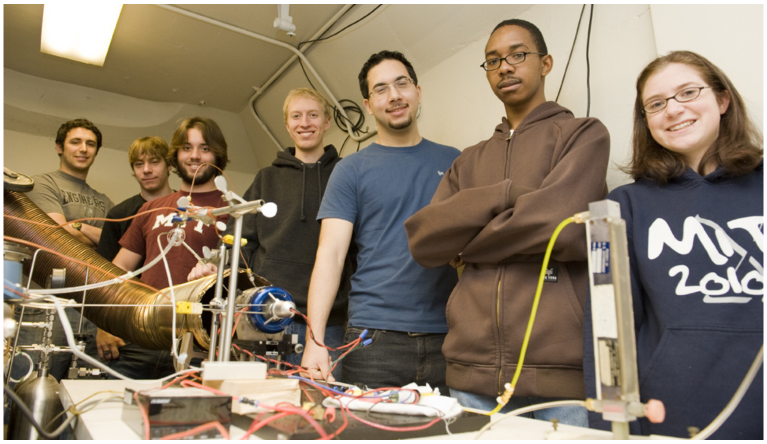

Figure 5. During the January Independent Activities Period, 12 undergraduate students participated in the Gas Turbine Lab's JetJoe Course. Under Gas Turbine Lab head Zolti Spakovszky, the class offered hands-on modeling and analysis, engine assembly, and operation of a small-scale gas turbine jet engine. Four teams of students established an aero-thermodynamic performance model and estimated the performance based on geometric information and component performance assumptions. (William Litant/MIT photo)

propulsion systems, energy conversion, and power, with activities in computational, theoretical, and experimental study of loss mechanisms and unsteady flows in fluid machinery, dynamic behavior and stability of compression systems, instrumentation and diagnostics, advanced centrifugal compressors and pumps for energy conversion, gas turbine engine and fluid machinery noise reduction and aero-acoustics, and novel aircraft and propulsion system concepts for reduced environmental impact.

Examples of current and past research projects include engine diagnostics and smart engines, aerodynamically induced compressor rotor whirl, a criterion for axial compressor hub-corner separation, axial and centrifugal compressor stability prediction, losses in centrifugal pumps, loss generation mechanisms in axial turbomachinery, the Silent Aircraft Initiative (a collaborative project with Cambridge University, Boeing, Rolls Royce, and other industrial partners), hybrid-wing-body airframe design and propulsion system integration for reduced environmental impact (NASA N+2), counter-rotating propfan aerodynamics and acoustics, an engine air-brake for quiet aircraft, inlet distortion noise prediction for embedded propulsion systems, novel aircraft concepts for 2035 (NASA N+3), high-speed microgas bearings for MEMS turbomachinery, small gas turbines and energy concepts for portable power, and carbon-nanotube bearings.

Zoltan Spakovszky is GTL director. Faculty, research staff, and frequent visitors include John Adamczyk, Nick Cumpsty, Elena de la Rosa Blanco, Mark Drela, Fredric Ehrich, Alan Epstein, Edward Greitzer, Gerald Guenette, Jim Hileman, 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 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 humans and computers can leverage the strengths of the other to achieve superior decisions together are 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 the 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 are of vital importance 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 now in common use.

ICAT faculty include R. John Hansman (director), Hamsa Balakrishnan, 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 fulltime 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.

AeroAstro and LIDS faculty includes Emilio Frazzoli, Jonathan How, and Moe Win.

For additional information about LIDS, see its full report.

Lean Advancement Initiative

The Lean Advancement Initiative (LAI) (http://lean.mit.edu/) is a unique learning and research consortium focused on enterprise transformation, and its members include key stakeholders from industry, government, and academia. LAI is headquartered in AeroAstro, 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." LAI is now in its fifth and most important phase and has moved beyond a focus on business-unit level change toward a holistic approach to transforming entire enterprises across a variety of industries. 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 more than 40 educational institutions in the United States, England, Italy, and Mexico and provides LAI members with unmatched educational outreach and training capabilities.

AeroAstro 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, on the Mir Space Station, and on many parabolic flights and developed experiments for the International Space Station (ISS).

This year MVL has more affiliated graduate students (25) than at any time in its four-decade history. Research sponsors include NASA, the National Space Biomedical Institute, the Office of Naval Research, the Department of Transportation's 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, space teleoperation, design of aircraft and spacecraft displays, and controls and cockpit human factors. Current MVL research projects deal with cockpit displays, controls, and vehicle-handling qualities for lunar landing; mathematical modeling of spatial disorientation; enhancing human performance in space teleoperation; ensuring the effectiveness of astronaut lunar exploration sorties; planetary mission planning; fatigue detection in locomotive engineers; and advanced helmet designs for brain protection in sports and against explosive blasts. This year, MVL received two new major collaborative grants: One grant is to study the effects of fatigue in space teleoperation performance, being conducted collaboratively with Harvard colleagues in the Division of Sleep Medicine at the Brigham and Women's Hospital. A second grant addresses human automation interactions and supervisory control of lunar landing vehicles. Both are four-year grants totaling $3.4 million. MVL also collaborates with the Volpe Center in Transportation Research and the Jenks Vestibular Physiology Laboratory of the Massachusetts Eye and Ear Infirmary.

Physical space continues to be a major constraint: the laboratory relinquished room 37-135 to Kavli and consolidated three other research projects in a renovated room, 37-127. MVL faculty and several graduate students and postdocs were active in the Space, Policy, and Society Research Group this year and contributed to MIT's white paper "The Future of Human Space Flight." MVL faculty members Dava Newman and Jeffrey Hoffman along with several graduate students took lead roles in planning the department's Giant Leaps celebration of the 40th anniversary of Apollo 11. The laboratory's Bioastronautics Journal Seminar enrolled 16 graduate students with another 10 faculty, students, staff, and undergraduates participating as listeners. For the sixth year, MVL MIT Independent Activities Period activities included a popular course on Boeing 767 systems and automation and aircraft accident investigation, cotaught with Brian N. Nield, Boeing's chief engineer for the 777.

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 National Space Biomedical Research Institute (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 9 universities, 3 federal agencies, and 53 advisory board members, the latter spanning a range of interests from local government to industry to citizens' community groups. During 2008–09, PARTNER continued to expand its research portfolio. New research projects include noise exposure response: annoyance; noise exposure response: sleep disturbance; sound structural transmission; environmental cost–benefit analysis of ultra low sulfur jet fuels; environmental cost–benefit analysis of alternative jet fuels; objective measures to support airspace management; metrics for an aviation CO_2 standard; near-term operational changes; isotopic analysis of airport air quality; and international collaborative emissions studies. New reports resulting from PARTNER research were released, including studies of en route traffic optimization to reduce environmental impact, land use management and airport controls, large eddy simulations of contrails, and aircraft emissions-related pollutant health risk prioritization.

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/time-efficient flight levels and enhancing air traffic control flexibility and airspace capacity.

PARTNER MIT personnel include Ian Waitz, who directs the organization, James Hileman (associate director), Hamsa Balakrishnan, John Hansman, Thomas Reynolds, Karen Willcox, Malcolm Weiss, Christoph Wollersheim, 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 SM thesis, SPL student Daniel Courtney designed and built a new type of space plasma thruster they have 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 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.

Figure 6. Graduate student Dan Courtney explains the operation of a miniature Hall Thruster ion engine to Space Propulsion Lab visitors during the AeroAstro Department's June open house.

Manuel Martínez-Sánchez directs the SPL research group. Paulo Lozano is a key participant.

Space Systems Laboratoy

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 International Space Station, and robotic operations for Mars and beyond. Research encompasses a wide array of topics that together comprise 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.

Major SSL initiatives study the development of formation flight technology. Significant research has been conducted using the Synchronized Position Hold Engage and Reorient Experimental Satellites (SPHERES) facility in the areas of distributed satellite systems, including telescope formation flight, docking, and reconfiguration. The SPHERES facility consists of three small satellites 20 centimeters in diameter that have flown inside the ISS since May 2006. They are used to test advanced control software in support of future space missions that require autonomous inspection, docking, assembly, and precision formation flight. Over the past three years, we have successfully completed more than 16 test sessions with six astronauts. The pending Space Act Agreement will make SPHERES a permanent national facility aboard the SS.

SSL is in the second year of the Space Engineering Academy (SEA) program; SEA will immerse junior Air Force officers in the development of flight hardware, providing first-hand experience in implementing best (and avoiding worst) practices in space system procurement. The SEA will engage Air Force graduate students in a two-year, end-to-end, flight-worthy satellite conceive, design, build, integrate, test, and operate program. Lessons learned in the three-semester senior capstone satellite design-build course (Course 16.83X) and the construction, testing, and subsequent analysis of the orbital surveillance maneuverability vehicle have contributed to the development of the graduate-level SEA program.

The electromagnetic formation flight testbed 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 the International Space Station 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, Jeffrey Hoffman, Edward F. Crawley, Daniel Hastings, Annalisa Weigel, Manuel Martinez-Sanchez, Paulo Lozano, Alvar Saenz-Otero, Paul Bauer (research specialist), SharonLeah Brown (administrator and outreach coordinator), Brian O'Conaill (fiscal officer), Marilyn E. Good (administrative assistant), and Deatrice Moore (financial 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/). They work cooperatively to advance the knowledge base and understanding that will help facilitate and accelerate development and use of advanced materials systems in various advanced structural applications and devices.

The laboratory has broadened its interests from a strong historical background in composite materials, as reflected in the name change from the former Technology Laboratory for Advanced Composites. A significant initiative involves engineering materials systems at the nanoscale, particularly focusing on aligned carbon nanotubes as a constituent in new materials and structures. This initiative is in partnership with industry through the Nano-Engineered Composite aerospace STructures (NECST) Consortium (http://necst.mit.edu/) founded at MIT in 2007. The research interests and ongoing work in the laboratory thus represent a diverse and growing set of areas and associations. Areas of interest include:

- nanoengineered hybrid advanced composite design, fabrication, and testing
- fundamental investigations of mechanical and transport properties of polymer nanocomposites
- characterization of carbon nanotube bulk engineering properties
- carbon nanotube synthesis and governing mechanisms
- composite tubular structural and laminate failures
- MEMS-scale mechanical energy harvesting modeling, design, and testing
- durability 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 length scale 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 the fabrication of 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 advancing 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 interest areas in the laboratory. This commitment is exemplified in the newly formed ` 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 Luis Rocha.

Wireless Communication and Network Sciences Group

The Wireless Communication and Network Sciences Group (http://wgroup.lids.mit.edu/) is involved in multidisciplinary research that encompasses developing fundamental theories, designing algorithms, and conducting experiments for a broad range of real-world problems. Current research topics include location-aware networks, network synchronization, aggregate interference, intrinsically secure networks, time-varying channels, multiple antenna systems, ultra-wide bandwidth systems, optical transmission systems, and space communications systems. Details of a few specific projects are given below.

The group is working on location-aware networks in GPS-denied environments which provide highly accurate and robust positioning capabilities for military and commercial aerospace networks. It has developed a foundation for the design and analysis of large-scale location-aware networks from the perspective of theory, algorithms, and experimentation. This process includes deriving performance bounds for cooperative localization, developing a geometric interpretation for these bounds, and designing practical, near-optimal cooperative localization algorithms. It is currently validating the algorithms in a realistic network environment through experimentation in the lab.

The lab has been engaged in developing a state-of-the-art apparatus that enables automated channel measurements. The apparatus makes use of a vector network analyzer and two vertically polarized, omnidirectional wideband antennas to measure wireless channels over a range of 2–18 GHz. It is unique in that extremely wide bandwidth data, more than twice the bandwidth of conventional ultra-wideband systems, can be captured with high-precision positioning capabilities. Data collected with this apparatus facilitate the efficient and accurate experimental validation of proposed theories and enable the development of realistic wideband channel models. Work is under way to analyze the vast amounts of data collected during an extensive measurement campaign that was completed in early 2009.

Lab students are also investigating physical-layer security in large-scale wireless networks. Such security schemes will play increasingly important roles in new paradigms for guidance, navigation, and control of unmanned aerial vehicle networks. The framework they have developed introduces the notion of a secure communications graph, which captures the information-theoretically secure links that can be established in a wireless network. They have characterized the s-graph in terms of local and global connectivity, as well as the secrecy capacity of connections. They also proposed various strategies for improving secure connectivity, such as eavesdropper neutralization and sectorized transmission. Lastly, they analyzed the capability for secure communication in the presence of colluding eavesdroppers.

Lab director Moe Win and a team of undergraduate and graduate students competed in the Institute of Soldier Nanotechnologies Soldier Design Competition. In this contest, they demonstrated the first cooperative location-aware network for GPS-denied environments, using ultra-wideband technology, leading to the team winning the L3 Communications Prize. They are now advancing the localization algorithms in terms of scalability, robustness to failure, and tracking accuracy.

To advocate outreach and diversity, the group is committed to attracting undergraduates and underrepresented minorities, giving them exposure to theoretical and experimental research at all levels. For example, the group has a strong track record for hosting students from both the Undergraduate Research Opportunities Program and the MIT Summer Research Program. Professor Win maintains dynamic collaborations and partnerships with academia and industry, including the University of Bologna and Ferrara in Italy, University of Lund in Sweden, University of Oulu in Finland, National University of Singapore, Nanyang Technological University in Singapore, Draper Laboratory, Jet Propulsion Laboratory, and Mitsubishi Electric Research Laboratories.

Moe Win directs the Wireless Communication and Network Sciences Group.

Wright Brothers Wind Tunnel

Since its opening in September 1938, the Wright Brothers Wind Tunnel (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, Wright Brothers Wind Tunnel work has been recorded in hundreds of theses and more than a thousand technical reports.

Wright Brothers Wind Tunnel 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 AeroAstro 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 of 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 AeroAstro 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. 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 the 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 UAVs. 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 telecommunication. A network operations area supports learning about the operations and management of networks. 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 departments' most exciting 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, a flying automobile, and the winning entry in the AIAA Design–Build–Fly competition.

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 environment are the investigation of reconfigurable wheels for planetary rovers and a study of bats' wing cilia enabling highly maneuverable flight. The Neumann and Gelb facilities also continue to be much used by the Robotics: Science and Systems I class (Course16.415/6.141), which was developed jointly by AeroAstro and Electrical Engineering and Computer Science faculty.

The follow-on to the Space Systems Engineering capstone class (Course 16.83X) is using the Gelb lab to build a high delta V (~1-2 km/s) microsatellite. The motivation is to provide a low-cost orbital transfer vehicle capability for maneuvering throughout the Earth–moon system. The goal is to deliver to the Air Force in January 2011 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 35 undergraduates and 10 graduates from multiple departments hands-on experience in designing, building, and testing actual flight hardware.

Graduate Program

While the dramatic advancements we have made in our undergraduate program were being studied and replicated by schools throughout the world, our graduate program had remained largely unchanged. Over the past two years, we have made significant revisions to enhance the excellence of our already top-ranked graduate program. These changes occurred throughout the program from graduate admissions to improved mentoring to the requirements of the doctoral program.

A specific focus last year was the complete revamping of our admissions process with the goals of increasing our yield of top students and controlling the overall size of our program. To achieve these goals, a graduate admission committee was formed and given the responsibility of overseeing the entire admissions process, including screening applications for admissibility, developing an admission target size, and making final decisions on admissions of all applicants. The net effect of these changes is an admissions rate of 19% this year, compared with 38% in previous years (the School of Engineering average admissions rate is approximately 20%). To increase our yield of those applicants admitted, we implemented a plan to increase the amount of funding offered to the admitted students through a department fellowship-based risk pool for proposed research. In addition, we have intensified our efforts to increase the total amount of our department fellowship resources. In the end, nearly 90% of all admitted students had funding before the mid-April decision deadline (compared with last year when only 40% were supported at this deadline), and the yield across our top-rated applicants increased slightly to 60% (compared with 56% previously).

Degrees

The Bachelor of Science (SB) 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 a second 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 S.M. thesis. This degree prepares the graduate for an advanced position in the aerospace field, and it forms a solid foundation for future doctoral study.

AeroAstro offers doctoral degrees (PhD and ScD) that emphasize in-depth study with a significant research project in a focused area. Entrance to the doctoral program requires students to pass a graduate-level examination in a field of aerospace engineering as well as 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*

	99–00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09
Sophomores	59	68	56	64	72	64*	65	65	65	74
Juniors	40	53	69	51	59	59*	52	60	66	55
Seniors	37	45	53	70	61	65*	76	56	66	62
Totals	**136**	**166**	**178**	**185**	**192**	**188***	**196**	**181**	**189**	**191**
% Women	30%	32%	33%	35%	34%	30%	26%	31%	30%	30%
% Underrepresented minorities	12%	21%	22%	30%	30%	27%	25%	26%	24%	32%

*Data based on the fall fifth-week enrollment.

Undergraduate Student Prizes

Awards presented at the AeroAstro Class of 2009 Recognition Dinner on Monday, May 11, 2009:

The Andrew Morsa Prize—awarded for demonstration of ingenuity and initiative in the application of computers to the field of aeronautics and astronautics: Fuzhou Hu, Matthew T. Peddie, and Piotr Fidkowski

Graduate Enrollment*

	2004	2005	2006	2007	2008	2009
Total Student Body	245	231	223	223	226	236
SM**	166	137	124	135	146	148
PhD***	67	94	99	88	80	88
Minority						
SM	10	7	7	9	8	8
PhD	3	6	4	3	5	6
Female						
SM	38	34	31	26	29	32
PhD	21	19	25	19	19	23

*Numbers based on fifth-week enrollment data.

** Includes students pursuing only the master's degree and students who have not yet passed the doctoral qualifying exam.

***Students who have passed the doctoral qualifying exam.

The Yvnge Raustein Award—given to a unified engineering student who best exemplifies the spirit of Yngve Raustein and to recognize significant achievement in unified engineering: Kathryn A. Gordon

The Apollo Award—given to an AeroAstro student who conducts the best undergraduate research project on the topic of humans in space: Ryan M. McLinko

The David J. Shapiro Award—given 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: Bruno Alvisio, Danielle M. DeLatte, Raqeebul I. Ketan, Natasha Bosanac, Eli A. Cohen, Jacob L. Rosenbluth, and Ramon L. Torres

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: Jillian M. James, Ashley E. Micks, and Rodrigo A. Zeledon

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: Stephanie A. Couch, Frances A. Gonzalez, Caroline S. Lowenthal, Ryan M. McLinko, and Tina P. Srivastava

The United Technologies Corp. Prize—awarded to an AeroAstro student for outstanding achievement in the design, construction, execution, and reporting of an undergraduate experimental project: Alexander L. Pina and Gregory T. Wellman; Ryan M. Daspit and Eric R. Munoz

The Admiral Luis De Florez Prize—awarded for “original thinking or ingenuity” as demonstrated by the individual effort of the student, not the ideas and suggestions of an advisor, instructors, or an advisory team: Louis E. Perna and Bruce T. Vest; Jesse M. Carr and Anton de Winter; Erich Mueller

The James Means Award for Excellence in Space Systems Engineering: Emily B. Grosse

The James Means Award for Excellence in Flight Vehicle Engineering: Joseph S. Pokora and Constantine G. Speridakos

The Henry Webb Salisbury Award—given in memory of Henry Salisbury to a graduating senior who has achieved superior academic performance in the Course 16 undergraduate program: David A. Sanchez

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

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