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 229 graduate students, 138 undergraduate students, and 35 faculty members, our community includes a former space shuttle astronaut, a former fighter pilot, former leaders of industry, a former secretary and three former chief scientists of the Air Force, a former National Aeronautics and Space Administration (NASA) associate administrator, 14 National Academy of Engineering members, 14 American Institute of Aeronautics and Astronautics Fellows, and two Guggenheim Medal recipients.

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.

The strategic report AeroAstro: Our Future defines our mission and values and identifies eight areas that represent grand challenges and grand opportunities for the department and for aerospace, the nation, and the world. 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 the following elements:

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

2. We are improving the short-term and lifelong value of the graduate student experience for both the student and the Institute research enterprise by pursuing an initiative to advance graduate education, graduate student mentoring, and graduate student professional development.
3. 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.
4. We are improving our physical space by enhancing maintenance procedures and investing in space renovations.

Faculty Notes

The AeroAstro faculty includes Hamsa Balakrishnan, Steven Barrett, Kerri Cahoy, Edward Crawley (0.5 full-time-equivalent [FTE] position, dual appointment with Engineering Systems Division [ESD], on leave while serving as president of the Skolkovo Institute of Science and Technology), Mary Cummings, David Darmofal, Olivier de Weck (0.5 FTE position, dual appointment with ESD), Mark Drela, Emilio Frazzoli, Edward Greitzer, Steven Hall, R. John Hansman, Wesley Harris (full-time administrative role as associate provost for faculty equity), Daniel Hastings (0.5 FTE position, dual appointment with ESD, full-time administrative role as dean of undergraduate education), Jonathan How, Paul Lagace, Nancy Leveson (0.5 FTE position, dual appointment with ESD), Paulo Lozano, Manuel Martinez-Sanchez, Youssef Marzouk, David Miller, David Mindell (0.5 FTE position, dual appointment with ESD), Eytan Modiano, Dava Newman (0.5 FTE position, dual appointment with ESD), Jaime Peraire, Raul Radovitzky, Nicholas Roy, Julie Shah, Zoltan Spakovszky, Ian Waitz (full-time administrative role as dean of the School of Engineering), Qiqi Wang, Brian Wardle, Annalisa Weigel, Sheila Widnall, Karen Willcox, Brian Williams, Moe Win, and Laurence Young. Professor Peraire is the department head, and Professor Willcox is the associate department head.

Willcox, Radovitzsky, Spakovzky, and Win have been promoted to the rank of full professor. Marzouk and Balakrishnan have been promoted to the rank of associate professor without tenure.

Professor Darmofal has been named the Raymond L. Bisplinghoff faculty fellow in recognition of his numerous contributions to the department, the Institute, and the profession. In addition, he assumed the role of director of the Aerospace Computational Design Laboratory (ACDL).

Professor Marzouk was awarded the Junior Bose Award for Excellence in Teaching, given each year "to the outstanding contributor to education from among the School of Engineering faculty members who are being proposed for promotion to associate professor without tenure." Also, he is the new Class of 1943 career development chair.

Professor Crawley has been elected a member of the Chinese Academy of Engineering.

Professor de Weck has been named a fellow by the International Council on Systems Engineering.

Professor Miller has been chosen as the new Jerome C. Hunsaker professor of aeronautics and astronautics. Also, he has been named vice chair of the Air Force Scientific Advisory Board effective October 1, 2012.

Professor Hastings has been appointed as the Cecil and Ida Green education professor of engineering systems and aeronautics and astronautics.

Professor Balakrishnan was presented the American Institute of Aeronautics and Astronautics (AIAA) Lawrence Sperry Award "for the development and implementation of advanced air traffic management techniques leading to significant environmental improvements." The award recognizes notable contributions by a young person (age 35 or under) to the advancement of aeronautics or astronautics.

Professor Young received a NASA Johnson Space Center Achievement Award for his contributions to the book *Wings in Orbit: Scientific and Engineering Legacies of the Space Shuttle, 1971–2010*.

Professor Leveson has been appointed to the National Petroleum Council, an advisory board for secretary of energy Steven Chu.

Professors Peraire and Willcox have continued to meet regularly with junior faculty to ensure adequate mentoring and professional growth. The department's weekly faculty meeting continues to provide a forum for faculty to share news on their research and to collaborate on issues important to the department and the school.

The AeroAstro Faculty Awards and Recognition Committee not only remains active but also serves as a model for other departments across the school.

Graduate Education

The department admitted 104 students from a pool of 507 applicants, for an admission rate of 20%; however, our yield decreased to 71% (74 students enrolling of the 104 admitted).

We continued to require formal end-of-semester progress reviews for all graduate students, with students and faculty meeting in an effort to enhance professional development, feedback, and mentoring.

The volume of our research expenditures grew 8% over the past year to $30.2 million.

We held our fourth Women in Aerospace Symposium (with the Department of Earth, Atmospheric, and Planetary Sciences [EAPS]) to foster a network of top women doctoral students in aerospace from around the United States. NASA astronaut Catherine G. "Cady" Coleman was our keynote speaker.

Professors Peraire and Willcox met with graduate students regularly throughout the year to promote feedback and stronger involvement in department business.

Astronaut and MIT alum Cady Coleman was a featured speaker at AeroAstro's 2012 Women in Aerospace Conference.

Undergraduate Education

We undertook an educational pilot study ("Promoting Independent Study in the AeroAstro Junior Year") focusing on the growing interest in creating more flexibility in the AeroAstro curriculum. Two undergraduate courses (16.90 Computational Methods for Aerospace Engineering and 16.20 Structural Mechanics) were identified for an experiment designed to emphasize faculty-student engagement and test the impacts of allowing students to occasionally attend classes from remote locations. The successful development of pedagogical approaches and technology-enabled teaching resources is a positive first step toward creating the necessary flexibility for AeroAstro undergraduate degree students to participate in valuable academic opportunities beyond the campus. We plan to further develop this model with other classes in the coming academic year. The department remains strongly committed to promoting undergraduate research opportunities. We hired 149 students for Undergraduate Research Opportunities Program (UROP) positions in AY2012.

The department's engagement in freshman outreach activities resulted in a healthy increase in our undergraduate enrollment (69 students compared to 42 in 2011). Among our efforts, we created a new program to provide department-funded UROP positions to freshmen. In AY2012, 32 (21%) of the 149 departmental UROP positions were filled by freshmen. During summer 2012, 26 of our 50 UROP students were rising sophomores.

We continue to require reflective memos of all undergraduate instructors as a means of promoting continuous improvement in faculty teaching performance.

Physical Space

We have established a space committee to manage the space in the department. The committee has toured all of the departmental space and assessed needs. Anthony Zolnik has been hired as the space manager.

We have repaired and improved classroom AV systems, as well as upgrading the furniture in the Robert C. Seamans Jr. Laboratory. In addition, we installed information screens in the Seamans Laboratory and in the Building 33 second-floor corridor, a busy campus thoroughfare.

We have initiated renovation studies of Building 17, which includes the Wright Brothers Wind Tunnel, and Building 31.

Communications

The AeroAstro communications office ensures the dissemination of department information, activities, initiatives, events, opportunities, and outreach to a number of constituencies including current faculty, prospective faculty, staff, and students; the MIT community; alumni; young students in both public and private schools; business and industry; and the general public.

A high point of the past communications year was the debut of our new website, the first complete revision in six years. Unlike the old site, which was created as static HTML, the new site is written in PHP and managed via the Drupal 7 content management system and framework. The site contains many new features, including downloadable high-resolution images from a photo gallery, a video gallery, a calendar that automatically sends email notifications to the community when events are posted, page-turning animations of the department's annual magazine, and other interactive features. Drupal modules developed for the site have been made available to all others in the School of Engineering.

Late in 2011, we began extensive use of Facebook and Twitter to interact with the AeroAstro/MIT community and interested individuals, schools, and industry throughout the world. The response has been significant. Indeed, a Cone Communications report commissioned by the School of Engineering rated AeroAstro Facebook user engagement as the highest of the School's eight departments with a Facebook presence, and Twitter mentions and retweets of AeroAstro tweets were the School's most extensive.

In addition to our other extensive communications activities, we continued to work closely with the MIT News Office to ensure extensive coverage, both in-house and by external media, of department research and innovation.

Outreach

AeroAstro's Space Systems Laboratory created the Zero Robotics competition to enable middle and high school students to participate in the science conducted aboard the International Space Station (ISS) using SPHERES (Synchronized Position Hold Engage and Reorient Experimental Satellites) microsatellites. SHPERES is an MIT AeroAstro project that started in 1999 as part of the department's capstone class, where students conceive, design, implement, and use skills they have learned in their time in AeroAstro. Zero Robotics specifically promotes interest in science, technology, engineering, and mathematics (STEM).

The two main annual Zero Robotics activities are the High School Tournament (an open competition that runs from September through December, with a national audience of high school teams competing through several elimination rounds for the opportunity to reach the finals) and the Middle School Summer Program (a five-week summer program designed to immerse middle students into programming and the math behind microgravity physics). The middle school program requires substantial involvement of the SPHERES team to help summer school instructors teach programming. Therefore, this program is centered regionally at MIT and other selected locations that can provide the necessary support.

Inspiration is a key Zero Robotics objective, with young people being provided assistance in building critical engineering skills such as problem solving, design thought processes, teamwork, and operations and presentation skills.

More than 140 high schools and more than 1,500 students from throughout the United States and Europe participated in the latest Zero Robotics high school competition.

Staff Recognition

Marilyn Good was the recipient of the Wings Award, established to recognize an individual support staff member in AeroAstro for excellence.

Man Vehicle Laboratory research scientist Alan Natapoff received the Spirit of XVI Award, given to an individual or team in Aeronautics and Astronautics whose work, commitment, and enthusiasm contribute significantly to the achievement of the department's mission.

The Vickie Kerrebrock Award, given in recognition of students, staff, faculty, or others (either individually or as members of a group) who have made significant contributions to building a sense of community, was presented to Helen Halaris and to the Women's Graduate Association of Aeronautics and Astronautics.

Marie Stuppard received the Ellen J. Mandigo Award. This award recognizes staff members who have "demonstrated intelligence, skill, hard work, and dedication to the Institute."

Jean Sofronas received the School of Engineering's Infinite Mile Award for Excellence, which is presented to people "whose work is of the highest quality [and who] stand out because of their high level of commitment and because of the enormous energy and enthusiasm they bring to their work."

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 UROP. In addition, research activities in other MIT laboratories and centers are open to students registered in aeronautics and astronautics.

Aerospace Computational Design Laboratory

The Aerospace Computational Design Laboratory's mission is the advancement and application of computational engineering for aerospace system design and optimization. ACDL researches 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 3D 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 (ODEs)/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. These 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 applies these methodologies to aircraft design and to the development of tools for assessing aviation environmental impact.

ACDL faculty and staff include David Darmofal (director), Doug Allaire, Mark Drela, Robert Haimes, Youssef Marzouk, Cuong Nguyen, Jaime Peraire, Qiqi Wang, and Karen Willcox.

Aerospace Controls Laboratory

The Aerospace Controls Laboratory (ACL) researches 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; mission planning for unmanned aerial vehicles (UAVs); sensor network design; and robust, adaptive, and nonlinear control. A key aspect 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 and robust coordination algorithms for multiple types of vehicles. A sample of recent research follows.

Robust planning in uncertain environments: ACL developed a distributed task-planning algorithm that provides provably good, conflict-free approximate solutions for heterogeneous multiagent/multitask allocation problems on random network structures. The consensus-based bundle algorithm (CBBA) has since been extended to include task time windows, coupled agent constraints, asynchronous communications, and limited network connectivity. CBBA has been used to plan for both networked UAV/unmanned ground vehicle (UGV) teams and human-robot teams, and real-time performance has been validated through flight test experiments. Recent path planning research has yielded chance-constrained rapidly exploring random trees (RRTs), a robust planning algorithm to efficiently identify trajectories that satisfy all problem constraints with some minimum probability. Finally, in collaboration with Professor Roy's group, ACL developed an efficient approach for modeling dynamic obstacles with uncertain future trajectories through the use of Gaussian processes coupled with an RRT-based reachability evaluation. ACL is involved in a multiyear, multidisciplinary University Research Initiative focused on enabling decentralized planning algorithms under uncertainty. Ongoing ACL research has demonstrated that the use of flexible nonparametric Bayesian models for learning models of uncertain environments can greatly improve planning performance.

UAV mission technologies: ACL has developed a novel hovering vehicle concept capable of agile, acrobatic maneuvers in cluttered indoor spaces. The vehicle is a quadrotor whose rotor tilt angles can be actuated, enabling upside-down hovering flight with appropriate control algorithms. As part of research on long-duration UAV mission planning, ACL has also constructed an autonomous recharge platform capable of autonomous battery replacement for small UAVs.

Information-gathering networks: Recent ACL research has addressed maximizing information gathering in complex dynamic environments through the use of mobile sensing agents. The primary challenge in such planning is its computational complexity, due to both the large size of the information space and the cost of propagating sensing data into the future. ACL has developed methodologies that correctly and efficiently quantify the value of information in large information spaces, such as a weather system, leading to a systematic architecture for mobile sensor network design. The lab's researchers have created cost-efficient distributed fusion algorithms using decentralized metrics. Recently developed algorithms embed information planning within RRTs to quickly identify safe information-gathering trajectories for teams of sensing agents, subject to arbitrary constraints and sensor models.

Multiagent decision making: Markov decision processes are a natural framework for formulating many decision problems of interest; ACL has identified approximate solution techniques that can utilize this framework while overcoming the problems of dimensionality typically encountered for exact solutions. By exploiting flexible, kernel-based cost approximation architectures, ACL's Bellman residual minimization algorithm computes an approximate policy by minimizing the error incurred in solving Bellman's equation over sampled states. For online systems, ACL introduced an incremental feature dependency discovery algorithm that expands the representation in areas where the sampled Bellman error persists. This algorithm has guaranteed rate and asymptotic convergence results and is computationally cheap, making it amenable to systems with restricted thinking time between actions. Finally, ACL has enabled fast, real-time learning in combination with cooperative planning in uncertain and risky environments while maintaining probabilistic safety guarantees for overall system behavior.

Aerospace Robotics and Embedded Systems Laboratory

The mission of the Aerospace Robotics and Embedded Systems Laboratory is the development of theoretical foundations and practical algorithms for real-time control of large-scale vehicle and mobile robot systems. Application examples range from UAVs and autonomous cars to air traffic control and urban mobility. The group researches advanced algorithmic approaches to control high-dimensional, fast, and uncertain dynamical systems subject to stringent safety requirements in a rapidly changing environment. An emphasis is placed on the development of rigorous analysis, synthesis, and verification tools to ensure the correctness of the design. The research approach combines expertise in control theory, robotics, optimization, queuing theory, and stochastic systems, with randomized and distributed algorithms, formal languages, machine learning, and game theory.

Real-time motion planning and control. The group is developing state-of-the art algorithms for real-time control of highly maneuverable aircraft, spacecraft, and ground vehicles. Focus areas include optimality and robustness, as well as provable safety and correctness with respect to temporal-logic specifications (e.g., rules of the road, rules of engagement). Current projects include high-speed flight in cluttered environments and high-speed off-road driving.

Multiagent systems. Large, heterogeneous groups of mobile vehicles such as UAVs and UGVs are increasingly used to address complex missions for many applications, ranging from national security to environmental monitoring. An additional emphasis in this work is scalability: namely, our objective is not only designing distributed algorithms to ensure provably efficient and safe execution of the assigned tasks, but also understanding exactly how the collective performance and implementation complexity scale as the group's size and composition change.

Transportation networks. Traffic congestion and extreme sensitivity to, for example, environmental disruptions are well-known effects of increasing access to transportation. As infrastructure development saturates, new approaches are necessary to increase the safety, efficiency, and environmental sustainability of transportation networks. The group's research in this area concentrates on the exploitation of real-time information availability through wireless communications among vehicles, and with existing infrastructure, to develop such approaches.

The Aerospace Robotics and Embedded Systems Laboratory is directed by Emilio Frazzoli.

Autonomous Systems Laboratory

The Autonomous Systems Laboratory (ALS) is a virtual lab led by Professors Williams and Roy. Williams' group, the Model-based Embedded and Robotics System (MERS) group, and Roy's Robust Robotics Group are part of the Computer Science and Artificial Intelligence Laboratory. ALS's work is focused on developing autonomous aerospace vehicles and robotic systems. ASL-developed systems are commanded at a high level in terms of mission goals. The systems execute these missions robustly by constantly estimating their state relative to the world and by continuously adapting their plan of action based on engineering and world models. Below are several recent demonstrations.

Autonomous vehicles are being used to maximize utility in an uncertainty environment while operating within acceptable levels of risk. Autonomous underwater vehicles enable scientists to explore previously uncharted portions of the ocean by autonomously performing science missions of up to 20 hours in length without the need for human intervention. Performing these extended missions can be a risky endeavor. Researchers have developed robust, chance-constraint planning algorithms that automatically navigate vehicles to achieve user-specified science goals while operating within the risk levels specified by the users.

Another demonstration involves human-robot interaction between a robotic air taxi and a passenger. The task is for the autonomous vehicle to help the passenger rethink goals when they no longer can be met. Companies such as the MIT spinoff Terrafugia offer vehicles that can fly between local airports and can travel on local roads. To operate these innovative vehicles, one must be trained as a certified pilot, thus limiting the population that can benefit from this innovative concept. In collaboration with Boeing, MERS has demonstrated in simulation the concept of an autonomous personal air vehicle, called PT, in which passengers interact with the vehicle in the same manner that they interact with a taxi driver.

A third demonstration involves human-robot interaction between an astronaut and the ATHLETE (All-Terrain Hex-Legged Extra-Terrestrial Explorer) lunar rover. MERS has developed methods for controlling walking machines guided by qualitative "snapshots" of walking gait patterns. These control systems achieve robust walking over difficult terrain by embodying many aspects of a human's ability to restore balance after stumbling, such as adjusting ankle support, moving free limbs, and adjusting foot placement. Members of the MERS group applied generalizations of these control concepts to control the JPL ATHLETE robot, a six-legged/wheeled lunar rover that performs heavy lifting and manipulation tasks by using its legs as arms.

Communications and Networking Research Group

The Communications and Networking Research Group's primary goal is the design of network architectures that are cost effective and 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 upon 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 (LANs).

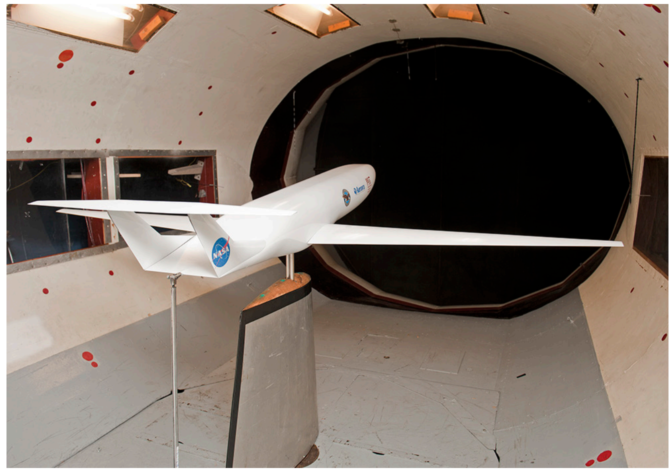
The group is working on a wide range of projects in the area of communication networks and systems with application to satellite, wireless, and optical systems. In recent years, the group has been developing efficient network control algorithms for heterogeneous wireless networks. Existing wireless networks are almost exclusively confined to single hop access, as provided by cellular telephony or wireless LANs. While multi-hop wireless networks can be deployed, current protocols typically result in extremely poor performance for even moderate-sized networks. Wireless mesh networks have emerged as a solution for providing last-mile Internet access. However, hindering their success is our relative lack of understanding of how to effectively control wireless networks, especially in the context of advanced physical layer models, realistic models for channel interference, distributed operations, and interface with the wired infrastructure (e.g., Internet). The group has been developing effective and practical network control algorithms that make efficient use of wireless resources through the joint design of topology adaptation, network layer routing, link layer scheduling, and physical layer power, channel, and rate control.

Robust network design is another exciting area of recent pioneering research by the group. In particular, the group has been developing a new paradigm for the design of highly robust networks that can survive a massive disruption resulting from natural disasters or intentional attacks. The work examines the impact of large-scale failures on network survivability and design, with a focus on interdependencies between different networked infrastructures such as telecommunication networks, social networks, and the power grid. The group's research crosses disciplinary boundaries by combining techniques from network optimization, queueing theory, graph theory, network protocols and algorithms, hardware design, and physical layer communications.

Eytan Modiano directs the Communications and Networking Research Group.

Gas Turbine Laboratory

The MIT Gas Turbine Laboratory (GTL) 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 lab's research is focused on advanced propulsion systems, energy conversion, and power, with activities in the 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 aeroacoustics, and novel aircraft and propulsion system concepts for reduced environmental impact.



The D-8 "double-bubble" aircraft, an AeroAstro design for NASA's "N+3" super-efficient, clean, and quiet commercial airliner, is positioned in the tunnel. Larger models of the aircraft are scheduled for testing in late 2012.

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 project), counterrotating 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 project), high-speed micro gas bearings for microelectromechanical systems turbomachinery, small gas turbines and energy concepts for portable power, and carbon nanotube bearings.

GTL faculty and research staff include Elena de la Rosa Blanco, Fredric Ehrich, Alan Epstein (emeritus), Edward Greitzer, Claudio Lettieri, Jürg Schiffmann, Zoltan Spakovszky (director), Choon Tan, and Alejandra Uranga.

Humans and Automation Laboratory

Research in the Humans and Automation Laboratory (HAL) 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 solve human supervisory control problems and identifying ways in which humans and computers can leverage their strengths 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, human performance modeling with hidden Markov models, collaborative human-computer decision making in time-pressured scenarios (for both individuals and teams), human supervisory control of multiple unmanned vehicles, and design of displays that reduce training time. 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 multi-workstation 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. Current research sponsors include the Office of Naval Research, the US Army, Lincoln Laboratory, Boeing, the Air Force Research Laboratory, the Air Force Office of Scientific Research, Alstom, and the Nuclear Regulatory Commission.

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

International Center for Air Transportation

The International Center for Air Transportation (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 that are now in common use.

ICAT faculty members 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) at MIT is an interdepartmental research center committed to advancing research and education in the analytical information and decision sciences, specifically systems and control, communications and networks, and inference and statistical data processing.

Since 1939, LIDS has been at the forefront of major methodological developments relevant to diverse areas of national and worldwide importance, such as telecommunications, information technology, the automotive industry, energy, defense, and human health. Building on past innovations and bolstered by a collaborative atmosphere, LIDS members continue to make breakthroughs that cut across traditional boundaries.

Members of the LIDS community share a common approach to solving problems and recognize the fundamental role that mathematics, physics, and computation play in their research. Their pursuits are strengthened by the laboratory's affiliations with colleagues across MIT and throughout the world, as well as with leading industrial and government organizations.

LIDS is based at MIT's Stata Center, a dynamic space that promotes a high level of interaction within the lab and with the larger MIT community. Currently 17 faculty members are affiliated with the laboratory, including Emilio Frazzoli, Jonathan How, Eytan Modiano, and Moe Win.

Lean Advancement Initiative

The Lean Advancement Initiative (LAI) is a learning and research consortium focused on enterprise transformation; its members include key stakeholders from industry, government, and academia. LAI is headquartered in AeroAstro, works in 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 US Air Force, MIT, labor unions, and defense aerospace businesses created a partnership to transform the US aerospace industry using an operational philosophy known as "lean." LAI is now in its sixth phase and focuses on 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 international Educational Network, which provides LAI members with unmatched educational outreach and training capabilities, includes more than 60 educational institutions around the world.

AeroAstro LAI participants include Deborah Nightingale (codirector), Earll Murman, and Annalisa Weigel.

Learning Laboratory

The AeroAstro Learning Laboratory, located in Building 33, promotes student learning by providing an environment for hands-on activities that span our conceive-design-implement-operate educational paradigm. The Learning Lab comprises four main areas, as follows.

Robert C. Seamans Jr. Laboratory. The Seamans Laboratory occupies the first floor. It includes the Concept Forum, a multipurpose room (used for meetings, presentations, lectures, videoconferences, distance learning, and informal social functions) where students work together to develop multidisciplinary concepts and learn about program reviews and management, and the Al Shaw Student Lounge, a large, open space for social interaction and operations.

Master's candidate Tony Tao folds the wings of a Locust, a micro UAV developed by AeroAstro students working with Lincoln Laboratory and Aurora Flight Sciences. The vehicle was fabricated using equipment in AeroAstro's Gelb Lab.

Arthur and Linda Gelb Laboratory: Located on the building's lower level, the Gelb Laboratory includes the Gelb Machine Shop, Instrumentation Laboratory, Mechanical Projects Area, Projects Space, and Composite Fabrication-Design Shop. The Gelb Laboratory provides facilities for students to engage in 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 to meet the needs of curricular and extracurricular projects.

Gerhard Neumann Hangar. The Gerhard Neumann Hangar is a high bay space with an arching roof. This space lets students work on large-scale projects that require considerable floor and table space. Typical of these projects are planetary rovers, autonomous vehicles, and reentry impact experiments. The structure also houses low-speed and supersonic wind tunnels.
A balcony-like mezzanine level is used for multi-semester engineering projects, such as the experimental three-term senior capstone course, and is outfitted with a number of flight simulator computer stations.

Digital Design Studio. The Digital Design Studio, located on the second floor, is a large room with 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. The room is equipped with information technologies that facilitate teaching and learning in a team-based environment. Adjacent and networked to the main design studio are two smaller design rooms: the AA Department Design Room and the Arthur W. Vogeley Design Room. These rooms are reserved for the use of individual design teams and for record storage. The department's IT systems administrator is positioned for convenient assistance in an office adjacent to the design center.

Some of the projects undertaken by students in the Learning Lab during the past year include a planetary rover with wheels that self-adjust for different surfaces, construction of an aircraft for the AIAA Design/Build/Fly competition, and development of the Locust miniature UAV.

Man Vehicle Laboratory

The Man Vehicle Laboratory (MVL) addresses human-vehicle and human-robotic system safety and effectiveness by improving understanding of human physiological and cognitive capabilities. MVL develops countermeasures and display designs to aid pilots, astronauts, and others. Research is interdisciplinary and uses techniques from manual and supervisory control, signal processing, estimation, robotics, 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 many parabolic flights and has developed experiments for the International Space Station.

MVL has five faculty and 20 affiliated graduate students. Research sponsors include NASA, the National Space Biomedical Research Institute (NSBRI), 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 for Technological Innovation, and the MIT Portugal Program. Space projects focus on advanced space suit design and the dynamics of astronaut motion, adaptation to rotating artificial gravity, development of mathematical models for human spatial disorientation accident analysis, artificial intelligence, and space telerobotics training. New major projects include a collaborative study with Draper Laboratory on manual and supervisory control of lunar/planetary landings and a study of fatigue effects on space teleoperation performance in collaboration with colleagues at the Brigham and Women's Hospital. Non-aerospace projects include performance and fatigue effects in locomotive engineers and advanced helmet designs for brain protection in sports and against explosive blasts. The laboratory also collaborates with the Volpe Transportation Research Center and the Jenks Vestibular Physiology Laboratory of the Massachusetts Eye and Ear Infirmary.

MVL faculty members include Charles Oman (director), Jeffrey Hoffman, Dava Newman, Julie Shah, and Laurence Young. They teach subjects in human factors engineering, space systems engineering, real-time systems and software, 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 of the NSBRI-sponsored Harvard-MIT Division of Health Sciences and Technology Graduate Program in Bioastronautics (Young), the Massachusetts Space Grant Consortium (Hoffman), the NSBRI Sensory-Motor Adaptation Team (Oman), the MIT-Volpe Program in Transportation Human Factors (Oman), and the MIT Portugal Program's bioengineering systems focus area (Newman).

necstlab

The necstlab (pronounced "next lab") research group explores new concepts in engineered materials and structures. The group's mission is to lead the advancement and application of new knowledge at the forefront of materials and structures understanding, with research contributions in both science and engineering. Applications of interest include enhanced (aerospace) advanced composites and multifunctional attributes of structures such as damage sensors. A significant effort over the past decade has been to use nanoscale materials to enhance the performance of advanced aerospace materials and their structures through the industry-supported NECST Consortium, which seeks to develop the underlying understanding to create enhanced-performance advanced composites using nanotechnology.

The necstlab group has interests that span fundamental materials synthesis questions through to structural applications of both hybrid and traditional materials. This includes long-standing projects in MEMS and now biofunctionalized nanoelectromechanical systems (bioNEMS)/MEMS. While not all encompassing, much of the group's work supports the efforts of the NECST Consortium. Beyond the consortium members, necstlab research is supported by industry, the Air Force Office of Scientific Research, the Army Research Office, NASA, the National Institute of Standards and Technology, the National Science Foundation, the Office of Naval Research, and others.

The lab maintains collaborations around the MIT campus, particularly with faculty in the Departments of Mechanical Engineering, Materials Science and Engineering, and Chemical Engineering, as well as with MIT labs and centers (including the Institute for Soldier Nanotechnologies, Materials Processing Center, Center for Materials Science and Engineering, and Microsystems Technology Laboratories) and Harvard's Center for Nanoscale Systems. Important to the contributions of necstlab are formal and informal collaborations with leading research groups from around the world.

Examples of past and current research projects include:

- BioNEMS materials design and implementation in microfluidics
- buckling mechanics
- carbon nanostructure synthesis from nontraditional catalysts
- continuous growth of aligned carbon nanotubes
- electroactive nanoengineered actuator/sensor architectures focusing on ion transport
- nanoengineered (hybrid) composite architectures for laminate-level mechanical performance improvements
- multifunctional properties including damage sensing and detection
- manufacturing
- polymer nanocomposite mechanics and electrical and thermal transport
- Si MEMS devices including piezoelectric energy harvesters, microfabricated solid oxide fuel cells, stress characterization, and 3D MEMS
- characterization of the physical properties of vertically aligned carbon nanotubes

The necstlab faculty includes Brian L. Wardle (director), John Dugundji (emeritus), and visitors Antonio Miravete and Desiree Plata.

Partnership for AiR Transportation Noise and Emissions Reduction

The Partnership for AiR Transportation Noise and Emissions Reduction (PARTNER) is an MIT-led FAA Center of Excellence sponsored by (in addition to the FAA) NASA, Transport Canada, the US Department of Defense, and the Environmental Protection Agency. PARTNER research addresses environmental challenges facing aviation through analyzing community noise and emission impacts on climate and air quality. PARTNER also studies a range of environmental impact potential mitigation options including aircraft technologies, fuels, operational procedures, and policies. PARTNER combines the talents of 12 universities, five government agencies, and more than 50 advisory board members, the latter spanning a range of interests from local government to industry and community groups.

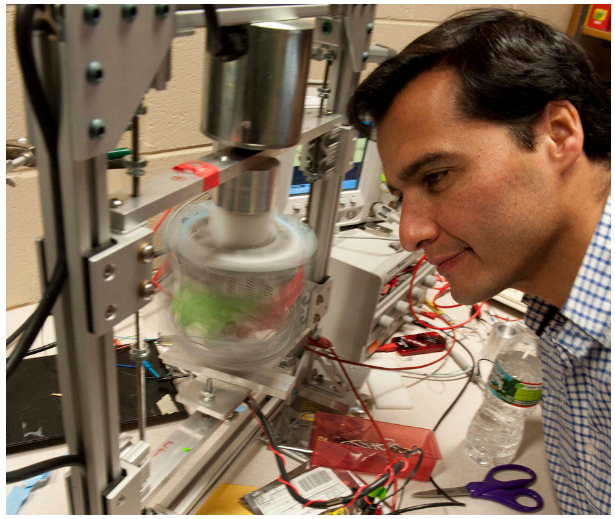
MIT's most prominent research role within PARTNER is in analyzing environmental impacts and developing research tools that provide rigorous guidance to policymakers who must decide among alternatives to address aviation's environmental impact. MIT researchers collaborate with an international team in developing tools at the aircraft level and the aviation system level to assess the costs and benefits of different policies and mitigation options.

Other PARTNER initiatives in which MIT participates include estimating the life cycle impacts of alternative fuels for aircraft, studies of aircraft particulate matter microphysics and chemistry, and economic analysis of policies. PARTNER collaborators' most recent reports include "Environmental Cost-Benefit Analysis of Ultra Low Sulfur Jet Fuel" and "CO_2 Emission Metrics for Commercial Aircraft Certification: A National Airspace System Perspective." In addition, MIT PARTNER researchers have contributed to recently published reports and papers on such topics as traditional and alternative fuel use, aircraft emissions, and emissions trading.

PARTNER MIT personnel include Ian Waitz (director), Seven Barrett (associate director), Hamsa Balakrishnan, John Hansman, Thomas Reynolds, Karen Willcox, William Litant (communications director), Jennifer Leith (program coordinator), and 15 to 20 graduate students and postdocs.

Space Propulsion Laboratory

The Space Propulsion Laboratory (SPL) studies and develops systems for increasing the performance and reducing the costs of space propulsion and related technologies. A major area of interest to the lab is electric propulsion, in which electrical rather than chemical energy propels spacecraft. The benefits are numerous, and thus electric propulsion systems are increasingly being applied to communication satellites and scientific space missions. These efficient engines 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 plasma thrusters and plumes



Professor Paulo Lozano works in the Space Propulsion Lab with a magnetically levitated spinning CubeSat — a vehicle that could be maneuvered by miniature propulsion systems — in a prototype balance that simulates the thrusters' zero-g characteristics.

and their interaction with spacecraft, numerical and experimental models of magnetic cusped thrusters, and space electrodynamic tethers, including their use as antennas for launching electromagnetic waves to remove high-energy particles from earth's Van Allen radiation belts. SPL students also work on ultra-fast (nanosecond) high-voltage discharges to trigger combustion reactions and eventually reduce aircraft engine pollution. SPL has a significant role as well in designing and building micropropulsion electrospray thrusters. In addition to providing efficient propulsion for very small satellites in the 1-kg category (such as CubeSats), such engines will enable distributed propulsion for the control of large space structures including deformable mirrors and apertures. SPL facilities include a supercomputer cluster where plasma and molecular dynamics codes are routinely executed and a state-of-the-art laboratory housing three vacuum chambers, clean room environment benches, an electron microscope, and electronic diagnostic tools to support ongoing research efforts.

Manuel Martinez-Sanchez directs SPL. Paulo Lozano is the associate director.

Space Systems Laboratory

Space Systems Laboratory (SSL) 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 initiatives include systems analysis studies and tool development, precision optical systems for space telescopes, and microgravity experiments operated aboard the International Space Station; in addition, SSL leads the AeroAstro efforts on student-built small satellites. Research encompasses an array of topics associated with 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.

Several SSL initiatives study the development of formation flight technology. The SPHERES facility is used to develop proximity satellite operations such as inspection, cluster aggregation, collision avoidance, and docking. The facility consists of three satellites 20 centimeters in diameter that have flown inside the International Space

Station since May 2006. In 2009 we expanded the uses of SPHERES to include STEM outreach. In the fall of 2009 (as noted above), we began an exciting program called Zero Robotics to engage high school students in a competition aboard the ISS using SPHERES. In December 2010, 10 students from two Idaho schools came to MIT and saw their algorithms compete against each other in a live feed from the ISS. Since then, Zero Robotics has been expanded to include middle school programs as well as a competition in Europe. In 2012, more than 130 high schools nationwide and 20 schools in Europe competed. Also in 2012, the SPHERES facility on the ISS was expanded to include vision-based navigation and magnetic control of satellite formations.

Video game entrepreneur and commercial space use supporter Richard Garriott speaks to 2011 Zero Robotics finalists at MIT. On screen, the live downlink from the ISS will show the SPHERES microsatellites executing the students' competing programs.

SSL performs research in space instrumentation and optics. The Wavefront Control Laboratory (WCL) develops instruments and algorithms that allow us to explore both earth and other worlds from space. WCL demonstrates wavefront control using MEMS deformable mirrors, Shack-Hartmann wavefront sensors, and liquid crystal atmospheric turbulence simulators. Wavefront control systems are needed for applications such as space-based direct imaging of exoplanets (planets around other stars), laser communication systems (to improve bit error rates), and imaging systems (to correct for atmospheric turbulence or aberrations caused by imaging system optics). WCL also uses radio frequency waves to study the atmosphere and ionosphere of earth and other solar system planets with a technique called radio occultation. In addition, WCL has projects with industry to investigate the connection between on-orbit component anomalies and space weather for commercial geostationary communications spacecraft. WCL also supports analyses of radio science gravity field data from exploratory spacecraft such as GRAIL.

SSL is also developing nanosatellites to advance and mature innovative instrumentation and spacecraft bus designs for remote sensing missions. Examples include a dual-spinning 3U CubeSat to host a passive microwave radiometer (the Microsized Microwave Atmospheric Satellite, or MicroMAS, in collaboration with Lincoln Laboratory), a cluster flight of three 3U CubeSats equipped with electrospray microthrusters (in collaboration with SPL and Aurora Flight Sciences), and a 3U CubeSat for transit detection of earth-like planets around the nearest, brightest stars (in collaboration with EAPS and Draper). Also under development are TERSat (Trapped Energetic Radiation Satellite), for precipitation of energetic particles from radiation belts under the Air Force's University Nanosatellite Program (in collaboration with SPL), and the REXIS (REgolith X-ray Imaging Spectrometer) instrument on NASA's OSIRIS-REx asteroid sample return mission launching in 2016.

SSL continues to lead the development of methodologies and tools for space logistics. Jointly with Aurora Flight Sciences, SSL is developing prototypes for automated asset tracking and management systems for ISS based on radio frequency identification technology. 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.

SSL personnel include David W. Miller (director), Kerri Cahoy, Olivier de Weck, Jeffrey Hoffman, Paulo Lozano, Manuel Martinez-Sanchez, Rebecca Masterson, Alvar Saenz-Otero, Paul Bauer (research specialist), Jori Barabino (fiscal officer), and Marilyn E. Good (administrative assistant).

Laboratory for Systems Safety Research

The increasingly complex systems we are building today enable us to accomplish tasks that were previously difficult or impossible. At the same time, they have changed the nature of accidents and increased the potential to harm not only life today but also future generations. Traditional system safety engineering approaches, which started in the missile defense systems of the 1950s, are being challenged by the introduction of new technology and the increasing complexity of the systems we are attempting to build. Software is changing the causes of accidents, and the humans operating these systems have a much more difficult job than simply following predefined procedures. We can no longer effectively separate engineering design from human factors and from the social and organizational structure in which our systems are designed and operated.

The goal of the Laboratory for Systems Safety Research (LSSR) is to create tools and processes that will allow us to engineer a safer world. Engineering safer systems requires multidisciplinary and collaborative research based on sound system engineering principles; that is, it requires a holistic systems approach. LSSR has participants from multiple engineering disciplines and MIT schools as well as collaborators at other universities and in other countries. Students are working on safety in aviation (aircraft and air transportation systems), spacecraft, medical devices and health care, automobiles, railroads, nuclear power, defense systems, energy, and large manufacturing/process facilities. Cross-discipline topics include:

- hazard analysis
- accident causality analysis and accident investigation
- safety-guided design
- human factors and safety
- integrating safety into the system engineering process
- identifying leading indicators of increasing risk
- certification, regulation, and standards

- the role of culture, social, and legal systems on safety
- managing and operating safety-critical systems

LSSR is directed by Nancy Leveson.

Technology Laboratory for Advanced Materials and Structures

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

TELAMS 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. Thus, the research interests and ongoing work in the laboratory represent a diverse and growing set of areas and associations. Areas of interest include:

- composite tubular structural and laminate failures
- MEMS-scale mechanical energy harvesting modeling, design, and testing
- MEMS device modeling and testing, including bioNEMS/MEMS
- structural health monitoring system development and durability assessment
- thermostructural design, manufacture, and testing of composite thin films and associated fundamental mechanical and microstructural characterization
- continued efforts to address 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 composite, active, and other materials. TELAMS testing capabilities include a battery of servohydraulic machines for cyclic and static testing, a unit for catastrophic burst testing of pressure vessels, and an impact testing facility. TELAMS maintains capabilities for environmental conditioning, testing at low and high temperatures, and testing in hostile and other controlled environments. There are facilities for microscopic inspection, nondestructive inspection, high-fidelity characterization of MEMS materials and devices, and a laser vibrometer for dynamic device and structural characterization, as well as the capability for computer microtomography.

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 materials 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. In all of 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. Lagace, John Dugundji (emeritus), and visitor Antonio Miravete.

Wireless Communication and Network Sciences Laboratory

The Wireless Communication and Network Sciences Laboratory is involved in multidisciplinary research that encompasses developing fundamental theories, designing algorithms, and conducting experiments for a broad range of real-world problems. Its 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 on 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 includes derivation of performance bounds for cooperative localization, development of a geometric interpretation for these bounds, and the design of 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 the development of a state-of-the-art apparatus that enables automated channel measurements. The apparatus makes use of a vector network analyzer and two vertically polarized, omni-directional 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 that 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 have also proposed various strategies for improving secure connectivity, such as eavesdropper neutralization and sectorized transmission. Lastly, they have analyzed the capability for secure communication in the presence of colluding eavesdroppers.

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

Moe Win directs the Wireless Communication and Network Sciences Laboratory.

Wright Brothers Wind Tunnel

Since its opening in September 1938, the Wright Brothers Wind Tunnel (WBWT) has played a major role in the development of aerospace, civil engineering, and architectural systems. In recent years, faculty research interests have 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, and the aeroelastic dynamics of airport control tower configurations (for the Federal Aviation Administration). There have also been tests of 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 more than 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, AeroAstro 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.

The department recently introduced the new Course 16-ENG degree to complement our existing aerospace engineering degrees (Course 16-1 and 16-2). The 16-ENG curriculum is designed to offer flexibility within the context of aerospace engineering. This aerospace context is achieved in two ways:

- inclusion of the unified engineering course, our integrative, foundational subject in aerospace disciplines
- use of our existing aerospace laboratory and capstone subject sequences, which emphasize authentic project-based learning within the aerospace context in multi-semester team environments with integral communications education

These are essential elements of our MIT AeroAstro educational program. They also combine well with any number of aerospace-related concentration areas. The technical depth of the concentration areas is ensured in part by a requirement that of the 72 units in the concentration, 42 must be engineering and 12 must be math/science. We are excited about the educational opportunities brought by this new degree. Undergraduate students who pursue 16-ENG will receive a more multidisciplinary or interdisciplinary engineering education, but one that still features the rigor and technical depth of the department's traditional aerospace engineering degrees.

Undergraduate Enrollment

	02–03	03–04	04–05	05–06	06–07	07–08	08–09	09–10	10–11	11–12
Sophomores	64	72	64	65	65	65	74	57	51	45
Juniors	51	59	59	52	60	66	55	65	47	46
Seniors	70	61	65	76	56	66	62	58	68	47
Total	185	192	188	193	181	197	191	180	166	138
% Women	35%	34%	30%	26%	31%	30%	30%	34%	29%	31%
% Underrepresented minorities	30%	30%	27%	25%	26%	24%	32%	40%	28%	38%

Learning Laboratory

The AeroAstro Learning Laboratory is a world-class facility developed to promote student learning by providing an environment for hands-on activities in our CDIO educational paradigm. The Learning Lab comprises the Robert C. Seamans Jr. Laboratory, the Arthur and Linda Gelb Laboratory, the Gerhard Neumann Hangar, and the Digital Design Studio.

The 16.62x Experimental Projects course 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. The motivation for these projects comes from a variety of sources, including faculty research interests, interactions with companies (e.g., Aurora Flight Sciences), and student-generated ideas.

Another major use of the Learning Lab is in our capstone design sequences, both on the aeronautics side (16.82/16.821) and on the space side (16.83/16.832). These multi-semester capstone subjects take students through an entire life cycle of a product from conception to design to implementation and operation.

For 16.82x, the collaboration in real-world design build projects for students initiated last year between Lincoln Laboratory and the department was extended to include a second project. In the collaboration, Lincoln Laboratory and the US Air Force have commissioned and provided funding for the design, construction, and testing of two UAV systems. The first system (AY2010) was designed to fly calibration payloads through sensors in Air Force test ranges. The second system (AY2011) was a small deployable UAV that could be launched from standard countermeasure dispensers on existing aircraft and fly environmental sampling missions. The students were highly motivated by the opportunity to develop a vehicle with a real customer.

The recently completed three-semester space systems engineering capstone sequence (February 2010 to May 2011) used the Gelb Laboratory to build two satellites. The first is a high delta-V (~1–2 km per second) engineering model of a microsatellite called CASTOR (Cathode Anode Satellite Thruster for Orbital Reposition). The motivation is to provide a low-cost orbital transfer vehicle capability for maneuvering throughout the earth-moon system. The second is a three-unit CubeSat called ExoplanetSat for detecting earth-like planets around nearby, sun-like stars. ExoplanetSat uses photometry to detect the dimming of the star's light as the planet transits across its disk, which requires one arc-second pointing stability. ExoplanetSat is scheduled for a launch, sponsored by NASA, in 2013. These projects offered approximately 35 undergraduates and 10 graduates from multiple departments hands-on experience in designing, building, and testing flight hardware.

This year's two-semester space systems engineering capstone sequence (September 2011 to May 2012) involves work on two new missions. The first is the x-ray imaging spectrometer REXIS (being developed in collaboration with Harvard, EAPS, and the MIT Kavli Institute for Astrophysics and Space Research), which will fly on NASA's OSIRIS-REx asteroid sample return mission. REXIS is a student experiment that will help the OSIRIS-REx mission, being developed by the University of Arizona and Lockheed-Martin, select the sampling location. The OSIRIS-REx student experiment selection committee cited MIT's CDIO curriculum as being a core strength of the MIT-Harvard proposal. The second initiative is a 4-km tether antenna called TERSat that emanates 150 Hz EMIC radio waves to precipitate damaging high-energy electrons and protons out of the earth's radiation belts.

Graduate Program

Over the past three years, we have made significant revisions to enhance the excellence of our already top-ranked graduate program. These changes, which occurred throughout the program, involved graduate admissions processes, mentoring practices, and doctoral program requirements.

Degrees

The bachelor of science (SB) degree program 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. Three degrees are available, one that emphasizes the disciplines that relate to the engineering of aerospace vehicles (Course 16-1), a second that defines a specialization in aerospace information technology (Course 16-2), and our new flexible engineering program (Course 16-ENG). All three degrees retain an emphasis on the fundamentals and provide strong integration with the overarching CDIO context.

The master of science (SM) degree program 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.

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.

Graduate Enrollment*

	06–07	07–08	08–09	09–10	10–11	11–12
Total graduate student body	223	226	236	226	226	229
SM**	135	146	148	130	111	121
PhD†	88	80	88	96	115	108
Minority						
SM	9	8	8	9	7	9
PhD	3	5	6	4	6	5
Female						
SM	26	29	32	30	22	21
PhD	19	19	23	17	20	16

*Numbers based on fifth-week enrollment data.

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

†Students who have passed their doctoral qualifying exam.

Undergraduate Student Prizes

A number of students were recognized at the May AeroAstro Annual Senior Awards Dinner.

George Pantazis received the Yvnge Raustein Award, presented to the unified engineering student who has best exemplified the spirit of Yvnge Raustein and who has demonstrated significant achievement in unified engineering.

The Lockheed Martin Prize for Excellence in Systems Engineering Teamwork was given to the REXIS student team of Mark A. Chodas, Ezekiel L. Willett, Nathaniel E. Keegan, Rachel W. Williams, Edward E. Whittemore, David C. Sternberg, Jennifer N. Quintana, Angelica Ceniceros, Vamsi K. Aribindi, Angelica Cardona, Megyery Zsuzsa, Jesus A. Zuniga, and Lisa K. Johnson.

Alejandro F. Arambula and Marissa A. Good received the United Technologies Corporation Prize, which is awarded to an AeroAstro student for outstanding achievement in the design, construction, execution, and reporting of an undergraduate experiment.

Christian A. Valledor and Andrew Wimmer received the Admiral Luis De Florez Prize awarded for "original thinking or ingenuity."

Jedediah M. Storey received the James Means Award for Excellence in Flight Vehicle Engineering.

Mark A. Chodas and Ezekiel L. Willett were the recipients of the James Means Award for Excellence in Space Systems Engineering.

Rachel W. Williams received the Henry Webb Salisbury Award, given in memory of Henry Salisbury and acknowledging a graduating senior who has achieved superior academic performance in the Course 16 undergraduate program.

Steven M. Ojeda was presented with the AeroAstro Undergraduate Teaching Assistantship Award, given to an undergraduate student who has demonstrated conspicuous dedication and skill in helping fulfill an undergraduate subject's educational objectives.

Jaime Peraire
Department Head
H. N. Slater Professor of Aeronautics and Astronautics