Department of Aeronautics and Astronautics

The MIT Department of Aeronautics and Astronautics (AeroAstro) is a vibrant community of uniquely talented faculty, students, alumni, and staff, all committed to excellence. The department eagerly anticipates and embraces the grand challenges of today and tomorrow, as it has throughout its more than 100 years of dedication to aerospace research and education.

AeroAstro is one of America's oldest and most celebrated aerospace engineering departments, with undergraduate and graduate programs consistently ranked among the best by *U.S. News & World Report*. Although the department remains focused on aeronautics and astronautics, the faculty is also engaged in research in a number of overlapping cross-disciplinary areas, with a significant footprint that belies its medium size.

This has been a remarkable year for the department in a host of ways. AeroAstro witnessed an increase in its total undergraduate enrollment to 185, its highest since 2009. With approximately 250 students, the department's graduate program remains among the most highly competitive aerospace programs in the nation.

At the end of AY2015, the department's faculty count stood at 33.5 (some faculty members have dual appointments). In fall 2014, AeroAstro welcomed Warren (Woody) Hoburg as the Boeing Assistant Professor of Aeronautics and Astronautics. Dava Newman, the Apollo Program Professor of Astronautics, was nominated for the post of NASA Deputy Administrator by President Barack Obama in the fall of 2014. The appointment was unanimously approved by the full US Senate late in the academic year and Dr. Newman was sworn in in May 2015.

Throughout 2014 and into 2015, AeroAstro celebrated the centennial of not only the Institute's first undergraduate offering in aeronautics but also the nation's first graduate degree in aeronautical engineering. Centennial events included a seminar series featuring General Janet Wolfenbarger, SM '85, the first female four-star general in the US Air Force (USAF) and then-commander of the USAF Materiel Command; Jean Botti, Airbus chief technology officer; and Mark Lewis, SB '84, SM '85, ScD '88, past president of the American Institute of Aeronautics and Astronautics. The final speaker of the centennial year was Michael Collins (Gemini 10, Apollo 11) who joined the department for a "Conversation on Apollo." Although strictly part of the Engineering Apollo curriculum, General Collins's talk was open to all of the Institute and the auditorium was filled.

The highlight of the department's centennial year was a three-day symposium and celebration (October 22–24). Featuring many of the aerospace community's most respected individuals, the event was an unqualified success. Day one of the symposium featured a history of aviation and space exploration, with a special session dedicated to the Apollo and Apollo–Soyuz test programs. Day two saw presentations on the future of aerospace, followed by a reception and banquet at the John F. Kennedy Library and Museum. The final day of the symposium was dedicated to aerospace education and included student talks, posters, exhibits, laboratory tours, and a special one-on-one with SpaceX chief executive officer and co-founder Elon Musk.

Speakers and panelists at the MIT Aeronautics and Astronautics Department Centennial Celebration, October 22–24, 2014, included:

Norman Augustine, former chief executive officer and president, Lockheed Martin

Buzz Aldrin, colonel USAF (retired), Gemini 12, Apollo 11 missions

Dominic Antonelli, captain US Navy (USN) (retired), space shuttle missions STS-119, STS-132

Patrick Blonigan, graduate student, Aeronautics and Astronautics Department

Karol "Bo" Bobko, colonel USAF (retired), Apollo–Soyuz Test Project support crew, space shuttle missions STS-6, STS 51-D, STS 51-J

Vance Brand, Apollo–Soyuz Test Project, space shuttle missions STS-5, STS 41-B, STS-35

Kerri Cahoy, Assistant Professor of Aeronautics and Astronautics, MIT

Kenneth Cameron, colonel US Marine Corps (USMC) (retired), space shuttle missions STS-37, STS-56, STS-74

Christopher Cassidy, captain USN, space shuttle missions STS-127, International Space Station (ISS) Expedition 35/36

Mark Caylor, president of Enterprise Shared Services, Northrop Grumman Corporation

Franklin Chang-Diaz, space shuttle missions STS 61-C, STS-46, STS-60, STS-75, STS-91, STS-111

Philip Chapman, colonel USAF (retired)

Catherine Coleman, colonel USAF (retired), space shuttle missions STS-73, STS-93, ISS Expedition 26/27

Michael Collins, Major General USAF (retired), Gemini 10, Apollo 11 missions

Edward Crawley, Ford Professor of Engineering, Professor of Aeronautics and Astronautics, MIT

Tom Crouch, senior curator, Aeronautics Department, National Air and Space Museum

Walter Cunningham, colonel USMC Reserve (retired), Apollo 7 mission

Deborah Douglas, curator of science and technology, MIT Museum

James Draper, son of Instrumentation Lab (now Draper Laboratory) founder Charles Stark Draper

Casey Denham, undergraduate student, Aeronautics and Astronautics Department

Mark Drela, professor of Aeronautics and Astronautics, MIT

Charles Duke, brigadier general USAF (retired), Apollo 16

Antonio Elias, chief technical officer, Orbital Sciences

Alan Epstein, vice president of technology and environment, Pratt & Whitney

E. Michael Fincke, colonel USAF (retired), ISS Expedition 9, ISS Expedition 18, space shuttle mission STS-134

Jack Fischer, colonel USAF, astronaut

Kenneth Gabriel, chief executive officer and president, Charles Stark Draper Laboratory

Karl Gantner, graduate student, Department of Aeronautics and Astronautics

Gwendolyn Gettliffe, graduate student, Aeronautics and Astronautics Department

Helen Greiner, chief executive officer, CyPhy Works

John Grunsfeld, shuttle missions STS-67, STS-81, STS-103, STS-109, STS-125

Charlie Guthrie, senior vice president and chief technology officer, Insitu Inc.

R. John Hansman, T. Wilson Professor in Aeronautics, MIT

Koki Ho, graduate student, Aeronautics and Astronautics Department

Jeffrey Hoffman, Aeronautics and Astronautics Department Professor of the Practice, shuttle missions STS 51-D, STS-35, STS-46, STS-61,STS-75

Brad Holschuh, graduate student, Aeronautics and Astronautics Department

Jon How, Richard Cockburn Maclaurin Professor of Aeronautics and Astronautics, MIT

Xun Huan, graduate student, Aeronautics and Astronautics Department

Steve Isakowitz, president, Virgin Galactic

Luke Jensen, graduate student, Aeronautics and Astronautics Department

Jeff Katz, founding chief executive officer and chairman, Orbitz; former Chief executive officer, Swissair

Kent Kresa, chairman emeritus, Northrop Grumman Corporation

John Langford, chairman and chief executive officer, Aurora Flight Sciences

Fuk Li, Director, Mars Exploration Directorate, Jet Propulsion Laboratory, NASA

Connie Liu, undergraduate student, Aeronautics and Astronautics Department

Anne Marinan, graduate student, Aeronautics and Astronautics Department

Michael Massimino, Professor of Mechanical Engineering, Columbia University; shuttle missions STS-109, STS-125

Robert Meyerson, president, Blue Origin, LLC

Robert Millard, chairman, MIT Corporation

David Miller, chief technologist, NASA

David Mindell, Frances and David Dibner Professor of the History of Engineering and Manufacturing and professor of aeronautics and astronautics, MIT

Elon Musk, chief executive officer and co-founder, SpaceX and Tesla Motors, Inc.

Dava Newman, professor of aeronautics and astronautics and engineering systems, director of the Technology and Policy Program, and MacVicar Faculty Fellow, MIT

Robert Niewoehner, captain USAF (retired), David F. Rogers Professor of Aeronautics, US Naval Academy

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

Tesla chief executive Elon Musk responds to a question from Professor Jaime Peraire , AeroAstro department head, during the department's Centennial Symposium session "One-on-One With Elon Musk." (Photo: Dominick Reuter)

Rafael Reif, President, MIT

Robie Samanta Roy, vice president, technology and innovation, Lockheed Martin

Darryl Sargent, vice president for national security and space systems, Charles Stark Draper Laboratory

Sanjay Sarma, director of Digital Learning and professor of mechanical engineering, MIT

Russell Schweickart, Apollo 9 mission

Norman Sears, former assistant director of the Apollo Program, MIT Instrumentation Laboratory

Pat Shanahan, senior vice president and general manager of airplane programs, Boeing Commercial Airplanes

Tony Tao, graduate student, Aeronautics and Astronautics Department

Ian A. Waitz, dean of engineering, Jerome C. Hunsaker Professor of Aeronautics and Astronautics, and MacVicar Faculty Fellow, MIT

Karen Willcox, professor of aeronautics and astronautics, MIT

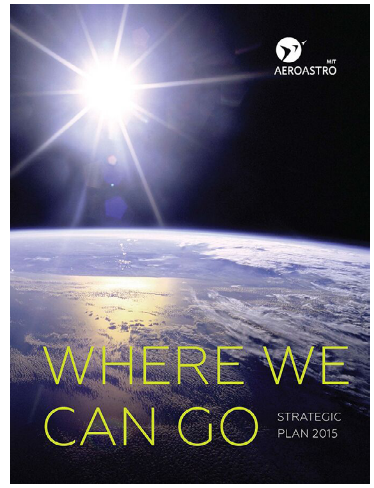
Laurence R. Young, Apollo Program Professor of Astronautics, director of the Health Sciences and Technology PhD Program in Bioastronautics, and professor emeritus, MIT

Maria Zuber, vice president of research and E. A. Griswold Professor of Geophysics, MIT

On April 8, 2015, the department hosted the AeroAstro Open House. Held in conjunction with the Cambridge Science Festival, hundreds of visitors from MIT and the Cambridge community, and from across Massachusetts and the country, partook in a wide range of activities: laboratory tours, flight simulators, vehicle demonstrations, displays, and hands-on activities for children including a parachute-build/egg drop, air-launched rockets, and a paper airplane competition.

In spring 2015, the department published its new strategic plan. Titled "Where We Can Go," the plan is a strategic initiative for the upcoming decade. The strategic planning process was driven by AeroAstro's commitment to:

- Identify strengths, shortcomings, opportunities, and challenges,
- Define core competencies and strategic thrusts,
- Prioritize department resource investment,; and
- Strengthen faculty consensus regarding the department's future directions.



The Aeronautics and Astronautics Department's new strategic plan, "Where We Can Go."

The department eagerly anticipates and embraces the aerospace challenges of the next century. With its remarkable students, alumni, faculty, and staff, AeroAstro is shaping the future of air and space transportation, exploration, communications, autonomous systems, engineering education, and national security.

The plan identifies six core competencies of the Aeronautics and Astronautics Department to strengthen and evolve:

- Vehicle design,
- Information science,
- Computation,
- Human–systems collaboration,
- Atmosphere and space sciences, and
- Complex systems,

and four strategic thrusts that build on and connect our competencies:

- Air transportation,
- Autonomous systems,
- Small satellites, and
- Education.

This plan anticipates evolutions in technology, education, and the aerospace industry. It updates and hones the department's vision, mission, and goals. This is AeroAstro's roadmap for where we can go—and where we will go.

Vision, Mission, and Strategy

The department aspires "[t]o enable novel aerospace and related systems through education, research, and leadership; and to use these systems to inspire future generations of engineers, leaders, and innovators who are critical thinkers possessing both a deep technical understanding and a systems perspective."

The mission of the MIT's Department of Aeronautics and Astronautics is:

- To educate tomorrow's leaders through innovative educational programs and pedagogies, which have as their context the conception, design, implementation, and operation of aerospace systems and processes;
- To conduct research that generates inventions, technologies, and solutions to contemporary aerospace and related engineering problems, in collaboration with colleagues at MIT, other universities, industry, and government in the United States and abroad; and
- To provide leadership to the Institute and to the national and international aerospace and engineering communities.

The department's strategy has the following elements:

1. Building a stronger faculty by hiring for excellence, mentoring, and promoting collaboration,
2. Enhancing excellence in graduate and undergraduate education by reinvigorating AeroAstro's commitment to the development, assessment, and continuous improvement of the department's pedagogy and of its students learning, and
3. Improving the department's physical space by enhancing maintenance procedures and investing in space renovations.

Promoting Faculty Excellence

AeroAstro faculty include Hamsa Balakrishnan, Steven Barrett, Edward Crawley [0.5 full-time equivalent (FTE), with a dual appointment in the Institute for Data, Systems, and Society (IDSS); on leave while president of the Skolkovo Institute of Science and Technology], Kerri Cahoy, David Darmofal, Olivier de Weck (0.5 FTE, dual appointment in IDSS), Mark Drela, Emilio Frazzoli, Edward Greitzer, Steven Hall, R. John Hansman, Wesley Harris, Daniel Hastings (0.5 FTE, with a dual appointment in IDSS, on leave as director of the Singapore–MIT Alliance for Research and Technology Center), Woody Hoburg, Jonathan How, Sertac Karaman, Paul Lagacé, Nancy Leveson (0.5 FTE, dual appointment in IDSS), Paulo Lozano, Youssef Marzouk, David Miller (on leave while NASA's chief technologist), David Mindell (0.5 FTE, dual appointment in the Science, Technology, and Society Program in the School of Humanities, Arts, and Social Sciences), Eytan Modiano, Dava Newman (0.5 FTE, dual appointment in IDSS, on leave as NASA Deputy Administrator), Jaime Peraire, Raul Radovitzky, Nicholas Roy, Julie Shah, Zoltan Spakovszky, Leia Stirling, Ian Waitz (now in a full-time administrative role as dean of the School of Engineering), Qiqi Wang, Brian Wardle, Sheila Widnall (0.5 FTE, dual appointment in IDSS), Karen Willcox, Brian Williams, and Moe Win. The department head is Jaime Peraire and the Associate Department Head is Eytan Modiano. [Faculty members who are listed as having dual appointments in IDSS previously had dual appointments in the Engineering Systems Division (ESD). In light of the dissolution of ESD, and pending faculty members' decisions on future affiliation, they are identified here as having dual appointments in IDSS.]

Department faculty members meet weekly, providing a forum for research presentations, departmental updates, and general discussion. The department also welcomes individuals from other units across campus to make presentations. As the campus and faculty struggle with difficult issues, especially in a year that was plagued by student and faculty suicides, AeroAstro was pleased to welcome special speakers in AY2015. Among these were Edmund Bertschinger, Alvar Saenz-Otero, and Abigail Francis, who made a presentation, "The Role of Faculty in Advancing a Respectful and Caring Community"; David Randall, associate dean of student support services; and Alan Siegel, chief of MIT Medical's mental health and counseling service.

Department leaders regularly hold meetings with junior faculty members. These meetings provide a forum for young faculty to express concerns, share comments, and seek the support of the leadership. In turn, Professors Peraire and Modiano are given the opportunity to assess how well junior faculty are acclimating to the department and the Institute, and to determine if any problems that might otherwise go unnoticed have arisen.

The department was saddened by the loss of several highly esteemed colleagues and friends: Professors Emeritus Eugene Covert, Shaoul "Ziggy" Ezekiel, and Karl "Uno" Inhard all passed away during the past year.

Promotions

- Brian Wardle was promoted to full professor.
- Hamsa Balakrishnan was promoted to associate professor with tenure.
- Julie Shah was promoted to associate professor without tenure.
- Qiqi Wang was promoted to associate professor without tenure.

Recognition

- Professor Dava Newman was appointed NASA deputy administrator, and was named Apollo Program Professor of Astronautics.
- Professor David Miller was elected as a fellow of the American Institute of Aeronautics and Astronautics
- Professors David Mindell, Zoltan Spakovszky, and Raul Radovitzky were elected American Institute of Aeronautics and Astronautics Associate Fellows.
- Dean Ian Waitz received the American Institute of Aeronautics and Astronautics (AIAA) 2015 Losey Atmospheric Sciences Award.
- The American Automatic Control Council selected Professor Hamsa Balakrishnan as recipient of its 2014 Donald P. Eckman Award.

- Professor Julie Shah was selected by *Technology Review* for inclusion on its annual list, "Innovators Under 35."
- Professors Steven Barrett and Sertac Karaman were awarded Singapore Research Professor chairs for 2015.
- Professor Karen Willcox was selected to co-chair the new Online Education Policy Initiative, an offshoot of a recent task force on the Institute's future.
- Professor Jon How was named editor-in-chief of *IEEE Control Systems Magazine*, the largest-circulation technical periodical devoted to control systems.
- Professor Jaime Peraire received the 2015 Ildefons Cerdà Medal, awarded by the Civil Engineering Society in Catalonia, Spain.

Promoting Excellence in Undergraduate Education

The department remains strongly committed to promoting undergraduate research, hiring a number of students through the Undergraduate Research Opportunity Program (UROP). In AY2015, AeroAstro hired 240 students through UROP, of whom 23% were freshmen. During summer 2015, 23 of the department's 48 UROP students (48%) were rising sophomores.

The department is teaming with the Department of Electrical Engineering and Computer Science (EECS) to offer advanced undergraduate research opportunities to its upperclassmen in AY2016. This so-called SuperUROP program has met with great success in EECS, where hundreds of undergraduate students have successfully completed year-long coursework and research working under the direct supervision of a faculty member. Students spend approximately 10 hours per week working in a laboratory on an approved project and attend a weekly lecture featuring speakers from academia and industry. Students are given both course credit and a stipend. The department has received funding from Boeing, Pratt & Whitney, Lincoln Laboratories, the Charles Stark Draper Laboratory, Lockheed Martin, Northrop Grumman, and Airbus to finance the 21 students who will be working with AeroAstro faculty this fall.

As a means for promoting continuous improvement in faculty teaching performance, the department requires reflective memoranda from all instructors who teach undergraduates. Following submission of a reflective memorandum, the associate department head meets with the instructor to review what has happened in the past term and to discuss ways in which she or he may improve performance.

Recognition

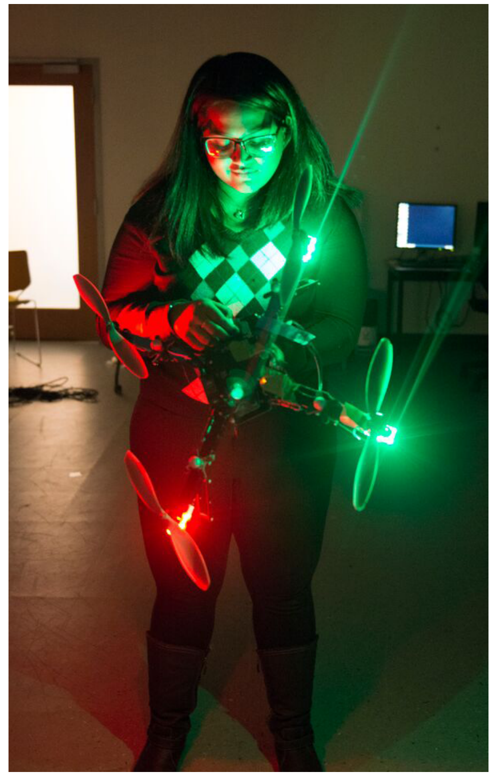
- Apollo Program Prize: Given to an AeroAstro student who conducts the best undergraduate research project on the topic of humans in space: Kathrine N. Bretl '16.
- Andrew J. Morsa Prize: Given for demonstration of ingenuity and initiative in the application of computers to the field of aeronautics and astronautics: Norman Cao '15 and Aaron P. Thomas '15; Mycal D. Tucker '15 and Christopher A. Maynor '15.

- Yvnge Raustein Award: Given to a Unified Engineering student who best exemplifies the spirit of Yvnge Raustein and to recognize significant achievement in Unified Engineering: Guillermo Bautista ’17.
- Admiral Luis De Florez Prize: Awarded for “original thinking or ingenuity”: Alexander W. Feldstein ’15 and Trang T. Dang ’15; Sebastien R. Fischer ’15 and Nicholas H. Roberts ’15; Peter J. Williams ’15 and Hayden K. Cornwell ’15.
- James Means Award for Excellence in Flight Vehicle Engineering: Harris S. Chalat ’15.
- James Means Award for Excellence in Space Systems Engineering: Connie Y. Liu ’15, Nicholas H. Roberts ’15, and Scarlett E. Koller ’16.
- Rene H. Miller Prize in Systems Engineering: Given to a student who has done the best piece of work in systems engineering in the AeroAstro department: Raichelle J. Aniceto ’16.
- Henry Webb Salisbury Award: Given in memory of Henry Salisbury to a graduating senior who has achieved superior academic performance in the Course XVI Undergraduate Program: Connie Y. Liu ’15 and Matthew T. Vernacchia ’15 G.
- AeroAstro Graduate Teaching Assistantship Award: Given to a graduate student who has demonstrated conspicuous dedication and skill in helping fulfill an undergraduate or graduate subject’s educational objectives: David C. Sternberg G.
- AeroAstro Undergraduate Teaching Assistantship Award: Given to an undergraduate student who has demonstrated conspicuous dedication and skill in helping to fulfill an undergraduate subject’s educational objectives: Alexander W. Feldstein ’15.
- AIAA Teaching Assistantship Award: Given by the AIAA Student Chapter to a teaching assistant in a Course 16 subject for outstanding commitment to pedagogy, inspiration, and superior contributions: Christopher Gilmore G.
- AIAA Undergraduate Advising Award: Given by the AIAA Student Chapter to a faculty or staff member who has demonstrated excellence in serving as an academic or subject 16.621/16.622 advisor and has made a real positive impact on a student’s time in the AeroAstro Department: Professor Leia Stirling.
- 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 Warren Hoburg.

Promoting Excellence in Graduate Education

AeroAstro received 566 applications this year for admission to its graduate programs. The department admitted 79 applicants (an admission rate of 14%). Of the 79 admitted, 60 students enrolled, for a yield of 76%. Women were 20% of the entering class; 10% met the criteria for members of underrepresented minority groups.

Continuing the department's tradition of formal end-of-semester progress reviews, department faculty provide written evaluations each semester and hold regular review meetings with all graduate students in an effort to enhance professional development, feedback, and mentoring. Professors Peraire and Modiano meet regularly with the graduate student body, engaging in a dialogue designed to promote feedback and develop a stronger sense of involvement in department business.



AeroAstro graduate student Abhizna Butchibabu prepares an unmanned aerial vehicle for her research in the Interactive Robotics Laboratory. (Photo: William Litant/ MIT)

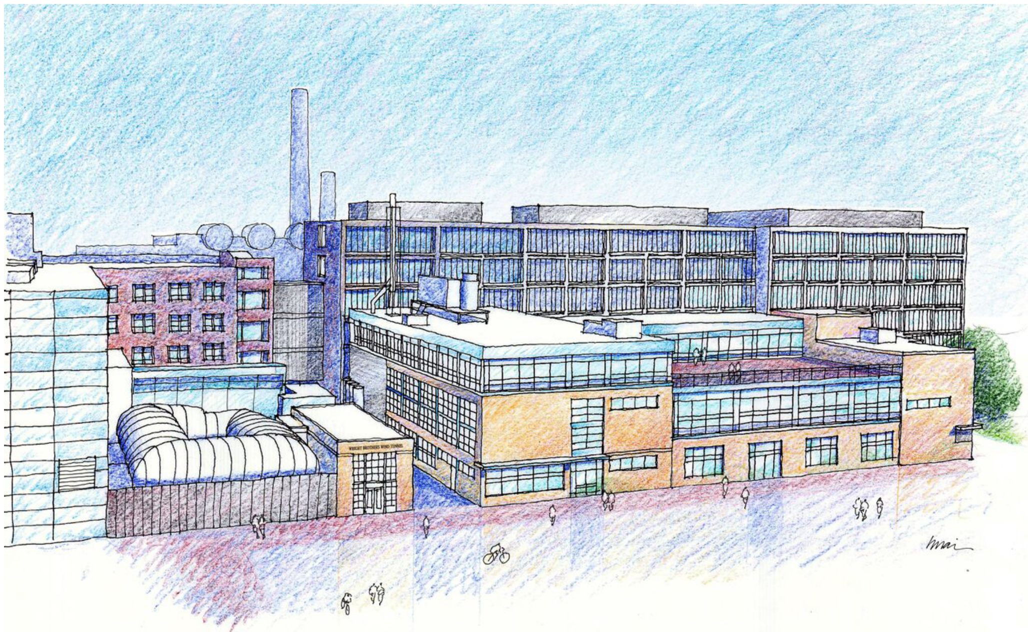
From September 2014 through June 2015, the department graduated 29 students with PhDs and 49 students with SMs.

Recognition

- Irene Constantina Dedoussi and Marzieh Paranddehgheibi were selected as 2015 Graduate Women of Excellence by the MIT Office of the Dean for Graduate Education.
- Crop analytics drone company Raptor Maps took the $100,000 grand prize at the 25th annual MIT $100K Entrepreneurship Competition. The team of three MIT aerospace engineering graduate students (Nikhil Vadhavkar, Forrest Meyen, and Eddie Obropta) developed an analytics platform that employs unmanned aircraft to pinpoint crop damage, target pesticide use, and increase yields.
- Sydney Do was a 2014–2015 recipient of the Josephine de Kármán Fellowship.
- Giuseppe Cataldo was the recipient of the 2014 AIAA Orville and Wilbur Wright Graduate Award for demonstrated excellence in research and its impact in the space sciences.
- Sreeja Nag and Tam Nguyen received first prize and an honorable mention, respectively, at the 2014 Small Satellite Conference Frank J. Redd Student Paper Competition.

Improving AeroAstro Physical Space

The long-awaited renovation of Building 31 is finally under way. Partnering with the department to underwrite the renovation are the Institute, the School of Engineering, the Department of Mechanical Engineering, and generous benefactors. The building will house state-of-the-art research and educational facilities and is expected to reopen in fall 2017.



The three-year, $52 million renovation of MIT Building 31 will include a high-bay space between the two wings where AeroAstro researchers can test-fly unmanned aerial vehicles. (Rendering: Imai Keller Moore)

As reported by the 2011 Corporation Visiting Committee, "It has become crystal clear that upgrading of research space has risen to the top of the list of priorities … the quality of space is simply deplorable. The equipment supporting the Gas Turbine Laboratory and Wright Brothers Wind Tunnel is ancient … urgently needs to be upgraded."

Although the renovation of Building 31 will serve to improve the conditions of the Gas Turbine Laboratory, issues with the 77-year-old Wright Brothers Wind Tunnel (WBWT) (Building 17) persist. Used by every student who matriculates in the department, the iconic WBWT is often down for repairs, interfering with not only research but also education. Although AeroAstro has completed a study of Building 17 and has plans to take this on as the department's next large capital project, securing funding will require that the department redouble its development efforts.

Space renovations have recently taken place in Buildings 37 and 35, resulting in new laboratories for several faculty as well as additional graduate student clusters. Until fall 2017, quantity and quality of space will remain a constant challenge for the department. In the meantime, AeroAstro continues to make improvements in the care and maintenance of existing space. Fundraising to support space and facilities renovation remains a top priority.

Resource Development

Development activity in 2014–2015 focused on enabling the renewal of Building 31 and bolstering the department's outreach programs. With the help of many partners in MIT's Office of Resource Development, AeroAstro was able to secure six major commitments, ranging from $500,000 to $5 million, to ensure that the Building 31 project could move forward. Many members of the AeroAstro Visiting Committee were among these donors and also helped with developing other sources of funding for the building. Central to this fundraising success was the Centennial Symposium, which brought many of the department's closest friends back to campus for personal conversations.

Northrop Grumman also contributed $1 million to support the Zero Robotics middle-school program and competition over the next five years. These funds allowed the program to hire a part-time program manager and to work on doubling the number of students who participate in the program.

Multiple development meetings took place in Seattle, Washington; Los Angeles and San Francisco, California; Washington, DC, and on the MIT campus, often including department head Jaime Peraire and other faculty.

Outreach

In January 2015, several faculty and staff members accompanied 40 sophomore students on an educational trip to the West Coast for visits to Boeing (Renton and Everett facilities), Blue Origin, Jet Propulsion Laboratory, SpaceX, and Northrop Grumman Aerospace. Students were afforded the opportunity to meet with alumni, to talk to the people who are doing the jobs they dream of, to ask questions, and to whet their appetites for aerospace. It is the department's plan to make the trip a tradition.

The department has partnered with Lincoln Laboratories to improve opportunities for its undergraduates—that is, Lincoln Laboratories' Beaver Works and AeroAstro will be working together to develop capstone projects for the department's upperclassmen. Lincoln Laboratories and AeroAstro will share space in the renovated Building 31, an area dedicated to undergraduates working on capstone projects. By partnering with one another, AeroAstro and Lincoln will forge a stronger relationship, one that will extend beyond this single venture.

AeroAstro has produced three online subjects for MITx: 16.101x Introduction to Aerodynamics, 16.110x, Flight Vehicle Aerodynamics, and 16.00x Introduction to Aerospace Engineering: Astronautics and Human Spaceflight. All three have been well received. The most recent addition, 16.00x Introduction to Aerospace Engineering: Astronautics and Human Spaceflight, with Professor Jeff Hoffman (who has flown on the space shuttle and ISS), met with rave reviews from the online community and was featured on the MIT website home page. The department remains enthused about additional online course offerings; several faculty members have submitted proposals to the dean of Digital Learning.

School Awards

- Administrative assistant Joyce Light was awarded the Infinite Mile Award, given to individuals whose work is of the highest quality and who stand out because of their high level of commitment and the enormous energy and enthusiasm they bring to their work.

Departmental Awards

- Administrative assistants Jean Sofronas and Joyce Light were presented with the Wings Award, recognizing support staff members in AeroAstro for excellence.
- Gas Turbine Laboratory manager James Letendre received the Spirit of XVI Award, a recognition given to an individual or team in AeroAstro whose work, commitment, and enthusiasm contribute significantly to the achievement of the mission of the department.
- 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 Ceili Burdhimo, an undergraduate in the department.

Research

The department's total research expenditures (adjusted for dual appointments) for 2014 were $31.167 million.

AeroAstro faculty and students are engaged in hundreds of research projects under the auspices of the 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 the Department of Aeronautics and Astronautics.

Research Labs and Centers

Aerospace Computational Design Laboratory

The mission of the Aerospace Computational Design Laboratory (ACDL) is the advancement and application of computational engineering for the design, optimization, and control of aerospace and other complex systems. ACDL research addresses a comprehensive range of topics, including advanced computational fluid dynamics and mechanics, uncertainty quantification, data assimilation and statistical inference, surrogate and reduced modeling, and simulation-based design techniques.

Advanced simulation methods developed by ACDL researchers facilitate the understanding and prediction of physical phenomena in aerospace systems and other applications. A long-standing interest of the laboratory has been the advancement of computational fluid dynamics for complex three-dimensional flows, enabling significant reductions in time from geometry to solution. Specific research interests include aerodynamics, aeroacoustics, flow control, fluid structure interactions, hypersonic flows, high-order methods, multi-level solution techniques, large eddy simulation, and scientific visualization. Research interests also extend to chemical kinetics, transport-chemistry interactions, and other reacting flow phenomena important for energy conversion and propulsion.

ACDL's efforts in uncertainty quantification aim to endow computational predictions with quantitative measures of confidence and reliability while addressing broad underlying challenges of model validation. Complementary efforts in statistical inference and data assimilation are aimed at estimating and improving physical models and predictions by conditioning on observational data. Current research has developed effective methods for error estimation, solution adaptivity, sensitivity analysis, uncertainty propagation, and the solution of stochastic differential equations, the solution of large-scale statistical inverse problems, nonlinear filtering in partial differential equations, and optimal experimental design. Applications range from aerospace vehicle design to large-scale geophysical problems and subsurface modeling.

ACDL research in simulation-based design and control is aimed at developing methods to support better decision-making in aerospace and other complex systems, with application to conceptual, preliminary, and detailed design. Recent efforts yielded effective approaches to partial differential equation (PDE)–constrained optimization, real-time simulation and optimization of systems governed by PDEs, multiscale and multi-fidelity 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 impacts.

ACDL faculty members are Professors Youssef Marzouk (director), David Darmofal, Mark Drela, Jaime Peraire, Qiqi Wang, and Karen Willcox. Research staff members include Steven Allmaras, Robert Haimes, and Cuong Nguyen.

Aerospace Controls Laboratory

The Aerospace Controls Laboratory researches autonomous systems and control design for aircraft, spacecraft, and ground vehicles. Theoretical research is pursued in such areas as decision making under uncertainty, path planning, activity, and task assignment, mission planning for unmanned aerial vehicles, sensor network design, and robust, adaptive, and nonlinear control. A key aspect of ACL is the Real-time Indoor Autonomous Vehicle test ENvironment (RAVEN), 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 vehicles. Aground projection system enables real-time animation of the planning environment, beliefs, uncertainties, intentions of the vehicles, predicted behaviors (e.g., trajectories), and confidence intervals of the learning algorithms. Recent research includes the following:

Robust Planning in Uncertain Environments: ACL developed a consensus-based bundle algorithm (CBBA) as a distributed task-planning algorithm that provides provably good, conflict-free, approximate solutions for heterogeneous multi-agent missions. Aside from extensions to task time-windows, coupled agent constraints, asynchronous communications, and limited networks, CBBA has been validated in real-time flight test experiments. ACL has also extended its development of chance-constrained rapidly exploring random trees (CC-RRT), a robust planning algorithm to identify probabilistically feasible trajectories, to new aerospace domains. For instance, ACL recently developed CC-RRT to solve robust pursuit-evasion problems. ACL is also involved in a multi-year Draper Laboratory University Research and Development Program project on precision landing of guided parafoils, with robustness to large and dynamic wind environments. Finally, ACL is participating in a multi-year, multi-university research initiative that is 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 environment can greatly improve planning performance.

Umanned Aerial Vehicle (UAV) Mission Technologies: ACL has recently demonstrated autonomous, closed-loop UAV flight in MIT's WBWT. This novel capability allows the ACL to test flight controllers designed for windy environments in a controlled and systematic manner. ACL has also developed a novel hovering vehicle that is 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. Additionally, as part of research on long-duration UAV mission planning, ACL has constructed an autonomous recharge platform that is capable of autonomous battery replacement and recharging for small UAVs. This capability allows ACL to demonstrate complex, multi-agent missions that last for several hours.

Information-Gathering Networks: Recent ACL research has addressed maximizing information gathering in complex dynamic environments through quantifying the value of information and the use of mobile sensing agents. The primary challenge in such planning is the computational complexity caused by both the large size of the information space and the cost of propagating sensing data into the future. ACL researchers created adaptive efficient distributed sensing in which each sensor propagates only high-value information, reducing the network load and improving scalability. Recently developed algorithms embed information planning within RRTs to identify safe information-gathering trajectories for teams of sensing agents quickly, subject to arbitrary constraints and sensor models.

Task Identification and Decision-Making: Markov decision processes (MDPs) and partially observable MDPs (POMDPs) are natural frameworks for formulating many decision-making problems of interest. ACL has identified approximate solution techniques that can utilize this framework while lessening the curse of dimensionality and the curse of history typically encountered for exact solutions. ACL has also developed a Bayesian nonparametric inverse reinforcement learning algorithm for identifying tasks from traces of user behavior. This technique allows a user to "teach" a task to a learning agent through natural demonstrations. ACL has also enabled fast, real-time learning in combination with cooperative planning in uncertain and risky environments while maintaining probabilistic safety guarantees for the overall system behavior. Finally, by efficiently using potentially inaccurate models of physical systems, ACL has developed a method that minimizes samples needed in real-world learning domains, such as a car learning to race around a track.

Robust State Estimation: Many navigation and robotic mapping systems are subject to sensor failures and sensor noise that do not match the assumed system models. In many cases, this model mismatch can cause divergence of the state estimates and poor navigation system performance. ACL has developed several robust state estimation algorithms that address these issues by learning a model for the sensor noise while simultaneously generating the navigation solution. These algorithms apply hierarchical and nonparametric Bayesian models along with inference techniques such as expectation-maximization and variational inference to learn the noise models. In practice, the robust algorithms provide significantly more accurate solutions while requiring little additional computation relative to non-robust state estimation techniques. ACL has also applied this Bayesian framework to the simultaneous localization and mapping (SLAM) problem to develop algorithms for vision-based SLAM solutions that are robust to landmark misidentifications that cause non-robust SLAM algorithms to fail catastrophically.

ACL faculty are Professors Jonathan How and Steven Hall.

Aerospace Robotics and Embedded Systems Group

The Aerospace Robotics and Embedded Systems group's mission is the development of theoretical foundations and practical algorithms for real-time control of large-scale systems of vehicles and mobile robots. 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. Current research areas include the following:

Autonomy and Future Urban Mobility: Autonomous, self-driving cars are no longer science fiction, but will be ready for commercial deployment soon. The group's work on self-driving vehicles is very broad, spanning the whole spectrum from technology development to the analysis of the socioeconomic impacts of such technology. Recent work includes:

- Affordable autonomy: can safe and reliable self-driving vehicles be designed at a cost that make them affordable for the general public? The group's demonstration vehicles at the Singapore–MIT Alliance for Research and Technology were developed with less than $30,000 worth of computers and sensors.
- Provable safety: how can it be ensured that the vehicle will behave safely and will respect all the rules of the road? The group has developed algorithms that can be proved to satisfy all "hard" rules while minimizing violations of "soft" rules or recommendations.
- Autonomy for mobility on demand: How would self-driving vehicles affect urban mobility in the future? The group envisions fleets of shared self-driving vehicles, develops algorithms for their sizing and operations, and analyzes their effects using real data from several cities worldwide.

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. Areas of focus 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.

Multi-agent systems: Large, heterogeneous groups of mobile vehicles, such as UAVs and unmanned ground vehicles, 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; the objective is not only the design of distributed algorithms to ensure provably efficient and safe execution of the assigned tasks, but also to understand 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, is a well-known effect 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 achieve this goal.

Emilio Frazzoli directs the Aerospace Robotics and Embedded Systems group.

The Autonomous Systems Laboratory

The Autonomous Systems Laboratory (ALS) is a virtual laboratory led by Professors Brian Williams and Nicholas Roy. Professor Williams's group, the Model-based Embedded and Robotics (MERS) group, and Professor Roy's Robust Robotics Group are part of the Computer Science and Artificial Intelligence Laboratory. ALS work is focused on developing autonomous aerospace vehicles and robotic systems. ALS-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 plans of action on the basis of engineering and world models.

Below are several recent demonstrations.

- *Operating autonomous vehicles 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 long 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 risk levels specified by the users. (A video is available at http://www.csail.mit.edu/videoarchive/research/robo/auv-planning.)

- *Human-robot interaction between a robotic air taxi and a passenger*. The task for the autonomous vehicle is to help the passenger rethink goals when the original ones 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 in which passenger interacts with the vehicle in the same manner that they interact today with a taxi driver. (A video is available at http://www.csail.mit.edu/videoarchive/research/robo/personal-aerial-transportation.)

- *Human-robot interaction between an astronaut and the Athlete 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. (A video is available at http://www.csail.mit.edu/videoarchive/research/robo/athlete-mers.)

Communications and Networking Research Group

The Communications and Networking Research Group's primary goal 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 that lack 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 communication networks and systems, with application to satellite, wireless, and optical systems. 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 local area networks. Although multi-hop wireless networks can be deployed, current protocols typically result in extremely poor performance for networks of even moderate size. Wireless mesh networks have emerged as a solution for providing last-mile internet access. However, hindering their success is a relative lack of understanding of how to control wireless networks, especially in the context of advanced physical layer models, realistic models for channel interference, distributed operations, and interfaces with the wired infrastructure (e.g., the internet). The Communications and Networking Research 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 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 that may result from natural disasters or intentional attack. 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 Gas Turbine Laboratory's mission is to advance the state of the art in fluid machinery for power and propulsion. The 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 aero-acoustics, novel aircraft and propulsion system concepts for reduced environmental impact.

Current research projects include:

- A unified approach for vaned diffuser design in advanced centrifugal compressors
- Investigation of real gas effects in supercritical CO_2 compression systems
- Modeling instabilities in high-pressure pumping systems
- Aeromechanic response in a high-performance centrifugal compressor stage ported shroud operation in turbochargers
- Manifestation of forced response in a high-performance centrifugal compressor stage for aerospace applications
- Multiparameter control for centrifugal compressor performance optimization
- Performance improvement of a turbocharger twin scroll type turbine stage
- A two-engine integrated propulsion system
- Propulsor design for exploitation of boundary layer ingestion
- Aerodynamics and heat transfer in gas turbine tip shroud cavity flows
- Secondary air interactions with main flow in axial turbines
- Compressor aerodynamics in large industrial gas turbines for power generation

- Flow and heat transfer in modern turbine rim seal cavities
- Modeling cavitation instabilities in rocket engine turbopumps
- Diagnostics and prognostics for gas turbine engine system stability characterization
- Investigation of the origins of short-wavelength instability inception in axial compressors
- Assessment of thermal effects on compressor transients
- Investigation of surface waviness effects on compressor performance

The Gas Turbine Laboratory's faculty and research staff include David Darmofal, Fredric Ehrich, Alan Epstein (emeritus), Edward Greitzer, Claudio Lettieri, Zoltan Spakovszky (director), Choon Tan, Neil Titchener, and Alejandra Uranga.

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 that underlie 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.

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

Laboratory for Aviation and the Environment

The Laboratory for Aviation and the Environment (LAE) was founded in the 1990s as the Aero-Environmental Research Laboratory by Ian A. Waitz, now dean of the School of Engineering.

One of the aviation industry's defining challenges is addressing aviation's environmental impact in terms of noise, air quality, and climate change. LAE's goal is to align the trajectory of aerospace technology and policy development with the need to mitigate these impacts. It does so by increasing the understanding the environmental effects of aviation, by developing and assessing fuel-based, operational, and technological mitigation approaches, and by disseminating knowledge and tools. LAE also contributes to cognate areas of inquiry in aerospace, energy, and the environment.

LAE researchers are analyzing environmental impacts and developing research tools that provide rigorous guidance to policymakers who must decide among alternatives when addressing aviation's environmental impact. The MIT researchers collaborate with international teams in developing aircraft-level and aviation-system-level tools to assess the costs and benefits of different policies and mitigation options.

A current LAE focus is on studying the environmental sustainability of alternative aviation fuels from biomass or natural gas. This research includes both drop-in fuel options, which can be used with existing aircraft engines and fuel infrastructure, and non-drop-in options such as liquefied natural gas, which would require modifications to aircraft and to infrastructure. Environmental metrics considered include lifecycle greenhouse gas emissions, land requirements, and water consumption. LAE researchers are also estimating trade-offs among different metrics and usages to understand better the full consequences of introducing a certain alternative fuel into the aviation system.

LAE has developed and publicly released a code that allows for modeling and evaluation of emissions and their effects throughout the troposphere and stratosphere in a unified fashion. LAE has also recently released a new global emissions dataset for civil aviation emissions that is the most current estimate of emissions that is publicly available. It is widely used by researchers worldwide, in areas including atmospheric modeling and aviation and the environment.

Other recent work quantifies air pollution and associated health effects attributable to the different economic sectors in the United States, and the environmental and economic impacts of higher octane gasoline usage for road transportation.

The LAE faculty includes Steven Barrett, director, Robert Malina, associate director, Hamsa Balakrishnan, John Hansman, Ian Waitz, and Karen Willcox. Also associated with LAE are Ray Speth, research scientist, and Brian Yutko, postdoctoral associate.

Laboratory for Information and Decision Systems

The Laboratory for Information and Decision Systems (LIDS) is an interdepartmental research center committed to advancing research and education in the analytical information and decision sciences: systems and control, communications and networks, and inference and statistical data processing.

Dating to 1939, LIDS has been at the forefront of major methodological developments that are 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 innovation 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 in MIT's Stata Center, a dynamic space that promotes a high level of interaction within the laboratory and with the larger MIT community. AeroAstro faculty affiliated with LIDS are Emilio Frazzoli, Jonathan How, Eytan Modiano, and Moe Win.

The Learning Laboratory

The AeroAstro Learning Laboratory, located in Building 33, promotes student learning by providing an environment for hands-on activities that span the department's conceive-design-implement-operate educational paradigm. The Learning Laboratory comprises four main areas:

Robert C. Seamans Jr. Laboratory. The Seamans Laboratory occupies the first floor. It includes:

- The Concept Forum: a multipurpose room for meetings, presentations, lectures, videoconferences and collaboration, distance learning, and informal social functions. In the Concept Forum, students work together to develop multidisciplinary concepts and learn about program reviews and management.
- The Al Shaw Student Lounge: a large, open space for social interaction and operations.

Arthur and Linda Gelb Laboratory. Located in the building's lower level, the 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 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 take considerable floor and table space, such as planetary rovers, autonomous vehicles, and re-entry 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.

Digital Design Studio. The Digital Design Studio, located on the second floor, is a large room with a number of 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's office is located adjacent to the Design Center for convenient assistance.

Man Vehicle Laboratory

The Man Vehicle Laboratory (MVL) improves the understanding of human physiological and cognitive capabilities as applied to human-vehicle and human-robotic system safety and efficacy, as well as decision-making augmented by technological aids. MVL develops countermeasures and display designs to aid pilots, astronauts, clinicians, patients, soldiers, 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 the space shuttle, on the Mir Space Station, and on many parabolic flights, and has developed experiments for the ISS.

Space applications include advanced space suit design and dynamics of astronaut motion, adaptation to rotating artificial gravity, mathematical models for human spatial disorientation, accident analysis, artificial intelligence, and space telerobotics training. Ongoing work includes the development of countermeasures using a short-radius centrifuge and development of a *g*-loading suit to maintain muscle and bone strength. New major projects include a collaborative study of adaptation in roll–tilt perception and manual control to altered-gravity environments using a centrifuge at the Massachusetts Eye and Ear Infirmary, and a study with University of California, Davis, on customized

Aerospace Controls Laboratory undergraduate student Wally Wibowo (left) and graduate student Justin Miller in front of AeroAstro's Newman Hangar with vehicles that the laboratory has outfitted with sensors of the type used in self-driving cars. This project, part of the Ford-MIT Alliance, aims to predict pedestrian behaviors on short time scales while providing data to support a mobility-on-demand system for the MIT campus. (Photo: William Litant/MIT) and just-in-time space telerobotics refresher training. Non-aerospace projects include General Electric locomotive cab automation and displays, advanced helmet designs for brain protection in sports and against explosive blasts, the development of wearable sensor systems and data visualizations for augmenting clinical decision making, and data fusion for improving situation awareness for dismounted soldiers.

Research sponsors include NASA, the National Space Biomedical Research Institute, the National Science Foundation, the Office of Naval Research, the Federal Aviation Administration, the Federal Railroad Administration, the Charles Stark Draper Laboratory, the Center for Integration of Medicine and Innovative Technology, the Deshpande Center, and the MIT Portugal Program. The laboratory also collaborates with the Volpe Transportation Research Center, Massachusetts General Hospital, and the Jenks Vestibular Physiology Laboratory of the Massachusetts Eye and Ear Infirmary.

The MVL faculty includes Professor Jeffrey Hoffman, director, Professor Emeritus Laurence Young, Dr. Chuck Oman, Professor Julie Shah, and Professor Leia Stirling. 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, statistical methods in experimental design, and leadership. The MVL also serves as the office of the director for the Harvard–MIT Division of Health Sciences and Technology Graduate Program in Bioastronautics, which is sponsored by the National Space Biomedical Research Institute (Young) and the Massachusetts Space Grant Consortium (Hoffman).

necstlab

The necstlab (pronounced "next lab") research group explores new concepts in engineered materials and structures, with a focus on nanostructured materials. 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, multifunctional attributes of structures such as damage sensing, and microfabricated (MEMS) topics. The necstlab group has interests that run from fundamental materials synthesis questions through to structural applications of both hybrid and traditional materials. Much of the group's work supports the efforts of the Nano-Engineered Composite Aerospace Structures (NECST) Consortium, an aerospace industry-supported research initiative that seeks to develop the underlying understanding needed to create enhanced-performance advanced composites using nanotechnology. Beyond the NECST Consortium members, necstlab research is supported directly or through collaboration 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 necstlab group maintains collaborations around the MIT campus, particularly with faculty in the Mechanical Engineering, Materials Science and Engineering, and Chemical Engineering departments, and with MIT laboratories and centers, including the Institute for Soldier Nanotechnologies, the Materials Processing Center, the Center for Materials Science and Engineering, and the Microsystems Technology Laboratory, as well as

Harvard's Center for Nanoscale Systems. Collaborations with leading research groups from around the world are important to the contributions of the necstlab.

Examples of past and current research projects include:

- Biofunctionalized nanoelectromechanical systems (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 improvement
- Multifunctional nanoengineered bulk materials, including damage sensing and detection
- Nanomanufacturing
- Polymer nanocomposite mechanics and electrical and thermal transport
- Silicon MEMS devices including piezoelectric energy harvesters, microfabricated solid oxide fuel cells, stress characterization, and three-dimensional MEMS
- Vertically aligned carbon nanotube characterization and physical properties

In the fall of 2014, the group moved into new laboratory space in Building 35. The necstlab group's faculty includes Brian L. Wardle, director, John Dugundji, professor emeritus, and visitor Antonio Miravete.

Space Propulsion Laboratory

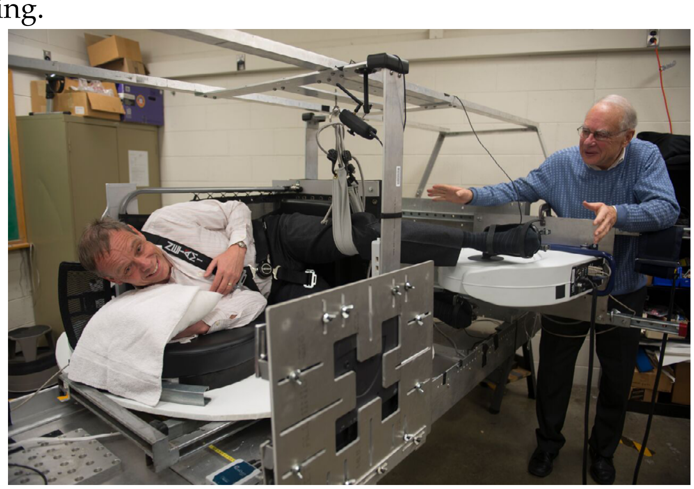
The Space Propulsion Laboratory (SPL) studies and develops systems for increasing the performance and reducing the costs of space propulsion and related technologies. A major area of interest to the lab is electric propulsion in which electrical, rather than chemical, energy propels spacecraft. The benefits are numerous—this is why electric propulsion systems are increasingly 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 far-away places. Areas of research include plasma engines and plumes and their interaction with spacecraft and thruster materials, and numerical and experimental models of magnetic cusped thrusters.

SPL also has a significant role in designing and building microfabricated electrospray thrusters, including their integration into space missions. In addition to providing efficient propulsion for very small satellites in the 1 kg category (such as CubeSats), these engines will enable distributed propulsion for the control of large space structures, such as deformable mirrors and apertures. A recent line of research is focused on the favorable scaling potential of electrospray thrusters for applications in power-intensive missions. SPL has delivered flight hardware to test the first electrospray thrusters in space in CubeSats. The science behind electrosprays is explored as well, mainly on the ionic regime where molecular species are directly evaporated from ionic liquid surfaces. Applications beyond propulsion are also investigated; for example, the use of highly monoenergetic molecular ion beams in focusing columns for materials structuring and characterization at the nano scale and also applications in vacuum technology. The SPL facilities include a computer cluster, where plasma and molecular dynamics codes are routinely executed, and a state-of-the-art laboratory that includes five vacuum chambers, a clean-room environment, an electron microscope, materials synthesis capabilities, nanosatellite qualification equipment (a vibration/thermal and in-vacuum magnetically levitated CubeSat simulator), plasma/ion beam diagnostic tools to support ongoing research efforts, and a laser micromachining facility.

The SPL faculty includes Professor Paulo Lozano, director, and Professor Emeritus Manuel Martinez-Sanchez.

Space Systems Laboratory

Research in the Space Systems Laboratory (SSL) contributes to the exploration and development of space. SSL's mission is to explore innovative space systems concepts while training researchers in this field. The major programs include systems analysis studies and tool development, AeroAstro student-built instruments and small satellites for exploration and remote sensing, precision optical systems for space telescopes, and microgravity experiments operated aboard the ISS and the NASA reduced-gravity aircraft. Research topics focus on space systems and include dynamics, guidance, and control; active structural control; space power and propulsion; modular space systems design; micro-satellite design; real-time embedded systems; software development; and systems architecting.



Swedish astronaut Christer Fuglesang tests a centrifuge-mounted pedaling device in the Man Vehicle Lab that could be used on the International Space Station to analyze the effect of artificial gravity levels and ergometer exercise on musculoskeletal and cardiovascular functions as well as on motion sickness and comfort. Emeritus Professor Larry Young assists. (Photo: William Litant/MIT)

SSL has a unique facility for space systems research, the Synchronized Position Hold Engage and Reorient Experimental Satellites (SPHERES). The SPHERES facility is used to develop proximity satellite operations such as inspection, cluster aggregation, collision avoidance-21 and docking, as well as formation flight. The SPHERES facility consists of three satellites 20 centimeters in diameter that have been inside the ISS since May 2006. SSL uses SPHERES to conduct STEM outreach through an exciting program called Zero Robotics, which engages high-school and middle-school students in a competition aboard the ISS using SPHERES. It has expanded to more than 100 US and 50 European teams annually. In 2014, Dante Lauretta, principal investigator of the Osirix REX Mission, and at the European Space Agency's European Space Research and Technology Centre by Matthew Taylor, project scientist of the Rosetta mission, joined finalists at MIT as guest speakers. MIT alumna and retired NASA astronaut Catherine "Cady" Coleman hosted the students at MIT, and astronaut Paolo Nespoli from the Italian Space Agency hosted the students at ESTEC. The competition was run aboard the ISS by three crewmembers: cosmonaut Elena Serova from Russia, astronaut Samantha Cristoforetti from Italy, and astronaut Barry "Butch" Wilmore from the United States. For the first time, teams from Russia and Mexico also participated in this growing competition.

Recently, SSL partnered with the Naval Research Laboratory and Aurora Flight Sciences for work on the Defense Advanced Research Projects Agency's Phoenix program for satellite servicing and assembly missions. To this end, a set of universal docking ports and halos was launched and operated on the SPHERES ISS facility in fall 2014. The universal docking ports enable active docking and undocking of the satellites, creating a rigid assembly; they add fiducial-based vision navigation. The Halo structure enables attachment of up to six electromechanical devices around a single SPHERES satellite, allowing researchers to study complex geometrical system reconfiguration.

SSL is also active in the area of nanosatellites, particularly CubeSats. In March 2014, the Microsized Microwave Atmospheric Satellite (MicroMAS), a joint effort between MIT SSL students, led by Professor Kerri Cahoy, and MIT Lincoln Laboratory staff, led by Dr. Bill Blackwell, was delivered to NanoRacks for launch to the ISS, from which MicroMAS was deployed in summer 2014. MicroMAS is a dual-spinning three-unit CubeSat hosting a microwave radiometer payload that captures temperature map images of Earth and is important for characterizing hurricanes and tropical storms. SSL will develop a follow-up to MicroMAS called the Microwave Radiometer Technology Acceleration mission (MiRaTA), which pairs an advanced miniature microwave radiometer with a GPS radio occultation receiver to help improve radiometer calibration. MiRaTA, sponsored by the NASA Earth Science Technology Office, is scheduled for a 2016 launch. SSL students are working with engineers at Aurora Flight Sciences and the AeroAstro Space Propulsion Laboratory on a cluster formation-flight nanosatellite project. SSL students are also engaged with Professor Sara Seager and students in the MIT Earth and Planetary Sciences department, engineers at the Charles Stark Draper Laboratory, and NASA's Jet Propulsion Laboratory on the novel ExoplanetSat nanosatellite, which uses a two-stage control system (reaction wheels plus piezo stage) to maintain precise pointing at a target star to obtain exoplanet transit measurements using advanced photometry.

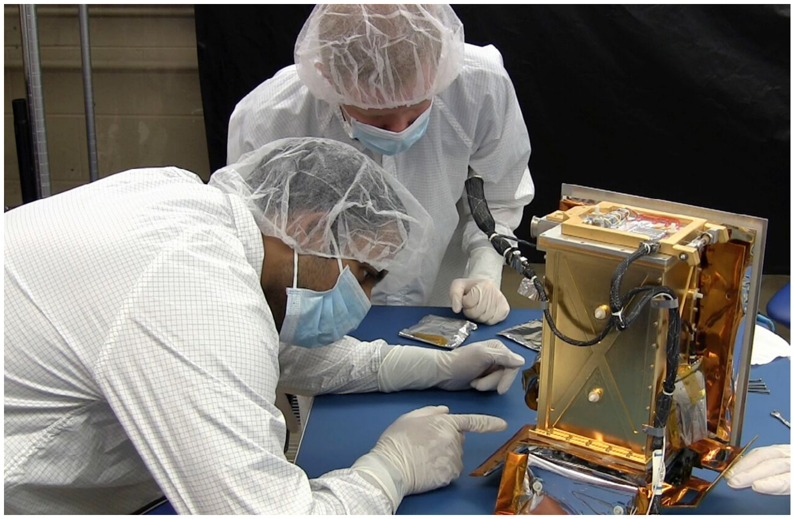
The Wavefront Control Laboratory (WCL), led by Cahoy, is a part of SSL that focuses on precision active optical systems for space applications. WCL students are working on three projects. One is the Deformable Mirror Demonstration Mission (DeMi), which will validate and demonstrate the capabilities of high actuator count MEMS deformable mirrors for high contrast astronomical imaging. The DeMi optical payload will characterize MEMS deformable mirror operation using both a Shack Hartmann wavefront sensor as well as sensorless wavefront control. The second project is a CubeSat Free Space Optical communications downlink that uses a staged control system with MEMS fast steering mirrors. The third project is a bistatic laser system for active characterization of the bidirectional reflectance distribution function of space materials. WCL students also are investigating whether or not standard communications satellite components can be used as space weather sensors, and they are developing algorithms that can predict the onset of space-weather related anomalies.

SSL is also developing and building the REgolith X-ray Imaging Spectrometer (REXIS) student collaboration instrument, which will be aboard the Origins, Spectral Interpretation, Resource Identification, Security Regolith Explorer (OSIRIS-REx) mission—NASA's next New Frontiers mission. OSIRIS-REx is an asteroid sample return mission that will launch in 2016 to visit the near-Earth asteroid Bennu. REXIS, one of five instruments onboard, will use a 2x2 array of Lincoln Laboratory–designed charged-coupled devices to measure the X-ray fluorescence from Bennu; this will allow characterization of the surface of the asteroid among the major meteorite groups as well as a coded aperture mask to map the spatial distribution of element concentrations in the regolith. Professor Richard Binzel, who holds a joint appointment in the Department of Earth, Atmospheric and Planetary Sciences (EAPS) and AeroAstro, and Dr. Rebecca Masterson are leading the project in collaboration with EAPS, the Kavli Institute, and the Harvard College Observatory. REXIS has included the work of more than 50 undergraduate and graduate students and has successfully completed its critical design review. The team is wrapping up the engineering model testing and is on the path to the flight hardware build. The REXIS flight instrument will be delivered to Lockheed Martin for integration onto the OSIRIS-REx spacecraft in the summer of 2015.

Dr. Alvar Saenz Otero is directing SSL while Professor David W. Miller is on leave from MIT as NASA's chief technologist. Professors Kerri Cahoy, Jeffrey Hoffman, Olivier de Weck, and Richard Binzel participate in the multiple SSL projects. Dr. Rebecca Masterson manages REXIS. Dr. Danilo Roascio leads the SPHERES team. The group is supported by research specialist Paul Bauer, fiscal officers Suxin Hu and Ngan Kim Le, and administrative assistant Marilyn E. Good. Collaborators include AeroAstro Professors Manuel Martinez-Sanchez and Paulo Lozano and EAPS Professor Sara Seager.

Space Telecommunications, Radiation, and Astronomy Laboratory

The Space Telecommunications, Radiation, and Astronomy Laboratory (STAR Lab) is affiliated with the Space Systems Laboratory. It focuses on developing instruments and platforms that enable weather sensing on Earth and other planets, including exoplanets, as well as monitoring "space weather"—the highly energetic flow of radiation, or charged particles, that is constantly streaming toward Earth from the sun. In addition to the flight CubeSat weather sensing projects (MicroMAS and MiRaTA) and work to optimize autonomously the return on spacecraft scientific observation, given constrained resources, STAR Lab projects also involve the use of active optical elements, sensing, and tracking systems.



In the Space Systems Laboratory cleanroom, AeroAstro graduate students Pronoy Biswas (left) and Mark Chodas prepare REgolith X-Ray Imaging Spectrometer (REXIS), an MIT/Harvard student-designed component of NASA's OSIRIS-Rex asteroid-explorer and sample-retrieving spacecraft, scheduled for launch in 2016. (Photo: William Litant/MIT)

Nanosatellite Optical Downlink Experiment (NODE): NODE is a miniaturized laser communication module for small satellites that incorporates commercial off-the-shelf components, including a MEMS fast-steering mirror for fine pointing, on standard three-axis stabilized spacecraft to achieve free space optical data rates of better than 50 Mbps when downlinking from low Earth orbit to amateur-astronomy-class 30 cm telescope ground stations. A flight demonstration of a NODE prototype is expected in late 2015 or early 2016. The laboratory is also developing an atmospheric sensor that overlaps with the NODE configuration.

Direct Imaging of Exoplanets: The STAR Lab is involved in mission design and technology demonstration efforts toward direct imaging of exoplanets, a method in which a space telescope equipped with an occulter is used to obtain images of planets around another star by blocking out (occulting) the parent star and measuring the the ever-so-faint spectra of exoplanets orbiting it. The spectra are used to tell us about the atmosphere and weather on the exoplanets, as well as give indications about life and habitability. One demonstration mission, the Deformable Mirror Demonstration, involves looking at bright stars and testing a MEMS deformable mirror on a 3U CubeSat using a miniaturized Shack Hartmann wavefront sensor. STAR Lab also collaborates with students in EAPS and staff at NASA Ames Research Center and Space Telescope Science Institute to do modeling of the retrieved atmospheric spectra.

Space Weather Sensing: In collaboration with the Department of Nuclear Science and Engineering, the STAR Lab is helping to develop miniaturized radiation sensors for satellites that can provide more information about the particle types and energies that affect orbiting assets than a simple dosimeter can. This effort complements work being done to analyze commercial operator satellite telemetry and anomaly databases to understand the sensitivity of spacecraft and components to space weather events and develop new spacecraft and system health monitoring algorithms.

Professor Kerri Cahoy directs the Star Lab.

System Engineering Research Laboratory

The increasingly complex systems being built 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 possibility of harming 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. Engineering design can no longer be separated from human factors and from the social and organizational system in which these complex systems are designed and operated.

The System Engineering Research Laboratory's goal 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. The laboratory 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, unmanned aircraft, air traffic control), spacecraft, medical devices and healthcare, automobiles, nuclear power, defense systems, energy, and large manufacturing and processing 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

It has recently been found that the laboratory's safety techniques are also effective for security, and researchers are now involved in cybersecurity and physical (nuclear) security in work for the US Department of Defense, the Federal Aviation Administration, and the US Department of Energy.

Professor Nancy Leveson directs the System Engineering Research Laboratory. Dr. John Thomas is a research engineer affiliated with the Systems Engineering Research Laboratory.

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 and understanding that will help facilitate and accelerate advanced materials systems development and use in various structural applications and devices.

TELAMS has broadened its interests from a strong historical background in composite materials, and this is reflected in the change of the laboratory's name; it was formerly the 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 on addressing the roles of lengthscale in the failure of composite structures,
- Numerical and analytical solid modeling to inform, and be informed by, experiments, and
- 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. 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 microscopic inspection, nondestructive inspection, high-fidelity characterization of MEMS materials and devices, and a laser vibrometer for dynamic device and structural characterization. This includes ties to ability 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 that is consistent with the broadening of the interest areas in the laboratory. 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 members within the MIT community.

The TELAMS faculty includes Professor Paul A. Lagacé, Professor 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 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 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 laboratory.

The laboratory has been 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 facilitates the efficient and accurate experimental validation of proposed theories and enables 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.

The laboratory's 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 theoretically information-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. Last, they analyzed the capability for secure communication in the presence of colluding eavesdroppers.

To support outreach and diversity, the group is committed to attracting undergraduates and members of 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 UROP 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, the University of Lund in Sweden, the University of Oulu in Finland, the National University of Singapore, Nanyang Technological University in Singapore, the Charles Stark Draper Laboratory, the Jet Propulsion Laboratory, and Mitsubishi Electric Research Laboratories.

Professor 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 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, and the aeroelastic dynamics of airport control tower configurations for the Federal Aviation Authority. There have also been some 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 78 years of operation, Wright Brothers Wind Tunnel work has been recorded in hundreds of theses and more than 1,000 technical reports.

The WBWT faculty and staff include Professor Mark Drela and technical instructor David Robertson.

Degree Programs

The bachelor of science (SB) degree is a four-year program designed to prepare each graduate for an entry-level position in the aerospace field and for further education at the master's level. The curriculum is flexible enough to give students options in their pursuit of careers in aerospace, ranging from fundamental research to responsible engineering leadership of large enterprises. The required undergraduate curriculum provides a core around which students can build in order to become practicing engineers upon receipt of the undergraduate degree, to continue on to graduate studies in any of the specialties, or to pursue fields outside engineering.

The department offers an SB degree in aerospace engineering (Course 16 – Aerospace Engineering). The degree emphasizes aerospace fundamentals and allows students to explore various aspects of aerospace engineering in greater depth through a wide selection of professional area subjects. In addition, an option in aerospace information technology exists for those students who select at least three professional area subjects from a designated list.

The Department of Aeronautics and Astronautics also offers a more flexible program, Course 16-ENG, with an emphasis on aerospace-related engineering. Given that the practice of aerospace engineering has become increasingly multidisciplinary, the flexible degree provides the opportunity to address educational needs for the expanding envelope of aerospace and related systems. The flexible degree program also builds on the department's strength in collaborative, multidisciplinary problem solving. In 2015, the 16-ENG degree program offered concentrations in aerospace software engineering, autonomous systems, embedded systems and networks, computational engineering, computational sustainability, energy, engineering management, environment, space exploration, and transportation.

The skills and attributes emphasized in all of AeroAstro's programs go beyond the formal classroom curriculum and include modeling, design, the ability for self-education, computer literacy, communication and teamwork skills, ethical context, and appreciation of the interfaces and connections among various disciplines. Opportunities for formal and practical training in these areas are integrated into the departmental subjects through examples set by the faculty, the disciplinary content, and the opportunity for substantive engagement. The curriculum also includes opportunities for students to participate in study-abroad programs.

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. In particular, the department participates in the Institute's new doctoral degree in computational science and engineering, administered by the Center for Computational Engineering (CSE). Students enrolled in the AeroAstro CSE program can specialize in a computation-related aerospace field through focused coursework and a doctoral thesis.

Graduate Enrollment*

	08–09	09–10	10–11	11–12	12–13	13–14	14–15
Total Graduate Student Body	**236**	**226**	**226**	**229**	**246**	**241**	**233**
SM**	148	130	111	121	125	117	107
PhD***	88	96	115	108	121	124	126
Minority							
SM	8	9	7	9	12	13	17
PhD	6	4	6	5	6	5	5
Female							
SM	32	30	22	21	23	23	26
PhD	23	17	20	16	22	26	25

*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.

Undergraduate Enrollment

	05–06	06–07	07–08	08–09	09–10	10–11	11–12	12–13	13–14	14–15
Sophomores	65	65	57	74	57	51	45	66	71	56
Juniors	52	60	66	55	65	47	46	43	53	65
Seniors	76	56	66	62	58	68	47	45	44	56
Totals	**196**	**181**	**189**	**191**	**180**	**166**	**138**	**154**	**168**	**177**
% Women	26%	31%	30	30%	34%	29%	31%	37%	36%	36%
% Underrepresented minorities	25%	19%	14%	32%	40%	28%	38%	30%	31.5%	32%

* Data based on the Registrar's Fall Fifth Week Enrollment Reports.

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