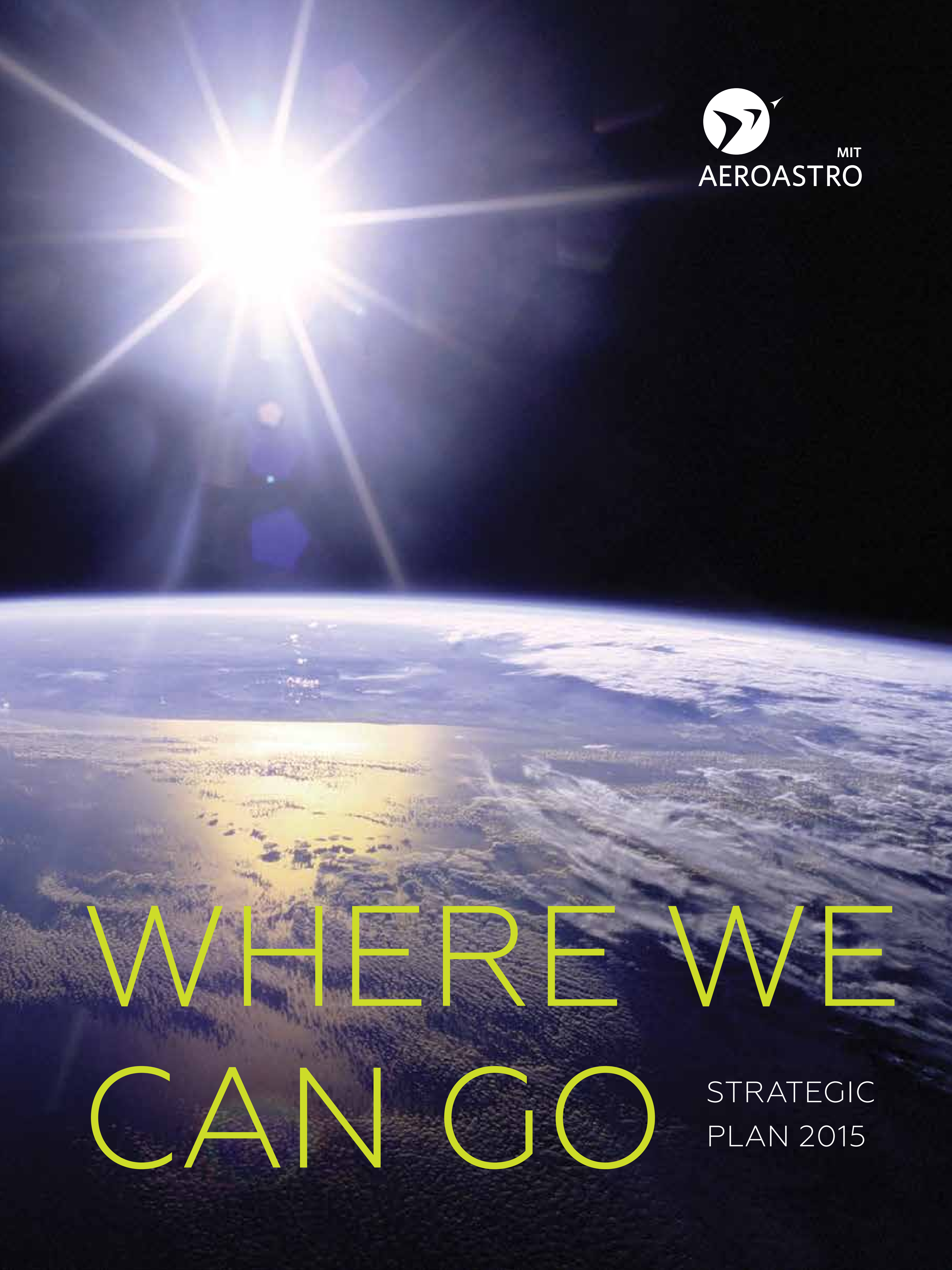

MIT AEROASTRO

WHERE WE CAN GO

STRATEGIC PLAN 2015

This strategic plan anticipates advancements in technology, education, and the aerospace industry. It updates and hones our vision, mission, and goals. This is our roadmap for where we can go — and where we will go.

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WH

ERE WE CAN GO

"Each person in this department has some kind of drive, some problem they want to solve. It's the people around you that keep you going and that's one of the main things I love about this department. Archeology is like discovering more about our past and where we've been. AeroAstro is understanding where we can go."

AARON OKELLO, CLASS OF 2016

The MIT Department of Aeronautics and Astronautics is a vibrant, robust, connected community of uniquely talented faculty, students, alumni, and staff, committed to excellence. We eagerly anticipate and embrace the grand challenges of today and tomorrow, as we have throughout our more than 100 years of aerospace research and education distinction.

Over the last 15 years, we have been inspired and guided by two strategic plans. Our 1998 and 2007 plans reviewed, modified, and invigorated our goals and positioned AeroAstro for the ensuing years of leadership and success.

The 2015 strategic planning process was driven by our commitment to:

- identify strengths, shortcomings, opportunities, and challenges
- define core competencies and strategic thrusts
- prioritize department resource investments
- strengthen faculty consensus regarding the department's future directions

AeroAstro is shaping the future of air and space transportation, exploration, communications, autonomous systems, education, and national security. This new strategic plan anticipates advancements in technology, education, and the aerospace industry. It updates and hones our vision, mission, and goals. This is our roadmap for where we can go — and where we will go.

FINDI

ECONOMIC AND SOCIAL IMPACT

SpaceX's Dragon was the first commercial spacecraft to deliver cargo to the International Space Station. (SpaceX)

The aerospace industry is a robust, powerful engine of employment, innovation, and income. The U.S. aerospace and defense industry employs 618,000 highly skilled workers. U.S. aerospace sales for 2014 were more than $228 billion, and the U.S. aerospace industry leads the country in the net export of manufactured goods. Thirty-five percent of the world annual trade value is shipped by air, greatly enabling e-commerce and just-in-time manufacturing.

Space sales, especially for civilian programs, are growing, as is the world's dependency on space-based systems for communications, climatology research and weather forecasting, monitoring of the earth's resources, precise navigation, national security, and extraterrestrial navigation. The industry is an incubator for new technologies associated with unmanned systems, GPS, satellites, materials, and sensors.

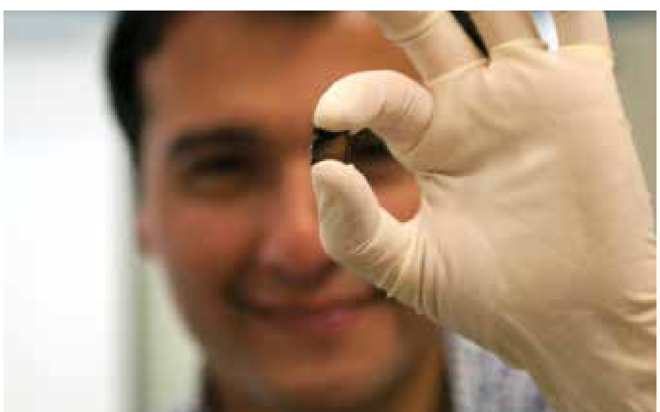
GLOBALIZATION

Boeing 787s on the assembly line. (Boeing)

Markets in emerging economies will double air transportation demand by mid-century. Space and aviation hardware design, manufacturing, and support services, once the bastion of a few nations, are spreading globally. More countries are developing an indigenous space capability that includes satellites, launch vehicles, and robotic and human exploration systems. European nations, Brazil, Canada, China, Japan, Russia, and other countries are developing and expanding civil aircraft manufacturing to meet burgeoning worldwide demand.

Distributed product design, especially that based on broadband communication networks, is enabling multiple design task requirements to be accomplished in parallel at a number of sources. Some elements of manufacturing that were previously outsourced are returning to U.S. shores for reasons that include shorter supply chains, the high quality of American manufactured goods, and availability of competitive domestic energy supplies.

NGS & TRENDS



ENERGY

Professor Paulo Lozano holds a tiny, highly-efficient electrospray spacecraft thruster, under development in the Space Propulsion Lab. (William Litant)

New propulsion and power source technologies for aircraft and spacecraft are of growing significance. The association between national security and the shifting availability of resources for energy consumption is of great concern to the world economy. Fuel costs and environmental concerns are driving a need for more efficient, greener aircraft.

Availability of radioactive isotopes used to power deep-space vehicles is limited. There is increased interest in alternative power sources (e.g., electricity, hydrogen, photovoltaics) for vehicles and systems.

ENVIRONMENT

Increasingly stringent environmental regulations are spurring the development of greener aircraft. (Shutterstock)

Climate change, coupled with increasingly stringent environmental regulation, provides both long-term challenges and opportunities for dramatic developments in aircraft and propulsion system design, ground and inflight operations, and fuel sources.

Demand is growing for aircraft and spacecraft that can be tasked with observations that contribute to climatic research, natural resource management, and other areas of environmental importance.

SPACE

Professor Dava Newman is developing next-generation spacesuits in the Man Vehicle Lab. (Len Rubenstein)

Space commercialization and exploration are growing as countries throughout the world initiate indigenous space programs supported by their own hardware and software. Primary drivers are private sector commercialization and a desire to enhance earth-focused needs such as improved navigation and tracking, and climate monitoring. Miniaturization of vehicle and satellite subsystems, and clusters of small satellites working in concert will enable new and more economical mission capabilities. The rapidly advancing technologies of electric space propulsion could obviate much of the need for onboard fuel supplies and/or resupply. In addition to NASA's desire to increase robotic exploration capabilities, the protection of astronauts for long duration missions, including Mars, requires advances in radiation protection and advanced life support systems. Further safety risks are posed by more than 500,000 pieces of earth-orbiting space debris.

UNMANNED AERIAL VEHICLES/AUTONOMY

A charging station designed in the Aerospace Controls Lab would allow UAVs to autonomously land, swap a depleted battery for a fresh one, and then continue with their mission. (William Litant)

While unmanned aerial vehicles ("drones") were once exclusively controlled by ground-based operators, they are increasingly controlled by autonomous systems with humans taking a supervisory role. Their use is rapidly expanding beyond hobbyists' projects and military operations, to a growing number of civil operations such as law enforcement, utility inspection, newsgathering, emergency services, and even parcel delivery. Demand will grow in all these areas. The Aerospace Industries Association anticipates that worldwide spending on unmanned aerial systems will nearly double between 2014 and 2024. Safety assurance and regulation are critical to UAV integration in the National Airspace System.

Applications for autonomous and robotic systems are progressing beyond UAVs to include driverless automobiles, robotic manufacturing, and earth and deep space exploration systems. The latter particularly will benefit from real-time ability to adapt autonomously.

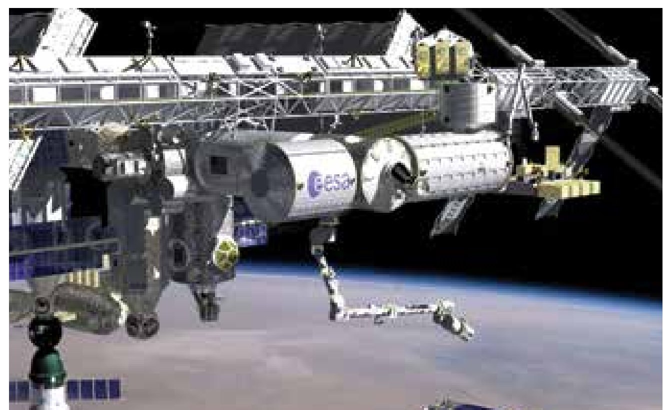
The aerospace industry is a robust, powerful engine of employment, innovation, and export income.

MATERIALS AND MANUFACTURING

The MAVEN spacecraft, which will survey Mars' upper atmosphere, has a primary bus structure of carbon fibre-reinforced composite. (Lockheed Martin)

Advanced materials, including metals, composites, and ceramics, with enhanced mechanical, thermal, and electrical properties, are enabling development of high-performance multifunctional lightweight aerospace structures. They are also creating manufacturing challenges.

Examples of advances in materials and manufacture include: composite structures used to reduce aircraft weight, industrial 3-D printing technologies and their integration into the design process, conducting composites employed in aircraft wing deicing and lightning strike protection, and new ceramics for higher thermodynamic efficiency in gas turbines and enhanced spacecraft heat shields.



SYSTEMS

The Japanese Aerospace Exploration Agency evaluated System Theoretic Process Analysis on the H-II Transfer Vehicle, seen here in an artist's concept docking with the International Space Station. (NASA)

The nature of systems engineering is one of interdisciplinary collaboration in complex system design and management. Areas of applicability include safety, reliability, assessment, and team integration/coordination, all of which increase in difficulty as systems become more elaborate. Rapidly expanding capabilities in sensing and analysis, and data-to-decision and data-model integration present opportunities for system engineers. For the foreseeable future, software will remain of paramount importance for system capability, safety, and performance. We are seeing an emergence of model-based systems engineering to manage growing complexity, while maintaining and increasing affordability and resilience.

Cyber security poses a major challenge to a wide range of networked and digital systems. Net-centric paradigms are the basis of practical, rapid transmission and sharing of voluminous data packages, but they can be vulnerable to hacking and other intrusions. Increasing system security robustness is of prime concern.

MITIG

U.S. Navy Cyber Defense Operations Command sailors monitor information systems and networks for unauthorized activity. (Joshua Wahl/U.S. Navy)

GATING FACTORS

Current shifts in defense research spending are directed to sustainment of assets, cyber security, and tactical defense systems.

There is concern regarding the aging, and resulting sustainability, of the aerospace workforce.

Dependent on factors ranging from international conflict and unrest, to changes in the political landscape and resulting priority shifts, research funding can be inconsistent and changeable. Current shifts in defense research spending are directed to sustainment of assets, cyber security, and tactical defense systems.

To protect indigenous industry, as well as research and development, most G20 members have instituted new restrictions on international trade and knowledge exchange. U.S. trade barriers (e.g., ITAR and EAR) pose roadblocks to foreign sales of space and defense products, including American satellite and UAV hardware and technologies.

Industry leaders are exhibiting mounting concern regarding the aging and sustainability of the aerospace workforce. Cuts to the U.S. space program in the 1970s and 1980s slowed the influx of young engineers, and those who entered the field in years prior to the '70s and '80s are reaching retirement age. It is estimated that approximately half of the top engineering leaders and managers will be eligible for retirement in the next five years, and there is concern about the ability to replace them over both the short and long term. Young people entering engineering fields today are enticed by healthcare technology, information technology, and other opportunities outside the aerospace field.

MOVING FOR

In the Space Systems Lab, (from left) Eric Peter, Evan Wise, and Anne Marinan examine a microsatellite engineering model's solar panels. (William Litant)

WARD

STRATEGIC VISION

We will enable the conception, design, implementation, and operation of novel and beneficial aerospace-related systems though preeminent education, research, and leadership. We will empower and inspire the next and future generations of critical-thinking engineers; leaders and innovators who possess deep technical understanding and broad systems perspective.

MISSION

The MIT Department of Aeronautics and Astronautics' mission 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
- conduct research that generates novel technologies and solutions to aerospace engineering challenges, in collaboration with colleagues at MIT, other universities, industry, the U.S. government, and other nations
- provide leadership to MIT, and to the worldwide aerospace and engineering communities

SHARED VALUES

AeroAstro faculty, students, and staff are renowned for excellence and innovation in their work and abilities. We share commitment to:

- the aerospace engineering profession and to leadership, through Institute, national, and international service
- personal and professional development of our students, faculty, and staff
- broad access to our initiatives and resources via open research and open education
- collaborative research addressing real-world challenges for the betterment of humankind

And, we share a passion for air and space vehicles and systems, the technologies that enable them, and the missions they fulfill.

CORE COMPET

Core competencies are an organization's main strengths and strategic advantages—a unique combination of pooled knowledge and technical acumen.

AeroAstro's core competencies foster and sustain our intellectual breadth and depth and our broad competitive advantage. We will strengthen, evolve, and multiply our competencies for the long term, internally and through collaboration across MIT and interacting with external partners, facilitating the pursuit of new, unique strategic opportunities.

CORE COMPETENCIES

- Disciplines essential to aerospace vehicle design
  - fluids
  - structures
  - materials
  - propulsion
- Real-time aerospace information sciences
  - guidance and navigation
  - estimation and control
  - autonomy
  - communication networks
- Advanced computation methods that support design and decision-making
  - numerical simulation
  - high performance computing
  - uncertainty quantification
  - inference
- Disciplines essential to human-system collaboration
  - human-machine systems
  - human factors
  - supervisory control and automation
  - biomechanics
  - life support
- Atmosphere and space sciences and their integration with aerospace systems
  - aviation's environmental impact
  - environmental monitoring
  - space science
  - space exploration
- Complex systems design, implementation, and operation
  - systems architecture
  - safety
  - optimization
  - lifecycle costing

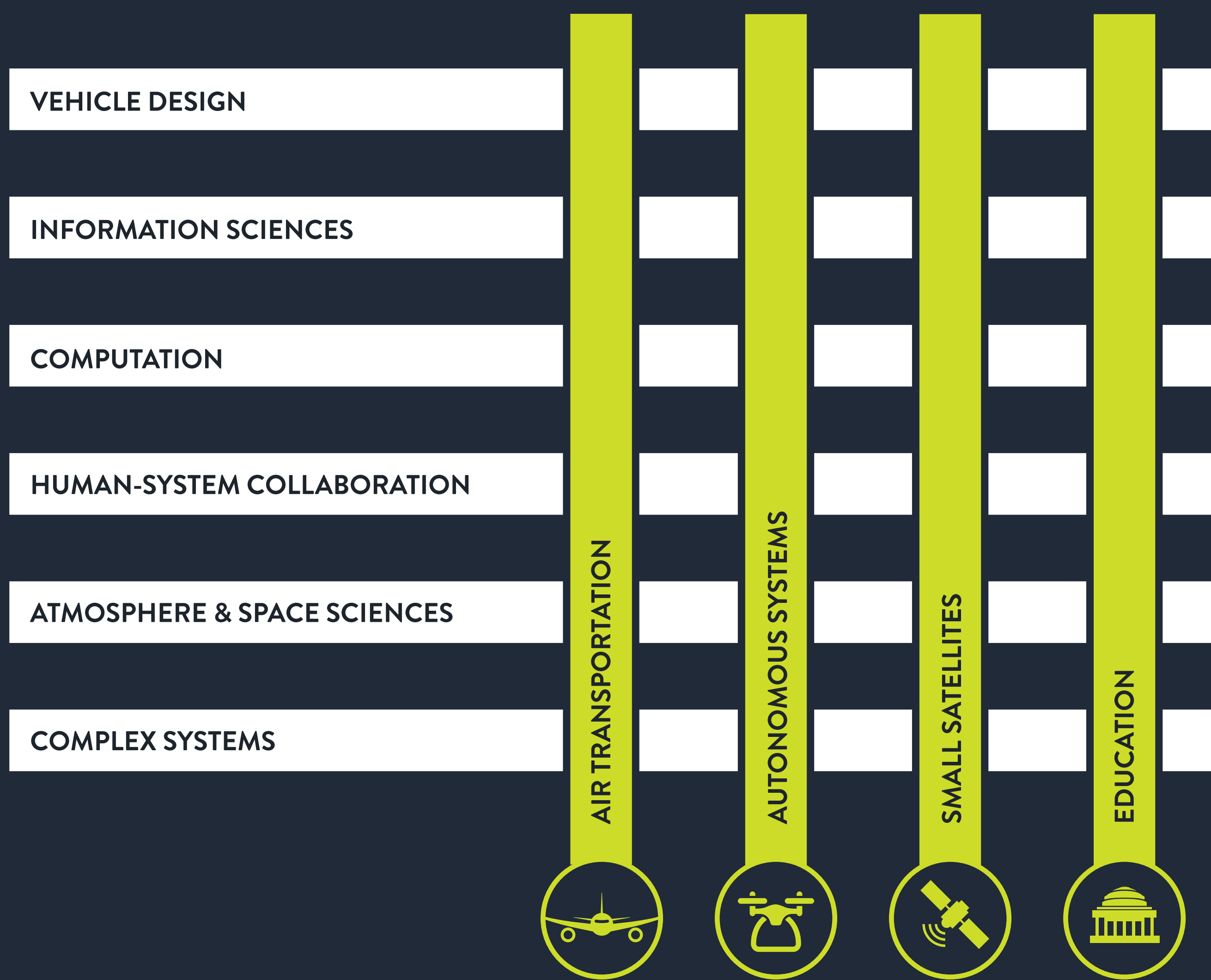
ENCIES

Man Vehicle Lab undergraduate researchers Sean Kropp (left) and Aaron Okello face off with different methods of motion capture. In the background, Professor Leia Stirling and graduate student Niek Bekers study this real-time monitoring. Human-system collaboration is an AeroAstro core competency. (William Litant)

STR

Core Competencies

to strengthen and evolve



Strategic Thrusts

that build on and connect our competencies

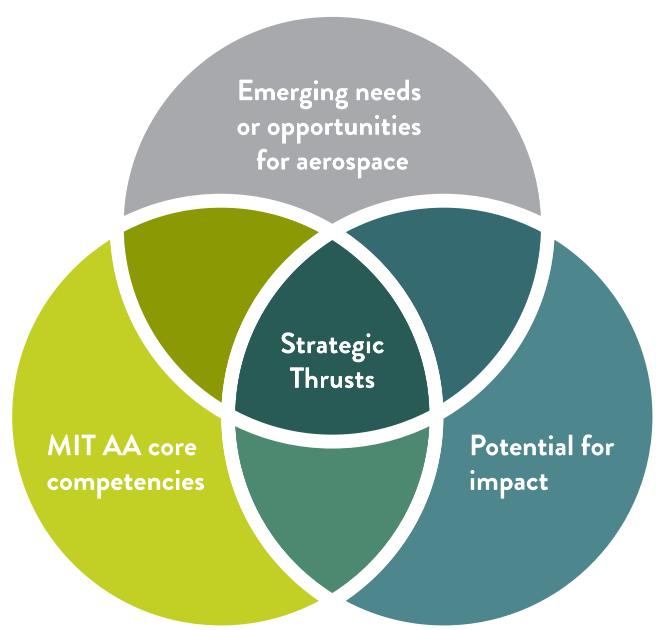
ATEGIC THRUSTS

Strategic thrusts are high-level initiatives arising from a strategic vision. They guide the creation of action plans to achieve major goals.

We have identified four strategic thrusts. They connect, and are supported by, our core competencies. They represent emerging opportunities where AeroAstro is positioned to lead and achieve major impact.

Our strategic thrusts are:

- Air Transportation
- Autonomous Systems
- Small Satellites
- Education



AIR TRANSPO

Aviation is a critical part of our national economy, providing for the movement of people and goods throughout the world, and enabling our economic growth. In the last 35 years there has been a six-fold increase in the mobility provided by the U.S. air transportation system.

In 2013, the American civil aircraft industry posted a delivery increase for the third consecutive year. Backlog for U.S. civil transport aircraft was nearly 4,800 aircraft valued at $344 billion. Foreign carriers represented 66 percent of those orders. The global aviation maintenance and repair market is projected to nearly double to $84.7 billion over the next seven years. The International Air Transport Association projects total worldwide air passenger numbers to reach 3.91 billion by 2017, a more than 30 percent increase in only five years.

Air cargo annually transports goods worth in excess of $6.4 trillion. This is approximately 35 percent of world trade by value. The cargo sector generates nearly $70 billion a year and is an important component of the aviation industry, which collectively supports 57 million jobs worldwide.

Among the financial and technical challenges facing the aviation industry are energy cost fluctuations, increasingly stringent environmental impact policies and restrictions, and a need for the air transportation infrastructure to keep pace with demand. Environmental impacts may be the fundamental constraint on 21st century air transportation growth.

Key elements driving aviation research will be the need for quieter, safer, affordable, and more efficient aircraft.

Created by an MIT-led team, the "D-8" concept aircraft is designed to use 70 percent less fuel than current commercial planes of its class. (Aurora Flight Sciences)

ORTATION

OPPORTUNITIES

New aircraft technologies require concurrent advancements in manufacturing processes that employ systems, optimization, digital simulations, novel materials, and robotics. Our abilities to address these issues are augmented by cross-disciplinary linkages with other departments, laboratories, and centers at MIT and throughout the world.

The worldwide demand for air transportation services, coupled with the need for climate neutral aviation growth and environmentally responsible aviation, provides incentives for:

- revolutionary aircraft technologies and concepts
- improved/enhanced air traffic control, airports and other infrastructure, and operations
- alternative propulsion systems and fuel/ energy sources

GOALS

With the needs and opportunities identified, we have established our Air Transportation strategic goals. We will:

- improve air transportation efficiency and lessen environmental impact
- enable new aircraft concepts through advancing aircraft design, propulsion, materials, manufacturing, control, and human-systems collaboration
- advance scientific understanding of aviation's environmental impact, develop impact-mitigating technical solutions, improve aviation operations efficiencies, and evaluate policies and regulations
- develop manufacturing processes that enable cost reductions, while sustaining and improving quality, and develop new materials for lightweight components
- conceive, design, and implement next-generation decision-making methods that integrate vehicle design, manufacture, maintenance, and operations

AUTONO SYSTEMS

In its *Roadmap for U.S. Robotics, 2013 Edition*, the Robotics Virtual Organization, an online consortium of which MIT is a member, reported that three factors are driving the adoption of robots for manufacturing, services, healthcare/medical, defense, and space: improved productivity in increasingly competitive environments, improved quality of life in the presence of an aging society, and removing first responders and soldiers from harm's way. The document says that robotics is one of a few technologies with a potential impact "as transformative as the internet."

According to the Robotic Industries Association, robot orders and shipments to North American industry set new records in the first nine months of 2014. Robot shipments through September totaled 18,490 robots valued at $1.1 billion. Sales activity was especially strong in the automotive industry, with orders up 48 percent over 2013. Non-automotive industries, including electronics, food and consumer goods, and metals, also posted double-digit growth in the first nine months of the year. There have been several years of annual growth of more than 40 percent in medical procedures performed by robots, and the heathcare industry is finding ever-increasing use for robotic systems in support of human mobility tasks such as meal preparation and personal hygiene.

More than six million autonomous vacuum cleaners and 200,000 lawnmowers have been sold, and service robots are increasingly used in other domestic service applications. Robotic use in space exploration, and for other extra-planetary purposes, is extensive. At the height of the Iraq and Afghanistan wars, the military deployed more than 25,000 robotic systems. More than half of U.S. Air Force pilots operate remotely-piloted systems.

OPPORTUNITIES

Emerging missions for autonomous air, space, ground, and marine vehicles abound, with new capabilities enabled by such factors as:

- algorithmic advances and increased data availability
- component and payload miniaturization
- novel sensors
- new vehicle configurations
- rapidly emerging heterogeneous manned/unmanned systems
- growing affordability
- societal demands for rapid advancement, application, and deployment

OMOUS
S

In the Aerospace Controls Lab, graduate student Buddy Michini explores means for humans and automated systems to orchestrate vehicle movements on aircraft carrier decks. (William Litant)

GOALS

With the needs and opportunities identified, we have established our Autonomous Systems strategic goals. We will:

- lead in aerospace autonomy, developing a broad perspective incorporating:
  - systems architecture and safety
  - human factors, cognitive systems
  - robotics and controls communication
  - sensing
  - communication
- develop autonomous systems that function safely and effectively for extensive durations in complex, dynamic environments
- offer networked complex systems mission planning and decision making
- enable persistent flight for deep space exploration, manufacturing, and maintenance
- overcome on-mission systems failures and operate in a degraded state
- devise autonomous solutions for real-world problems such as adaptive sensing systems by combining AeroAstro expertise in such areas as autonomy, experimental design, uncertainly quantification and decision-making, with strategic collaborators' specific domain experience
- apply AeroAstro autonomy expertise to domains beyond aerospace (e.g., motor vehicles, oil and gas development)

March 4, 2015: the Space Systems Lab and Lincoln Laboratory jointly-designed MicroMAS satellite is deployed from the International Space Station. MicroMAS will make temperature maps of tropical storms and hurricanes, characterizing structure and improving prediction models. (NASA)

SMALL SATELLIT

Small (sometimes called "miniaturized") satellites are of low mass and size, typically under 500 kg. These satellites offer many benefits compared to their traditional, larger counterparts, including reduced launched weight; reduced design costs; ease of mass production; ability to operate in constellations for high data rate communications; formation flight, enabling multiple-point data acquisition and in-orbit vehicle inspection; and space-based research opportunities for schools, institutions, and individuals.

Traditional space mission costs are high and timescales are lengthy. A risk-averse environment has fostered a reluctance to employ newly-developed technologies and architectures. Small satellites represent a vibrant technology within an industry that, historically, has experienced low-to-moderate growth.

Between 2004 and 2014, some 75 small satellites were launched; it is predicted that number may exceed 1,000 by 2019. Future satellite systems will include satellites that deploy smaller satellites, which, in turn, may release tinier counterparts. Commercially available technologies, such as those used in smartphones, enable small satellites to be quickly developed and manufactured, and to perform tasks once assigned to large, dramatically more expensive platforms.

MIT's strengths, and the strengths of its connections with government, industry, and academia in both space science and engineering, place us in a unique position to contribute to, and benefit from, the rapid advances in the development and application of small satellites.

ES

OPPORTUNITIES

Small satellites enable radical new means of approaching both traditional and novel applications. There are technological challenges, presenting MIT AeroAstro with exciting opportunities for:

- high-performance actuator and sensor miniaturization
- scalable, high-efficiency impulse propulsion systems
- new materials and manufacturing methods
- new control, estimation, and autonomy techniques
- optimization of multi-satellite orbital constellations
- revolutionary communications strategies

To reduce overall system cost, innovative methodologies are needed to link conceptual trades, requirement specifications and negotiation, detailed design, manufacturing, launch, and operations into a consistent framework.

Small satellite project scope, turnaround time, and cost make project conception, design, and implementation uniquely suited to our aerospace student and class engagement.

GOALS

With the needs and opportunities identified, we have established our Small Satellites strategic goals.
We will:

- build departmental capability to develop small satellites and missions to support research by enabling technological maturation and new science-supporting sensing and measurement capabilities
- introduce an integrated design environment to improve small satellite manufacturing including:
  - additive manufacturing
  - scalable/modular architectures
  - automated mission assurance
- integrate small satellite research with interactive student learning experiences.
- transform space systems development from the current "craft industry" (high costs, extensive lead times, high complexity) into an enterprise empowered to cost-effectively, expeditiously, and robustly customize on demand.

EDUCATI

On the first page of our 1997 Strategic Report we noted that aerospace is an intellectually and economically vigorous field that offers challenges, opportunities, and excitement for students and researchers. This is as true today as it was then. We remain committed to shaping the future of transportation, communication, exploration, and security. There is no greater evidence of this commitment than our dedication to educating tomorrow's engineering leaders through innovative educational programs, opportunities, and pedagogies.

For more than a century, AeroAstro has maintained a worldwide reputation for education innovation. In 1914, MIT introduced the nation's first course in aeronautical engineering, "Aeronautical Engineering for Naval Constructors." The beginning of the 21st century found MIT AeroAstro making a dramatic change to our undergraduate education, one that, within a few years, would impact engineering education around the world. In partnership with our student, industry, government, and academic stakeholders, we developed a syllabus that imbues our students with a deep knowledge of the four phases of the aerospace system lifecycle: conceiving, designing, implementing, and operating. This is a means to motivate our students to master deeper working knowledge of technical fundamentals while giving them the skills, knowledge, and attitudes vital for leadership in the creation and operation of products, processes, and systems. Born in AeroAstro, this CDIO (conceive, design, implement, operate) framework for engineering education has been adopted by more than 100 university engineering programs located throughout the world and become the focus of an international consortium.

In recent years, through MITx and our charter engagement with the edX consortium, MIT has become an innovative leader in online education, developing digital learning tools offering MIT-quality courses to learners worldwide. AeroAstro is an active participant in exploring effective worldwide digital learning. In 2013, we offered the first massive open online course (MOOC) in aerodynamics. There is much more to come.

We are dedicated to melding the best practices of 100 years of aerospace education with our pioneering efforts in the nascent area of digital learning.

Graduate student Jon Gibbs studies air flow with a blended wing aircraft model in the Wright Brothers Wind Tunnel. (William Litant)

OPPORTUNITY

From creation of the nation's first aeronautics class more than 100 years ago, to the design of an engineering syllabus that has been adopted by universities and cited by accrediting organizations throughout the world, to our active role in blending interactive online education with proven residential learning models, the MIT Aeronautics and Astronautics Department has proven itself a leader in advancing engineering education. Of particular importance is the adoption of AeroAstro-pioneered pedagogies in the teaching of non-aerospace engineering disciplines, thereby demonstrating their broad-based applicability. This positions the department to take a leadership role in MIT-wide educational and pedagogical development, and to contribute to MIT's global leadership in these areas. In particular, we can position ourselves to lead the development of aerospace-related MOOCs and other forms of digital learning through participation in MITx and edX.

We also maintain a commitment to aerospace engineering outreach, providing live and recorded programs and demonstrations at MIT, middle and high school classrooms, science fairs, and other venues.

GOALS

With the needs and opportunities identified, we have established our Education strategic goals. We will:

- develop an on-campus undergraduate educational model for aerospace engineering using research-based best practices, which incorporates and maximizes online learning resources
- develop an undergraduate aerospace engineering online learning model
- develop a lifelong learning strategy for aerospace engineering in cooperation with offerings to in-house graduate students, maximizing online resources
- develop a graduate aerospace engineering educational model building upon undergraduate-level experiences
- foster an interest in, and understanding of, aerospace engineering, and encourage young people to consider careers in the field

SUMMARY


(Boeing)

As the MIT Department of Aeronautics and Astronautics embarks on its second century, we embrace the aerospace challenges at our doorstep.

Markets in emerging economies will double air transportation demand by the mid-21st century. Countries throughout the world are developing indigenous space capabilities. It is expected that, within a relatively short time, we will be sending humans to asteroids and the planet Mars, and robotic explorers to even more exotic locales.

As the MIT Department of Aeronautics and Astronautics embarks on its second century, we embrace the aerospace challenges at our doorstep. With our remarkable students, alumni, faculty, and staff, AeroAstro is shaping the future of air and space transportation, exploration, communications, autonomous systems, education, and national security. This plan presents a compelling case for MIT and our stakeholders to partner with us in implementing our strategic visions and goals. This is our blueprint for the future.

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