MIT AEROASTRO

To Look Ahead, Look Up

STRATEGIC PLAN 2020

The future of humankind is inextricably linked to aerospace. In order to see further, we must anticipate advances in technology, education, and industry. It requires a clear vision of the future we want to build, the core actions we take to achieve it, and the values that will guide us.

This strategic plan charts our course for the future. And we look ahead by looking up.

A Rapidly C
Landscape

The MIT Department of Aeronautics and Astronautics (MIT AeroAstro) is a vibrant community of uniquely talented and passionate faculty, students, researchers, administrators, staff, and alumni. As the oldest program of its kind in the United States, we have a rich tradition of technical excellence, academic rigor, and research scholarship that has led to significant contributions to the field of aerospace for more than a century. Today, we continue to push the boundaries of what is possible to shape the future of air and space transportation, exploration, communications, autonomous systems, national security, and education.

In envisioning the next iteration of our Department's strategic plan, it was important to identify and address the critical challenges for the aerospace enterprise over the next 20 years. These challenges guide how we can best invest our resources in research and education to remain competitive, to leverage the unique academic environment at MIT, and to have a tangible effect on the external world.

The 2020 strategic planning process was a true team effort led by a steering committee (see page 25) with every cohort of our community weighing in to provide valuable feedback as we envisioned the future of our Department together. This document aims to summarize these efforts, specifically regarding (1) changes to the external environment; (2) mission, vision and values; and (3) future strategic directions in research, education, and culture and leadership.

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KEY DRIVERS OF THE STRATEGIC PLAN

Growth of entrepreneurial aerospace

The aerospace industry remains an important contributor to global economic activity and to research and innovation in the United States and other countries. Entrepreneurship, especially from startups, has become a significant driver of the field over the past decade and established industry players have joined forces with wealthy individuals to establish novel corporate venture arms. Game-changing technological advances, such as increasingly autonomous vehicles, novel manufacturing techniques, and new materials that enable new vehicle design and operational concepts, have enabled a democratization of aerospace. In addition, the price point for significant activities in both air and space has dropped considerably.

MIT Schwarzman College of Computing

In 2018, MIT announced the formation of the Schwarzman College of Computing (SCC), the most significant structural change at MIT since the creation of the School of Humanities, Arts and Social Sciences in the late 1950s. A significant component of the Department's research program addresses challenges in autonomy and computational engineering—both of which will be key areas of focus in the SCC—because they are integral to the future of aerospace.

Demographics and inclusion in the aerospace field

Diversity is a reliable and available source of new ideas, ingenuity and creativity in any field. However, there has been almost no change in the inclusion of women and under-represented minorities across the entire landscape of aerospace—undergraduate students, graduate students, and the professional workforce—in the past decade. The interplay of past, present, and future national demographics defines the pool of students who later become the faculty and staff who form the intellectual and cultural foundation of our community. For these reasons, diversity and inclusion must be a core value of the Department to be an inclusive home for people of all races, genders, religions, ethnicities and backgrounds.

WHY IS A STRATEGIC PLAN IMPORTANT?

1. It guides faculty hiring, thereby setting the long-term directions for the Department.
2. It outlines a vision for the future as a focal point for the faculty, staff, students, and other Department stakeholders.
3. It informs the allocation of discretionary resources (money and space).

Vision & M

VISION

The vision of the MIT Department of Aeronautics and Astronautics is to create:

An aerospace field that is a diverse and inclusive community, pushing the boundaries of the possible to ensure lasting positive impact on our society, economy, and environment.

MISSION

In the MIT Department of Aeronautics and Astronautics, we look ahead by looking up. At its core, aerospace empowers connection—interpersonal, international, interdisciplinary, and interplanetary. We seek to foster an inclusive community that values technical excellence, and we research and engineer innovative aerospace systems and technologies that have world-changing impact. We educate the next generation of leaders, creative engineers, and entrepreneurs who will push the boundaries of the possible to shape the future of aerospace. We do these things while holding ourselves to the highest standards of integrity and ethical practice. Working together with our partners in public and private sectors, we aim to expand the benefits of aerospace to create a more sustainable environment, strengthen global security, contribute to a prosperous economy, and explore other worlds for the betterment of humankind.

ission

The mission outlines core actions taken by the Department to achieve our vision, which articulates our ideal future state of the aerospace field.

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. Image credit: Aurora Flight Sciences

Our Values

Values are fundamental beliefs of an organization that guide behavior and everyday decision-making. We acknowledge that while some of the values have been realized, others are aspirational.

CREATE AN OPEN, DIVERSE, INCLUSIVE, AND SUPPORTIVE COMMUNITY

We aspire to nurture an open, diverse, and supportive community, which learns by inviting members to give feedback and reflecting collectively on how we meet our values.

SUCCEED TOGETHER

We collaborate across the growing MIT aerospace ecosystem, draw strength from connectivity with the broader MIT community, and proactively engage with national and international partners.

VISION

MISSION

ETHICS & INTEGRITY

LEAD THROUGH EXCELLENCE IN RESEARCH & EDUCATION

We lead through the strength of our research, the depth of learning our students achieve, and the invention, innovation, and discovery from the interaction between research and education.

Department Structure

DEPARTMENT RESEARCH SECTORS

Computing

Fields of study

- Autonomous Systems
- Communications and Networks
- Controls
- Aerospace Computational Engineering
- Human-Autonomy Collaboration

Space

Fields of study

- Humans in Aerospace
- Space Propulsion
- Space Systems
- Engineering Systems

Air

Fields of study

- Air-Breathing Propulsion
- Aircraft Systems Engineering
- Air Transportation Systems
- Aviation, Energy & Environment
- Materials and Structures

A model of AeroAstro is shown to the right, which makes explicit the distinction between the inputs (enablers) and the outputs (impacts). It can be seen that impact has many facets, not only the type of impact but in what sectors of the profession it touches.

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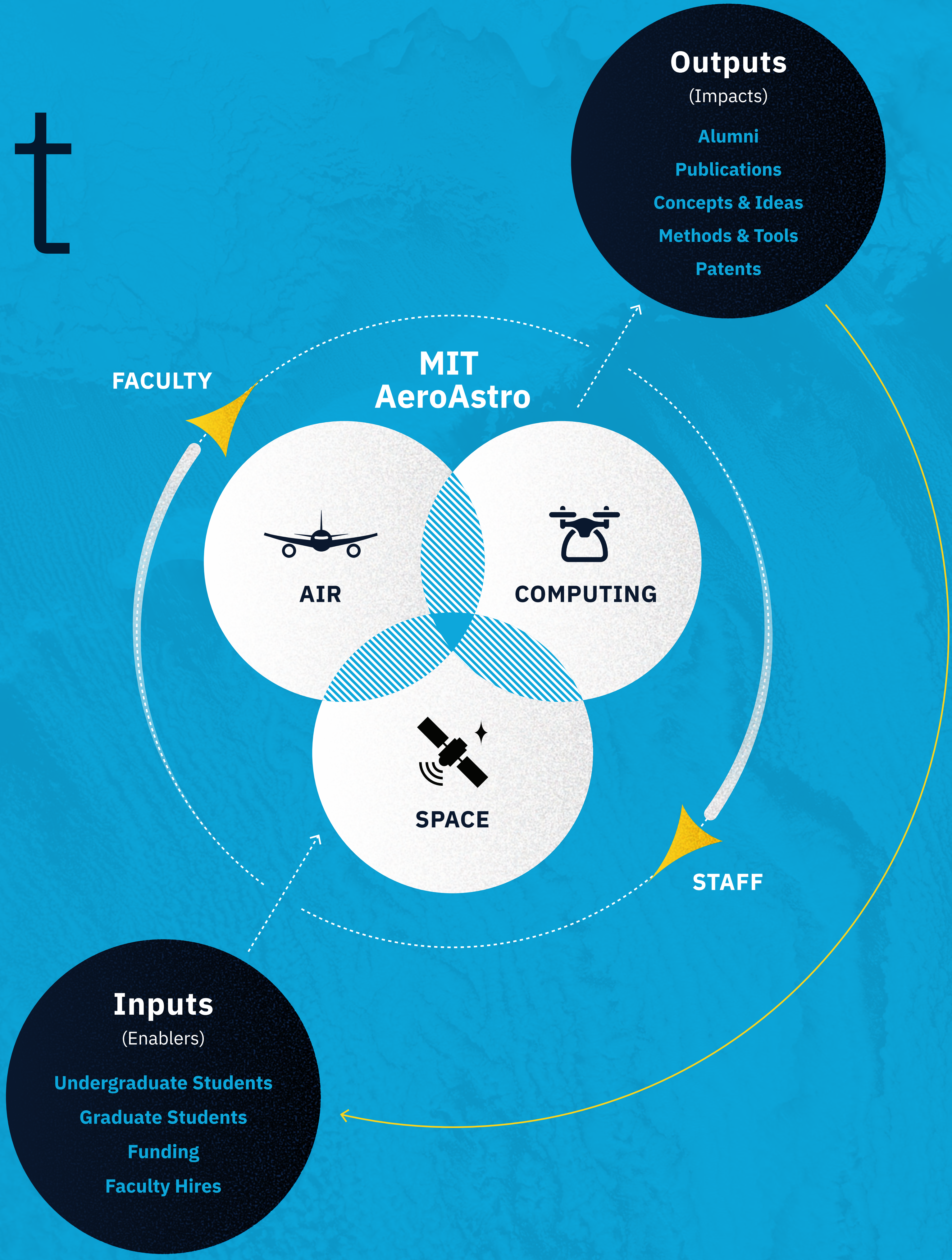

Outputs
(Impacts)
Alumni
Publications
Concepts & Ideas
Methods & Tools
Patents
MIT
AeroAstro
FACULTY
AIR
COMPUTING
SPACE
STAFF
Inputs
(Enablers)
Undergraduate Students
Graduate Students
Funding
Faculty Hires

Findings & Trends

ASTRONAUTICS

New space-based business models

Challenges

- An ecosystem of startups and novel business models has been disrupting industries and creating new products by driving innovation.

Opportunities

- Satellite-based Earth observation, remote sensing, and communications
- Space launch companies
- Manufacturing and mining in space

Space exploration

Challenges

- Private billionaires are investing heavily in space technologies and space programs, contributing to a rapidly changing ecosystem.

Opportunities

- Democratization of aerospace is leading to renewed enthusiasm and ambitious new space ventures.

Strategic control over space

Challenges

- Past anti-satellite tests and satellite collisions have shown the risks for rapidly increasing orbital debris. Increased access to space will generate more space debris, increasing the likelihood of Kessler Syndrome, in which the high density of objects in low Earth orbit collide, generating more debris that increases the likelihood of a cascade where each collision increases the risk of further collisions.

Opportunities

- Technical innovation in debris tracking and removal methods

Hypersonic vehicles concepts

Challenges

- “Hypersonic” refers to the ability to fly and controllably maneuver vehicles moving faster than the speed of sound (at high Mach numbers) in the atmosphere. Russia announced the successful deployment of its hypersonic glide vehicle, “Avangard”. This success could potentially pose challenges from a national security standpoint, but it is a clear and marked demonstration that hypersonic vehicles are possible.

Opportunities

- Develop hypersonic vehicles and technologies for defense purposes to promote national security

Solutions for long-term space missions

Challenges

- Issues need to be identified, including systems for energy and oxygen production.
- Astronaut performance and safety

Opportunities

- Nuclear power in space and in situ resource utilization
- Facilitate human spaceflight through countermeasures, mobility, life support systems, and radiation protection

Members of NASA's Mars 2020 project install the Mars Oxygen In-Situ Resource Utilization Experiment (MOXIE) into the chassis of NASA's next Mars rover. MOXIE will demonstrate a way that future explorers might produce oxygen from the Martian atmosphere for propellant and for breathing.
Image credit: NASA/JPL-Caltech

AERONAUTICS

Commercial scheduled air transport

Challenges

- Rising energy prices and increasing environmental pressures
- A number of startups plan to introduce supersonic flight

Opportunities

- New technologies, such as novel airframe designs, materials, jet engines, and vehicle electrification
- Sector projected to grow by 4-5 percent per annum, with growth focused primarily on emerging markets.

Unmanned aerial vehicles (UAVs)

Challenges

- Urban air mobility (UAM) still faces significant implementation hurdles, specifically in urban areas (e.g. noise, traffic management, certification, safety).
- Emergence of new drone-based business models (e.g. for remote sensing or last-mile delivery).

Opportunities

- The common trend across UAV and UAM applications is the increase in autonomy at both the vehicle and system levels.
- Expected to grow exponentially over the coming decades. The Federal Aviation Administration projects the fleet of small UAVs to triple over the next few years.
- The UAM market is projected to have a yearly market volume of $2.5B to $500B, and more than 70 manufacturers are currently working on potential vehicles for UAM applications.

Infrastructure congestion and air traffic management

Challenges

- Increasing traffic levels are leading to capacity shortages, slowing market growth in some world regions.
- The estimated number of unaccommodated flights due to capacity shortages in Europe will reach 3.7M per year by 2040.
- The safe integration of autonomous operations into the airspace system remains a significant challenge. As evidenced by the closure of London Gatwick airport due to drone sightings, these new forms of demand could create new safety challenges for the aviation sector.

Opportunities

- Urban areas are expected to see a dramatic increase in demand, with some of them expected to experience a 200x increase in the number of flights today due to unmanned aircraft systems operations, and a 30x increase from UAM operations.

Core C


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SAILING FESTIVAL

apabilities

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

Alejandra Uranga, Prof. Mark Drela, Technical Instructor David Robertson and graduate students Kevin Sabo and Trevor Long constructed a 2x3 wind tunnel in The Hangar in Building 33. Image credit: Mark Drela

In the 2015 plan, the Department identified a core set of capabilities necessary for the Department to maintain. These core capabilities are essential for research and teaching in the field. These capabilities form the basis on which the cross cutting strategic emphases in research can be undertaken and allow the Department to pivot to new areas as necessary. These are:

1. The disciplines central to the design of aerospace vehicles (fluids, structures, energy conversion, materials);

2. The discipline of real-time aerospace information sciences (guidance and navigation, estimation and control, autonomy, communications, networks);

3. Advanced computation methods to support design and decision-making (numerical simulation, high-performance computing, uncertainty quantification, inference);

4. The disciplines essential to human-system collaboration (human-machine systems, human factors, supervisory control and automation, biomechanics, life support);

5. The sciences of atmosphere and space and how they inform aerospace systems (environmental impact of aviation, environmental monitoring, science of space, space exploration); and

6. The design, implementation and operation of complex aerospace systems (system architecture, safety, optimization, lifecycle costing).

Strategic T

Strategic thrusts are high-level initiatives pursued in tandem with our core capabilities. They support the mission and vision and align with our core values. We have identified seven strategic thrusts that connect with and support our core capabilities and represent emerging areas of opportunity where we are uniquely positioned to lead and achieve major impact.

The research thrusts focus on long-term trends (for example, the growing effect of aerospace on the environment) rather than specific systems. They build upon our strengths while anticipating future changes as the aerospace field continues to evolve (for example, increasing autonomy in aerospace, increasing use of groups of satellites). The education thrusts respond to evident trends in education (for example, the impact of computing on the world more broadly) while the innovation and culture thrusts respond to the priorities of our students and alumni.

OUR STRATEGIC THRUSTS ARE:

Research thrusts

Thrust 1: Integrate autonomy and humans in real-world systems

Thrust 2: Develop new theory and applications for satellite constellations and swarms

Thrust 3: Aerospace environmental mitigation and monitoring

Educational thrusts

Thrust 4: Lead development of the College of Computing education programs in autonomy and computational science and engineering

Thrust 5: Develop education for digital natives and digital immigrants

Culture & leadership thrusts

Thrust 6: Become the leading department at MIT in mentoring, advising, diversity, and inclusion

Thrust 7: Make innovation a key component in MIT AeroAstro leadership

Thrusts

The Aerospace Controls Laboratory researches autonomous systems and control design for aircraft, spacecraft, and ground vehicles. Image credit: Lillie Paquette

RESEARCH THRUSTS

THRUST 1

Integrate autonomy and humans in real-world systems

With the advent of deep learning through artificial intelligence, human-autonomy collaboration is poised to transform the aerospace sector radically, including vehicle manufacturing, the overall aviation system, and future military operations. It will also help achieve the goals set by the next generation of space science and exploration. Aerospace technologies, the design processes, and the engineering practices are also driving rapid innovation in autonomy in other safety-critical, consumer-related sectors (e.g. autonomous cars, robotic delivery vehicles, etc.) that have the potential to significantly enhance human well-being and productivity. The demand for secure, high-integrity systems will only continue to grow, a trend we can already observe with large numbers of UAVs in the airspace with piloted systems, at airports with robots loading and unloading aircraft, with air taxis coming close to vehicles on the ground, and in space as astronauts and robots increasingly work together. As these technologies mature, the transition and deployment into real-world environments (including operations in close proximity to humans) leads to significant new challenges in the areas of trust, verification, and the integration with new public policies.

Thrust 1 will examine the development of trusted, verifiable, self-learning autonomous systems that can anticipate and work with human behavior. The research thrust will identify a set of focused challenge problems, engage policymakers around these problems, and develop new methodologies for these problems.

THRUST 2

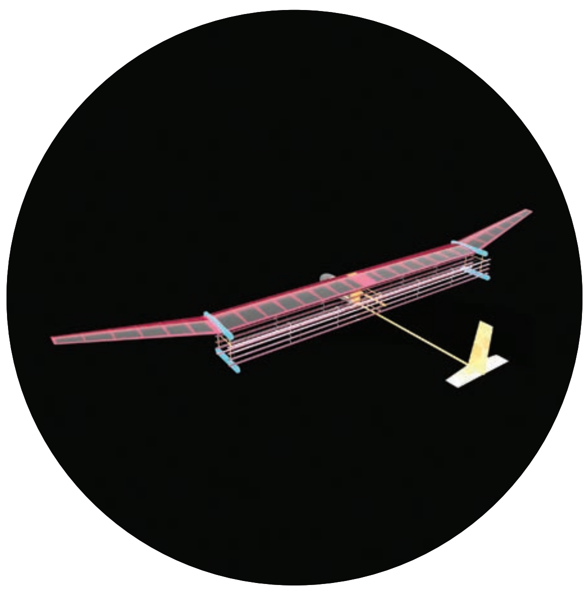
Develop new theory and applications for satellite constellations and swarms

Cost efficiencies and technological advances have ushered in a new era of large-scale satellite constellations and swarms involving smaller satellites (such as CubeSats). Swarms refer to two or more spacecraft (up to a few dozen) that have tight formation-flying requirements in Earth orbit or beyond to accomplish a joint mission such as remote sensing via interferometry, synthetic aperture radar, or distributed apertures. Constellations involve hundreds or thousands of spacecraft covering the entire planet for remote sensing or telecommunications with either continuous n-fold coverage or very short revisit times. These systems have both interesting Earth-oriented applications (for example, internet access) and space-oriented applications (for example, interferometry). The advent of smaller satellites poses new research

Thrust 1: The Sensing, Perception, Autonomy, and Robot Kinetics (SPARK) develops the algorithmic foundations of robotics through the innovative design, rigorous analysis, and real-world testing of algorithms for single and multi-robot systems. Image credit: Lillie Paquette

Thrust 2: The SpaceX Starlink mission is a satellite constellation that aims to expand internet access across the globe. Image credit: U.S. Air Force photo by 1st Lt. Alex Preisser

Thrust 3: A general blueprint for an MIT plane propelled by ionic wind. The system may be used to propel small drones and even lightweight aircraft, as an alternative to fossil fuel propulsion. Image credit: MIT Electric Aircraft Initiative



challenges and opportunities around trade-space analysis and optimization, autonomous research operations, new technology development, and space situational awareness and space traffic management.

In Thrust 2, the application of small satellite clusters (homogeneous and heterogeneous) will be explored in all their dimensions. The range of possibilities is vast, including new architectural concepts in space (for example, reconfigurability, federation, and disaggregation) as well as in-space servicing, assembly, and manufacturing. The Department will address the entire suite of possibilities from conception to operation of these systems. A critical element is how to ensure cybersecurity for these systems. One important metric is the formation of a small satellite center to focus the effort in the Department.

THRUST 3

Aerospace environmental mitigation and monitoring

Addressing anthropogenic environmental and climate challenges is the moonshot of our generation. The aerospace industry is often considered a significant contributor to anthropogenic climate change. At the same time, aerospace technologies can serve humanity in understanding and mitigating our environmental footprint. Currently, satellites play a significant role in Earth observation since they provide much of the data required for analyzing and understanding the anthropogenic climate impacts, both in terms of emissions and climate impacts on Earth's systems: oceans, land, air, and near space. Our understanding of processes in the Earth's atmosphere particularly benefits from continuous remote monitoring and sensing—especially in combination with novel artificial intelligence approaches that enable us to analyze and visualize large amounts of data in (near-) real time. Other applications for aerospace-enabled environmental monitoring approaches with satellites, high-altitude planes, pseudo-satellites, balloons, or drones can include monitoring air quality, traffic flows, disasters, or compliance.

Thrust 3 includes monitoring as well as mitigation, with potential impact areas that range from the health of our atmosphere to oceans to biodiversity, and more. Specifically, we identified opportunities in reducing the environmental impact of aerospace systems (air and space), using aerospace systems for monitoring, designing for efficiency to reduce impact, implementing autonomy, artificial intelligence, and computational engineering, and understanding and mitigating environmental impacts.

EDUCATION THRUSTS

THRUST 4

Lead development of the College of Computing education programs in autonomy and computational science and engineering

The Department has considerable faculty strength in autonomy (including human-robot interactions) and computational science and engineering. Both areas are also vital to a modern view of aerospace engineering and must include issues such as how to enable humans to perform higher level tasks and cyber security. In light of these considerations, the Department will continue to develop and offer degree programs in autonomy and in computational engineering. These degrees will be cross-listed in the SCC and will be supported by the College as well as the Department.

Image credit: Lillie Paquette

Thrust 4: The Interactive Robotics Group uses robots such as Robotina to understand human-robot interaction. Image credit: Joseph Lee/Office of Graduate Education

Thrust 5: Image credit: Lillie Paquette

THRUST 5

Develop education for digital natives and digital immigrants

Thanks to the widespread availability of learning resources on the internet, many students arrive on their first day at MIT armed with digital skills that far surpass those of previous generations. In particular, they know how to navigate the internet to locate information, they can organize online collaboration for class projects, and they know how to create presentations. Traditional teaching methods often do not take advantage of all the new ways students have of learning. If we can align our teaching and leverage the digital skillset of incoming students, we will improve students' overall educational experience, creating an opportunity for leadership both at MIT and globally. In addition, the digital world enables us to develop professional education opportunities for alumni and others that provide tailored means to learn about new fields.

With Thrust 5, we aim to bring the best lecturers and content to the students while allowing for more flexible organization of the actual course work. The Department will explore the development and deployment of a library of digital nuggets by producing high-quality, short and modular aerospace engineering content that are de-contextualized and pedagogically aligned so they can be easily repurposed and integrated across multiple platforms. This includes short course materials, videos, tests, experimentation, etc., in stand-alone bricks that take five to 25 minutes to complete and can be included in any teaching form.

CULTURE & LEADERSHIP THRUSTS

Prof. Wesley Harris with AeroAstro PhD student Lawrence Wong.
Image credit: Joseph Lee/ Office of Graduate Education

THRUST 6

Become the leading department at MIT in mentoring, advising, diversity, and inclusion

Despite a rich history of technical and human achievement, one area where the aerospace field has fallen short consistently is in the inclusion of women and minorities.

The overall conclusion is that the Department, like the national aerospace field, is challenged in inclusion at every level. Data from the MIT academic climate survey indicates that the experience of women faculty is, on average, worse than male faculty. The same also holds true for women graduate students in the PhD program. Our enrolled student surveys tell us that our graduate students express a desire for more frequent and

Thrust 6: Prof. Carmen Guerra-Garcia, whose research focuses on applications of plasmas in aerospace, tests a plasma generation and electrical measurement system with graduate students, Colin Pavan and Yiyun Zhang. Image credit: Lillie Paquette

Thrust 7: Optimus Ride, a startup out of MIT, runs a fleet of self-driving vehicles that operate in areas the company comprehensively maps, or geofences. Prof. Sertac Karaman co-founded the company with several MIT alumni. Image credit: Optimus Ride

better advice and mentoring from the faculty. Further, we also have a retention issue for women faculty, and a related set of issues for women graduate students. Our staff focus groups also tell us that staff do not feel included in the Department.

In Thrust 6, the Department will commit to becoming the Institute leader in diversity, inclusion, advising, and mentoring at every level for every group in our community. We will examine and adopt the best practices through research, discovery, experimentation, and self-examination, and we will track our progress with rigor. These efforts will require close collaboration with the Office of the Vice Chancellor, the associate provost and the Institute community and equity officer.

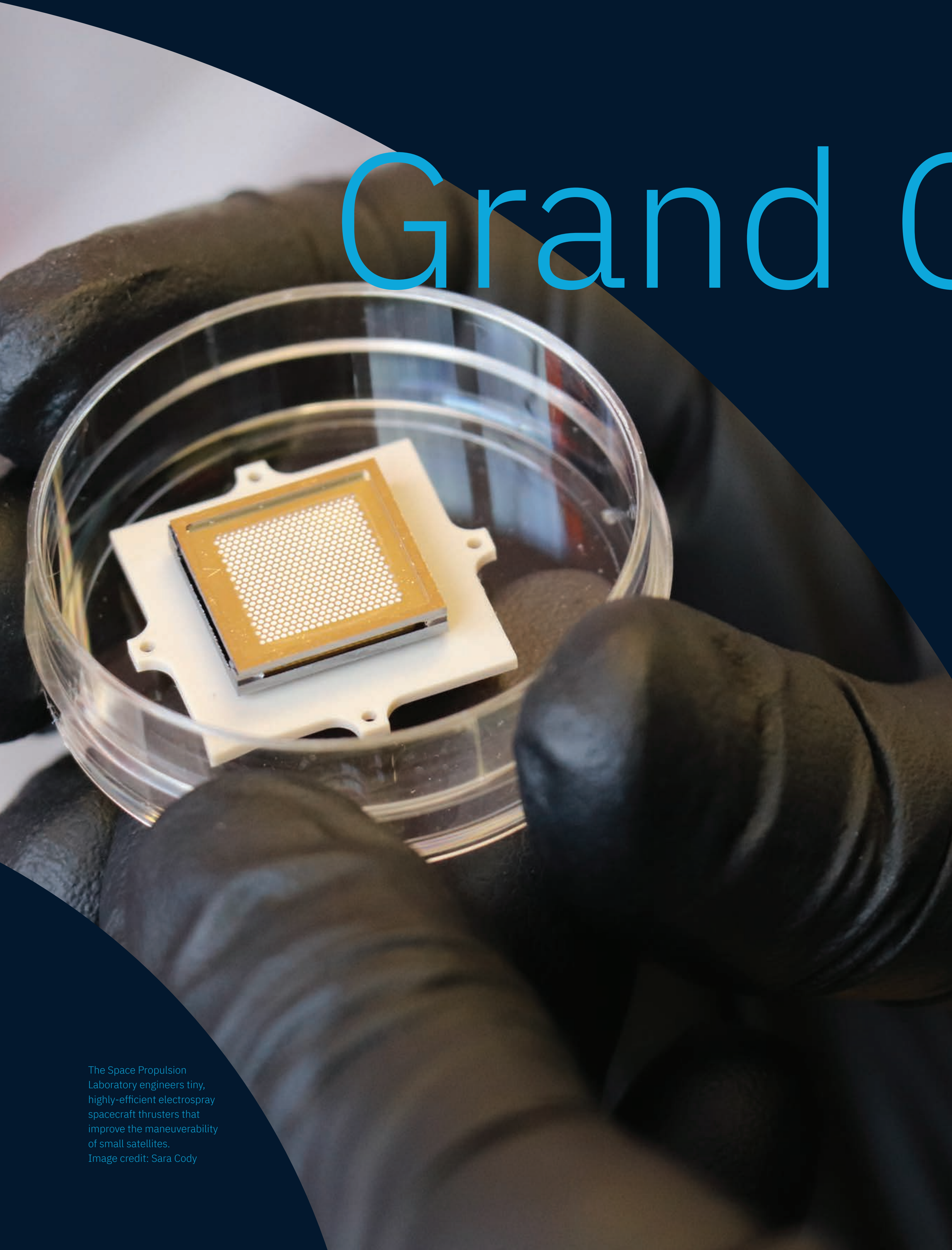
THRUST 7

Make innovation a key component in MIT AeroAstro leadership

The Department has a long history of innovation and solving critical problems; examples range from pioneering work in the early days of flight to fundamental contributions to the Apollo missions. As Silicon Valley and large tech companies are driving innovation and entrepreneurship on the West Coast, AeroAstro is well-positioned to create a similar, entrepreneurial environment that encourages out-of-the-box thinking and realizes the potential of the research produced by the Department. Positioning AeroAstro as leaders in innovation will enable our Department to continue to attract and retain the best students and faculty while making substantial contributions to the field of aerospace.

The focus of Thrust 7 is the cultivation and promotion of the innovative spirit that our department is known for and the dissemination of new innovations in aerospace that the Department produces to local, national, and international communities. We will also commit to innovate through education by finding new ways to effectively educate the next generation of students. There is a broad innovation ecosystem available to leverage at MIT, and we will aim to strengthen our connection to this ecosystem.

Grand C



The Space Propulsion Laboratory engineers tiny, highly-efficient electrospray spacecraft thrusters that improve the maneuverability of small satellites.
Image credit: Sara Cody

Challenges

A "grand challenge" is a large, long-range collective effort of a number of the faculty members that addresses an important challenge of the field.

POTENTIAL GRAND CHALLENGES

Zero space debris

The near-earth space is increasingly contaminated with space debris ranging from dead satellites to spent boosters to pieces of space systems. The problem is likely to grow substantially as the number of active satellites grows due to the launch of large constellations. The vision is to engineer a technical system that would interact with the debris (perhaps remotely) to either bring it down or to move it to a place where it can be repurposed, assuming this made economic and policy sense. The goal is to arrive at a state where there is zero space debris around the earth.

Turing test for UAVs

The Turing test for computers provides a benchmark that will indicate when machines exhibit truly intelligent behavior—when it is indistinguishable from that of a human. For a UAV to pass a Turing test, a remote observer of a UAV flying in a complex environment (e.g. landing and taking off from an uncontrolled airfield in a complex airspace) would be unable to differentiate if it was remotely piloted or if it was piloting itself via artificial intelligence.

Urban air mobility

Urban air mobility (UAM) holds much promise to alleviate congestion by moving a significant fraction of commuters from the roads and into the air. Currently the most popular vision is vertical takeoff and landing (VTOL) vehicles with multiple rotors driven by electric motors, powered by some combination of batteries and turbo-electric generators. But since many small rotors cannot perform an autorotation descent, the required flight-critical power redundancy makes UAM VTOL vehicles have nearly twice the gross weight for a given payload compared to fixed-wing aircraft, and also have inferior speed and range capability. The objective of this grand challenge is to develop a super short takeoff and landing (SSTOL) fixed-wing aircraft with blown lift, which can operate from extremely small airfields, even from heliports.

As we look ahead to the future, we embrace our challenges and opportunities to shoot for the stars.

AeroAstro PhD students Tim McGrath and Jeremy Stroming test out their microgravity erg machine during a MIT Media Lab Space Exploration parabolic flight. Image credit: Steve Boxall/ Space Exploration Initiative

This strategic plan positions the Department well for the next several years by responding to key drivers in the aerospace field. It outlines an exciting future for research and education and addresses the cultural and diversity issue while showing leadership both at MIT and in the field. The seven strategic thrusts build on our inherent strengths, buttress the weaknesses both of the Department and of the aerospace field, seize opportunities, and respond to threats.

Together with our remarkable students, alumni, faculty, and staff, we will shape the future of air and space transportation, exploration, communications, autonomous systems, national security, and education. This is our blueprint for the future.

ACKNOWLEDGMENTS

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