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AEROASTRO

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Cover: As Keith Lockhart leads the Boston Pops and pictures of the solar system glide across a screen, Buzz Aldrin waits to deliver the next portion of his narration of Gustav Holst's *The Planets*. MIT AeroAstro sponsored the special space- and moon-themed concert as part of its "Giant Leaps" events commemorating the 40th anniversary of the first moon landing.

The high point of the Apollo 11 mission is straightforward: **40 years ago, Buzz Aldrin and Neil Armstrong walked on the moon.** More challenging is telling the story of how they got there, what the world learned by watching them, and what the adventure means today.

Perspective is Everything

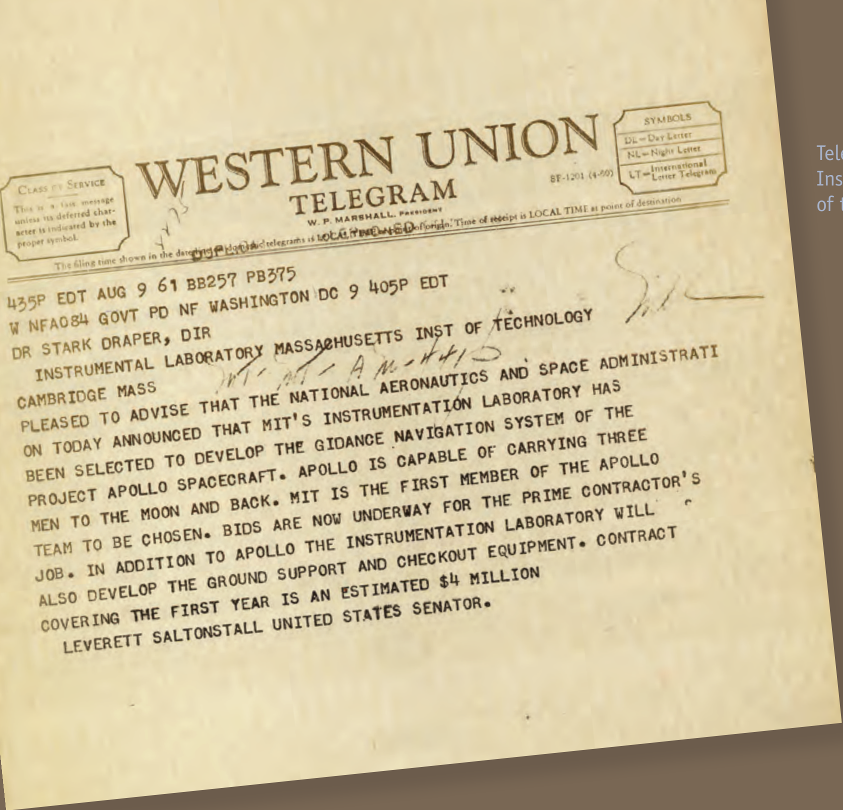
Forty years ago, three men were strapped inside the top of a 363-foot tall rocket at the Kennedy Space Center in Florida; they waited, and the world watched. The rocket lifted off successfully and sent them more than 244,000 miles through space until they entered lunar orbit. Two of the men then climbed into the Lunar Module, detached it from the Command Module, and descended to the surface of the moon.

The Eagle had landed. One small step for a man. One giant leap for mankind. Our perspectives of the moon, the earth, the universe, and what we are capable of achieving, changed forever. The lunar landing was a collaboration of visionaries, politicians, engineers, scientists, managers, and many others. It inspired a generation.

The high point of the Apollo 11 mission is straightforward: 40 years ago, Buzz Aldrin and Neil Armstrong walked on the moon. More challenging is telling the story of how they got there, what the world learned by watching them, and what the adventure means today.

Last year when we began planning MIT's recognition of the moon landing anniversary, we decided from the onset that it would be far more than a social event and a historical retrospective. We would use the opportunity to reflect on the legacy of human space exploration, and discuss how lessons learned can be applied to the future of space exploration and air transportation. This special issue of our annual publication, *AeroAstro*, focuses on the highlights of our commemorative activities.

Our events began in April when we invited women doctoral candidates from leading academic programs around the United States to the first of what will become an annual event; the Women in Aerospace Symposium. (see page 49). The symposium was also the venue for our annual Lester D. Gardner Lecture where our speaker was Yvonne Brill, a veteran of 60 years in aerospace engineering. Our events continued with outreach programs to local schools, and sponsorship of the Sally Ride Science Festival as part of the Cambridge Science Festival.


WESTERN UNION
TELEGRAM
W. P. MARSHALL, PRESIDENT

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DR STARK DRAPER, DIR
INSTRUMENTAL LABORATORY MASSACHUSETTS INST OF TECHNOLOGY
CAMBRIDGE MASS
PLEASED TO ADVISE THAT THE NATIONAL AERONAUTICS AND SPACE ADMINISTRATI
ON TODAY ANNOUNCED THAT MIT'S INSTRUMENTATION LABORATORY HAS
BEEN SELECTED TO DEVELOP THE GIDANCE NAVIGATION SYSTEM OF THE
PROJECT APOLLO SPACECRAFT. APOLLO IS CAPABLE OF CARRYING THREE
MEN TO THE MOON AND BACK. MIT IS THE FIRST MEMBER OF THE APOLLO
TEAM TO BE CHOSEN. BIDS ARE NOW UNDERWAY FOR THE PRIME CONTRACTOR'S
JOB. IN ADDITION TO APOLLO THE INSTRUMENTATION LABORATORY WILL
ALSO DEVELOP THE GROUND SUPPORT AND CHECKOUT EQUIPMENT. CONTRACT
COVERING THE FIRST YEAR IS AN ESTIMATED $4 MILLION
LEVERETT SALTONSTALL UNITED STATES SENATOR.

Telegram of August 9, 1961 notifying the MIT Instrumentation lab of its selection as the first member of the Apollo development team. (MIT Museum)

On June 10, 11, and 12, 2009, MIT AeroAstro held a truly once-in-a-lifetime event, which we named "Giant Leaps." Among Giant Leaps' features were a symposium with many of the engineers, astronauts, and managers who were part of Apollo; a memorial to Apollo program principal architect and former MIT School of Engineering Dean Robert C. Seamans Jr.; an MIT Museum exhibit of Apollo artifacts; a travelling display encouraging young people to consider aerospace careers; and a Boston Pops concert with AeroAstro alumnus Buzz Aldrin (Sc.D. '63) narrating selections from Gustav Holst's "The Planets."

In this issue, you'll read the perspectives of legendary Apollo program members, current aerospace leaders, and of our future aerospace leaders. We considered challenges and opportunities on Earth as they relate to air transportation, the environment, and earth sensing, and challenges and opportunities in space exploration. And, perhaps most importantly, we examined the role that engineering, science, and technology can play in inspiring generations of technical and non-technical leaders.

Included in the back flap of this issue of *AeroAstro* is a DVD that provides a synopsis of the symposium. You can also contact me to request a complete set of DVDs of the events.

MIT, Draper Lab, and Apollo

An important milestone from August 9, 1961 is shown here. It is a telegram announcing the award of the first Apollo contract to the MIT Instrumentation Laboratory. The lab was directed by then Aeronautics and Astronautics Department head, Charles Stark "Doc" Draper. The $4 million contract in 1961 (equivalent to $25–$35 million in today's dollars) represented a significant vote of confidence in the skills and leadership of the students, faculty, and staff of the Department of Aeronautics and Astronautics to rise to one of the greatest technical challenges in history.

The MIT Instrumentation Laboratory developed Apollo's guidance, navigation, control, and computer systems. At the same time, former MIT AeroAstro student, professor, and Dean of Engineering, Robert C. Seamans Jr. was NASA associate administrator and a key Apollo Program manager. The MIT Instrumentation Laboratory was renamed the Draper Laboratory in 1970, and became an independent not-for-profit research and development corporation in 1973. It has continued to be a pioneer in the application of science and technology in the national interest. Thus, it is particularly fitting that the Draper Laboratory is the lead sponsor for Giant Leaps.

In addition to these and many other engineering and management contributions to the Apollo Program by MIT faculty, students, staff, and alumni, five of the Apollo astronauts were trained in the AeroAstro department, including four of the 12 who walked on the surface of the moon: Buzz Aldrin, ScD ’63; Charles Duke, SM ’64; Ed Mitchell, ScD ’64; Rusty Schweickart SB ’56 and SM ’63; and Dave Scott, SM and EAA ’62.

MIT continues in this tradition, with 36 astronauts to date holding MIT degrees — more than any other institution with the exception of the military academies. In October 2008, four MIT astronauts were in space at the same time aboard the International Space Station: Michael Fincke, SB ‘89 in AeroAstro and EAPS; Gregory Chamitoff, PhD ‘92 in AeroAstro; Heidemarie Stefanyshyn-Piper, SB ‘84 and SM ’85 in Mechanical Engineering; and Stephen Bowen, ENG ‘93 in Ocean Engineering.

MIT and the Future of Aerospace

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

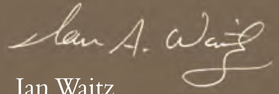
And, while we have many distinguished members, we are a young department with a strong sense of community. We value collaboration — within the department, across MIT, and with colleagues around the world. Our environment is connected, busy, global, hectic, open, collegial, and fun. Recently, we identified eight areas that represent grand challenges and grand opportunities for the department and for aerospace:

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

Through making advances in these and related areas, MIT AeroAstro will shape the future of air and space transportation, exploration, communication, and national security. You can learn more about our activities in these areas in the section of this issue titled Lab Reports (p. 56).

I hope you enjoy reading this issue about both the history of Apollo and the future of aerospace. And, I welcome you to contact me by email (iaw@mit.edu) or visit us in 02139 to learn more about the department.

Sincerely,



Ian Waitz

Jerome C. Hunsaker Professor and Department Head of Aeronautics and Astronautics

The Massachusetts Institute of Technology, the School of Engineering, and the Department of Aeronautics and Astronautics gratefully acknowledge the sponsors of the Giant Leaps commemoration of the Apollo Program.

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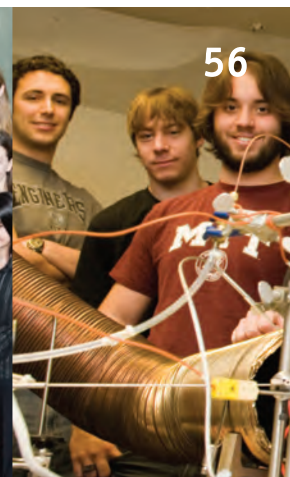
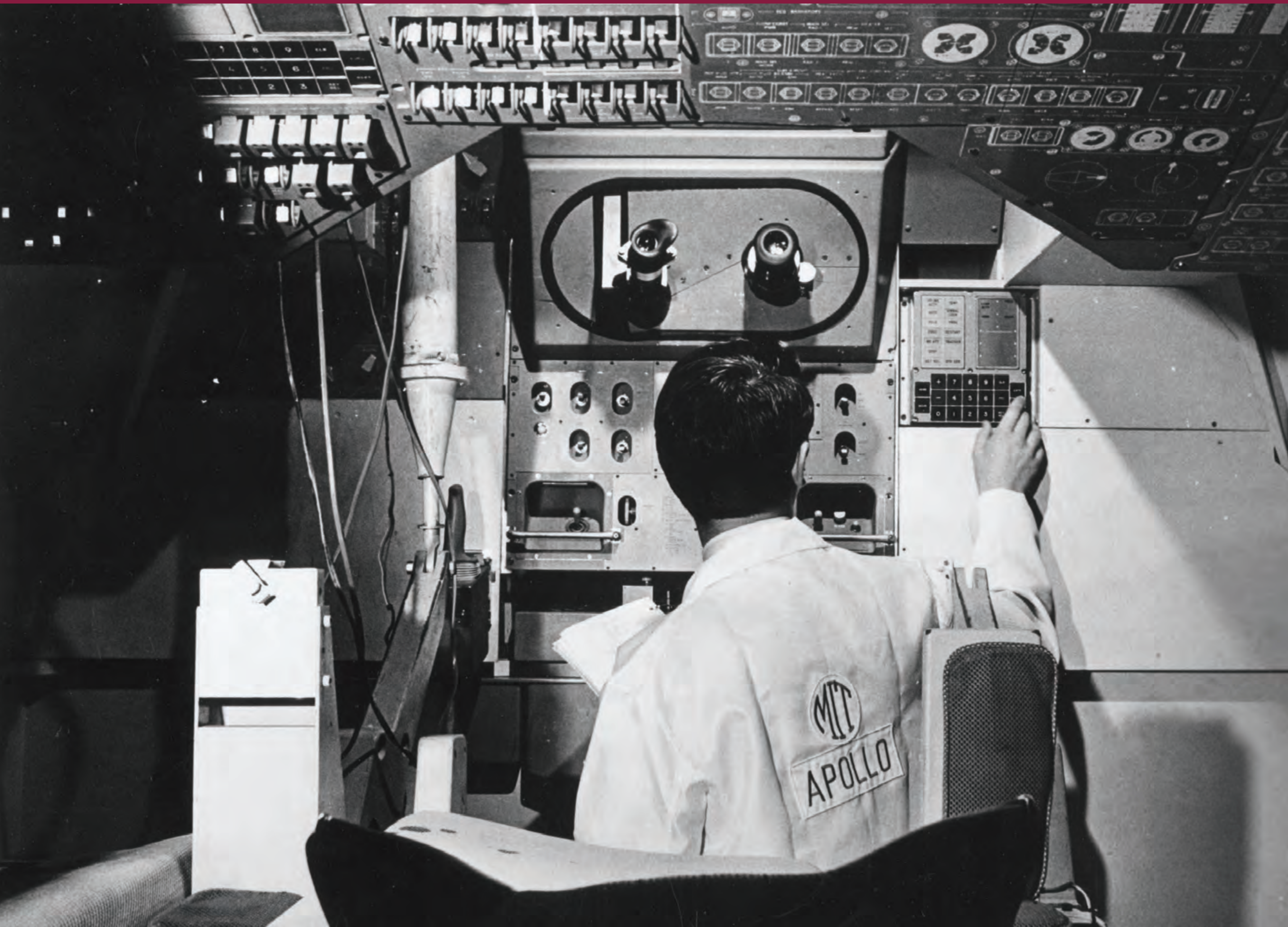
CONTENTS



An MIT Instrumentation Lab engineer checks Apollo Command Module onboard guidance computer programs in a special simulator that could run complete missions to test program accuracy. (Charles Stark Draper Historical Collection, MIT Museum; Courtesy The Charles Stark Draper Laboratory)



MIT AND NAVIGATING THE PATH TO THE MOON

By John Tylko

As NASA was planning the Apollo project in the early 1960s, one of the greatest technical challenges was the problem of navigating a spacecraft from Earth to the moon.

To solve this challenge, NASA selected the MIT Instrumentation Lab to design and develop the onboard guidance, navigation and control systems for both the Apollo command and lunar modules. The first major contract of the Apollo program was awarded to MIT on August 10, 1961. This milestone occurred just 10 weeks after President John F. Kennedy announced the national goal of landing a man on the moon before the end of the decade.

The late Institute Professor Charles Stark Draper recalled a pivotal meeting in August 1961 with NASA Administrator James Webb and Deputy Administrator Robert C. Seamans Jr. (SM 1942, ScD '51, Aeronautics and Astronautics) and, later, MIT Dean of Engineering.

"After some preliminary explanations of the mission plan being considered for Apollo, (we were asked) if guidance for the mission would be feasible during the 1960s decade," Professor Draper said. "We said, 'Yes.' When we were asked if the Instrumentation Laboratory would take responsibility for the navigation and guidance system, we again said 'Yes.' They asked when the equipment would be ready. We said, 'Before you need it.' Finally, they asked, 'How do we know you're telling the truth?' I said, 'I'll go along and run it.'"

Draper followed up with a formal letter to his former student, Robert Seamans, dated November 21, 1961. "I would like to formally volunteer for service as a crew member on the Apollo mission to moon … if I am willing to hang my life on our equipment, the whole project will surely have the strongest possible motivation." At the time, Draper was head of the MIT Aeronautics and Astronautics Department, a post he held from 1951 to 1966.

Although NASA did not take Doc Draper up on his offer to fly to the moon with the astronauts, the MIT Instrumentation Lab delivered on its promise of building a reliable guidance and navigation system using computer technology available in the early 1960s.

The Apollo Guidance Computer weighed 70 pounds, consumed 55 watts of power and occupied only 0.97 cubic feet inside the spacecraft. These first digital flight computers were limited to only 36,000 words of fixed memory and 2,000 words of RAM, and operated at a 12-microsecond clock speed.

The AGC was one of the first computers to use integrated circuits. During 1963, the MIT Instrumentation Lab consumed 60 percent of the integrated circuit production in the United States. By 1964, Fairchild Industries had shipped more than 100,000 ICs for use in the Apollo program. Approximately 2000 man-years of engineering were consumed in the development of the Apollo computer hardware.

ALTHOUGH NASA DID NOT TAKE DOC DRAPER UP ON HIS OFFER TO FLY TO THE MOON, THE MIT INSTRUMENTATION LAB DELIVERED ON ITS PROMISE OF BUILDING A RELIABLE GUIDANCE AND NAVIGATION SYSTEM.

Software for the Apollo Guidance Computer was developed using a mix of assembly language and an interpreted mathematical language. Defined program milestones were adopted for preliminary design reviews, critical design reviews, first article configuration inspection and customer acceptance readiness reviews. Processes for software validation and verification were developed, making extensive use of hardware and software simulators. Before the first lunar landing, more than 1,400 man-years of software engineering effort had been expended, with a peak manpower level of 350 engineers reached in 1968.

During the first manned lunar landing, Apollo 11 astronauts Neil Armstrong and Buzz Aldrin (ScD '63 Aeronautics and Astronautics) reported a series of program alarms indicating that the AGC was overloaded. An erroneous switch position caused the computer to process inputs from the lunar module's rendezvous radar, overwhelming its computational throughput. Despite its overloaded condition, the AGC continued to function properly. With input from flight controllers in the Mission Control Center in Houston, Armstrong made the determination to proceed with the landing.

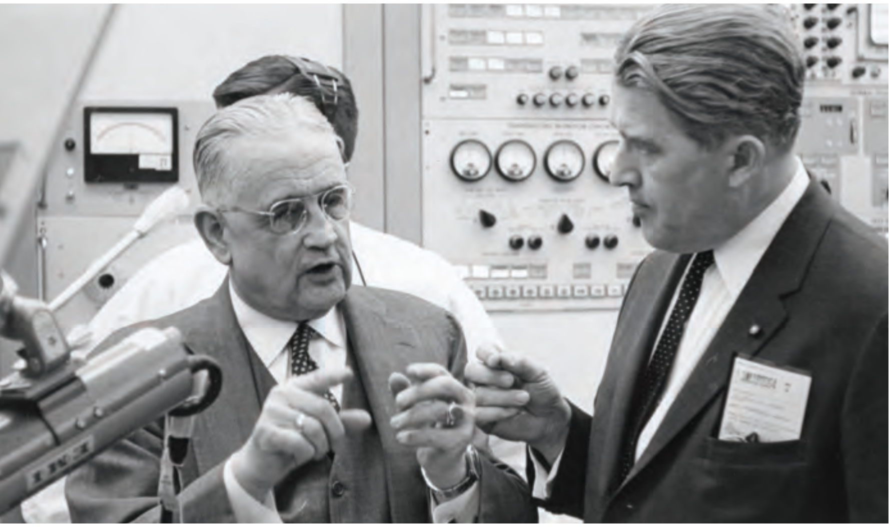
Perhaps the most remarkable example of the capabilities of the Apollo Guidance Computer and the ingenuity of the engineers at the Instrumentation Lab occurred during the Apollo 14 mission, when a faulty abort switch in the lunar module threatened a successful landing. Within two hours, engineers wrote and tested new software commands which allowed the computer to ignore the erroneous abort signal and continue the lunar landing sequence. These commands were verbally transmitted to the astronauts and manually entered into the lunar module's computer, allowing astronauts Alan B. Shepard and Edgar D. Mitchell (ScD '64, Aeronautics and Astronautics) to execute a flawless landing on the moon.

THE GUIDANCE COMPUTER PERFORMED FLAWLESSLY ON 15 APOLLO FLIGHTS FLIGHTS, THREE SKYLAB MISSIONS, AND IT NAVIGATED THE FINAL APOLLO SPACECRAFT TO A DOCKING WITH A RUSSIAN SOYUZ IN 1975.

The Apollo Guidance Computer performed flawlessly on 15 manned flights, including nine flights to the moon and six successful lunar landings. It was used for the three manned Skylab missions and navigated the final Apollo spacecraft to a docking with a Russian Soyuz spacecraft in 1975.

Astronaut David R. Scott (SM and EAA, '62 Aeronautics and Astronautics), who used the Apollo Guidance Computer to navigate on two Apollo missions said, "With its computational capability, it was a joy to operate—a tremendous machine. You could do a lot with it. It was so reliable, we never needed the backup systems. We never had a failure, and I think that is a remarkable achievement."

When a team of engineers from NASA's Flight Research Center visited NASA Headquarters in 1970, they met with the newly appointed associate administrator for aeronautics, Neil Armstrong. They described their interest in demonstrating a fly-by-wire aircraft control



Charles Stark "Doc" Draper (left) tours Wernher Von Braun through the MIT Instrumentation Lab during a March 1964 NASA VIP visit. (MIT Museum collection)

system using an analog computer. Armstrong challenged them to consider using a digital computer instead. "I just went to the moon and back on one," said Armstrong, who suggested they contact the MIT Instrumentation Lab.

In 1972, a modified Navy F-8C Crusader made its first successful flight at NASA's Flight Research Center using a digital fly-by-wire system based on a modified Apollo Guidance Computer and software developed by the Instrumentation Lab.

As the Apollo program came to an end in the early 1970s, NASA asked the MIT Instrumentation Lab to begin developing the space shuttle avionics system. Following its divestment from MIT in 1973, the renamed Charles Stark Draper Laboratory continued the development and testing of the space shuttle's flight control system for both on-orbit and powered flight operations. Draper Laboratory continues to play an active role in each space shuttle mission, verifying that the payload configuration won't cause adverse dynamic interactions with the flight control software.

Forty years later, many members of engineering team at the MIT Instrumentation Laboratory that developed the hardware and software for the Apollo Guidance Computer consider working on Apollo to be the highlight of their engineering careers.

Software engineer Margaret Hamilton captured the spirit of working on Apollo at the MIT Instrumentation Lab. "How fortunate I was to work with and share this experience with the many talented and dedicated people who made this possible. There was no second chance. We knew that. We took our work seriously, many of us beginning this journey while still in our 20s. Coming up with solutions and new ideas was an adventure. Dedication and commitment were a given. Mutual respect was across the board. Because software was a mystery, a black box, upper management gave us total freedom and trust. We had to find a way and we did. Looking back, we were the luckiest people in the world; there was no choice but to be pioneers."

Alex Kosmala started working on Apollo software at the Instrumentation Lab in 1963. "No one in those early days had any notion of the magnitude and complexity of the programming task that Apollo would eventually demand. The word "software" had not even been coined at this time. It was only later that it became evident just how major a component the software would assume in the scheme of things. For a long time after I joined the Apollo program I had no faith that its objectives could ever be accomplished. Although we put in prodigious efforts, each in our assigned area of effort, the scope and magnitude of what yet remained to be achieved never seemed to diminish. And the speed with which President Kennedy's "by the end of this decade" was fast approaching was truly frightening."

"THE GUIDANCE EQUIPMENT FOR THE MISSION WAS CREATED OUT OF PRIMITIVE PRINCIPLES, PROLIFIC IMAGINATION, AND A LOT OF HARD WORK."

INSTRUMENTATION LAB APOLLO TECHNICAL DIRECTOR DAVID HOAG

"In an incredible and audacious task, the landing of men on the moon, the guidance equipment for the mission was created out of primitive principles, prolific imagination, and a lot of hard work," wrote David Hoag (SB '46, SM '50, Aeronautics and Astronautics), Apollo Technical Director at the MIT Instrumentation Laboratory during the 1960s.

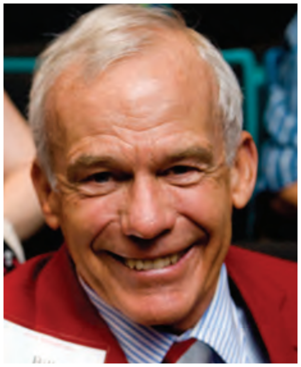
In the foreword of the 1972 report "MIT's Role in Project Apollo," Charles Stark Draper summarized his view of the MIT Instrumentation Laboratory's accomplishments: "Man's rush into spaceflight during the 1960s demanded fertile imagination, bold pragmatism, and creative extensions of existing technologies in a myriad of fields. The achievements in guidance and control for space navigation, however, are second to none for their critical importance in the success of this nation's manned lunar landing program, for while powerful space vehicles and rockets provide the environment and thrust necessary for space flight, they are intrinsically incapable of controlling or guiding themselves on a mission as complicated and sophisticated as Apollo. The great achievement of this Laboratory was to supply the design for the primary hardware and software necessary to solve the Apollo guidance, navigation and control problem. It is to the credit of the entire team that this hardware and software have performed so dependably throughout the Apollo program."

"The Apollo Guidance Computers were early examples of what we would today call 'embedded' computers—which now appear in everything from iPhones to automobiles," says MIT Professor David Mindell, author of "Digital Apollo" which explores how human pilots and automated systems worked together to achieve the successful lunar landing. "The MIT machines showed the world that computers, previously known as refrigerator-sized cabinets, could be made small and reliable enough for even the most demanding, and life-critical applications."

John Tylko is a lecturer in MIT's Department of Aeronautics and Astronautics and is vice president of business development for Aurora Flight Sciences, a company that develops unmanned air vehicles. He co-founded General Computer Company and its spin-off, VideoGuide, and is a recipient of MIT's Founders Award, which recognizes entrepreneurship.

WE ASKED GIANT LEAPS PARTICIPANTS:

WHAT DID THE MOON LANDING TEACH US?



"Apollo let us look back and realize how fortunate we were to be where we were, and we really had to devote a lot of attention to protecting and preserving planet Earth."

BILL WIDNALL, DIRECTED MIT/DRAPER TEAM THAT DEVELOPED APOLLO'S GUIDANCE, NAVIGATION, AND CONTROL SYSTEM.

"I don't believe that either the politicians or we engineers had the vision of what we were about to launch. But in retrospect, what it brought about was a tremendous change in the state of the world."

CHRIS KRAFT, APOLLO FLIGHT OPERATIONS DIRECTOR

"When we started, we didn't know what we were getting into. An expert at Cornell said there was ten meters of impalpable dust on the moon's surface. Fortunately, he was wrong."

JOE GAVIN, FORMER PRESIDENT OF GRUMMAN CORP., HE DIRECTED THE DEVELOPMENT OF THE APOLLO LUNAR LANDING MODULE

"That one idea can change the world — and unite people in a common goal."

CHELSEA HE, MIT AEROASTRO GRADUATE STUDENT

"It takes government, industry, science, and engineers to reach a very complex goal."

AARON COHEN, MANAGER OF THE COMMAND AND SERVICE MODULE IN THE APOLLO SPACECRAFT PROGRAM

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

Reflections on Apollo and the next Giant Leaps

THE GIANT LEAPS SYMPOSIUM

by Dick Dahl

MIT's three-day Giant Leaps event in early June brought together Apollo veterans and modern-day leaders in aerospace engineering, energy, environment, public policy, and education in a rare opportunity to examine the lunar program and how its lessons might be used in the future.

In his introductory remarks at a one-day symposium, Aeronautics and Astronautics Department head Ian Waitz said that MIT saw the 40th anniversary of the lunar landing as a perfect opportunity to look back at the history of Apollo and to future challenges in aerospace. In reflecting on that historic accomplishment, Waitz said that the famous "earthrise" image taken by astronaut Bill Anders stands out as a visual metaphor that MIT adopted for the "Giant Leaps" event.

"I think we all understand that when the world vicariously stood on the moon and looked back at the earth and out to the heavens, our perspective of all three of those things changed," he said. "And likewise, we hope today as we look back on history and we stand here today and then look out to the future, that our perspective will change. We've sought to extend the metaphor yet further for aerospace, not only looking out at the future of aerospace exploration but also looking at earth and air transportation and some of the challenges of energy and environment."

Richard Battin, who became the director of the Apollo guidance navigation system, remembered the earliest days of MIT's involvement. On Oct. 4, 1957, when the USSR touched off the space race with its launch of Sputnik, Battin worked in Draper's MIT Instrumentation Laboratory, located in a less-than-posh space next to the railroad tracks on Massachusetts Ave. With the support of a contract from the Air Force, the lab responded to Sputnik by devising a space vehicle of its own. It became known as the Mars Probe, which its planners intended would pass by Mars and return to Earth. He recalled that the work on the Mars probe, which focused on development of an on-board computer navigation system, continued until the day when MIT received the telegram from NASA announcing that MIT had been chosen as the first Apollo team member, and awarding the Instrumentation Lab $4 million to develop the guidance navigation system.

"What happened to the Mars probe? Well, it never flew," Battin said. "But the computer work for the Mars probe was the basis for the Apollo guidance system."

Aaron Cohen, manager of the Apollo Command and Service Module, recalled that the story of Apollo also included tragedy, such as the fire that took the lives of three astronauts during a service-module test on Jan. 27, 1967. But he pointed out that it was a tragedy that led to great safety improvements.

"There were many changes made to the ... module to make it more reliable and safer," he said. "The most important changes were to eliminate the flammable materials, but also since we never could identify the ignition source, we took great care to protect the wires from being damaged, thus avoiding a spark that could cause a fire. Overall, there were more than 100 changes made."

ONLY 22 (OF 14,000 APOLLO TEST ANOMALIES) DEFIED ANALYSIS. AND IN THE CASE OF THOSE 22 WE CHANGED SOMETHING ANYHOW."

LM PROGRAM DIRECTOR JOSEPH GAVIN JR.

Joseph G. Gavin Jr., director of the Lunar Module Program, recounted the rigorous testing procedures that his group performed — and the ironclad rules that arose from them. One, he said, was "There's no such thing as random failure."

"If indeed the design has been done properly and the environment is understood, there has to be a reason for the failure which you can find and which you can fix. And in the course of 10 years of Apollo we recorded something over 14,000 anomalies from all the test programs. Of those, only 22 defied analysis. And in the case of those 22, we changed something anyhow."

Harrison "Jack" Schmidt, Apollo astronaut and former U.S. senator, summarized Apollo broadly by listing its keys to success.

The second Giant Leaps Symposium panel focused on applying lessons learned from the Apollo Program to the future of energy, environment, and air transportation. The panel, which was moderated by AeroAstro department head Ian Waitz (left) included (from left) director of the president's Office of Science and Technology Policy John Holdren, Boeing Commercial Airplanes V.P. of business strategy and marketing Michael Bair, Department of Energy Advanced Research Projects Agency program manager David Danielson, Pratt & Whitney V.P. for Technology and Environment and AeroAstro professor Alan Epstein, and FAA chief scientific and technical advisor for environment and energy Lourdes Maurice.

The most critical component of Apollo's success, he said, was "the reservoir of young engineers and skilled workers" that were available.

"The average age of the vast majority of the employees in NASA was between 20 and 30 years old," he said. "And you've got to remember that. It is just absolutely critical to have the stamina, imagination, motivation that comes with young people. And if your agency has an average age as NASA does today of about 50 years, you probably are starting out with a problem and you need to figure out how to fix that."

Another, he said, was "adequate management reserves of funding."

"We basically had a management reserve of 100 percent," he said. "You'll never get that today. But it is extraordinarily critical to reduce program risk and human risk in any kind of complex program of this kind."

Christopher C. Kraft Jr., director of flight operations for Apollo, said he felt the overall lesson of Apollo was one of possibilities.

"Apollo taught us we could do anything we set our mind to in this country — anything! — if we know what we want to do, where we want to go and have the commitment to get it done. There are many people who say, 'If we can go to the moon and bring man safely back in 10 years as we did in Apollo, we can do anything.' The problem I have with that is they don't recognize what that means. We need a commitment, a dedication of everybody in this

The Symposium's future of space exploration panelists: (from left) MIT AeroAstro professor Edward Crawley, NASA Goddard Space Flight Center chief scientist James Garvin, Space Adventures vice chairman Richard Garriott, MIT AeroAstro lecturer Erika Wagner, Orbital Sciences CEO David Thompson, Lockheed Martin VP James Crocker, and MIT professor Maria Zuber.

country who matters to make those kinds of things happen. That's what we had for Apollo."

Following the presentations from the Apollo veterans, two panels examined Apollo from a different angle, contemplating how lessons learned from the venture might be applied today and in the future.

John P. Holdren, director of the Office of Science and Technology Policy for the Executive Office of the President, was the keynote speaker of the first panel, which looked at "the next giant leaps in energy, environment, and air transportation. He identified a variety of challenges currently of concern to the nation: economic recovery, health care, reduction of dependence on foreign oil and cutting greenhouse-gas emissions, and homeland security. Looking back at how Sputnik and the space race influenced a generation of young people to enter science, he hoped that "we can inspire a new generation with these major issues to which science and technology have so much to contribute."

Michael B. Bair, vice president, business strategy and marketing, at Boeing Commercial Airplanes, said the same kind of commitment is needed in private enterprise. While the airline industry has had a "pretty remarkable" run in improving fuel efficiency over the last 50 years, "we're running out of ideas" for future improvements. One answer, he suggested, may be biofuels.

Lourdes Q. Maurice, chief scientific and technical advisor for environment at the Federal Aviation Administration, said that in addressing problems of climate change and reducing energy consumption, the U.S. needs to take a more international perspective. "It's not all about the U.S.," she said. "Everyone is going to have some input. Everyone is doing to be part of the decision making and we all have to think a little bit differently."

The final panel, "The Next Giant Leaps in Space Exploration," looked to the future — and, once again, to the stars.


Apollo's flight director Christopher Kraft makes a point during the Symposium session "Apollo: reflections and lessons."

The keynote speaker, Maria Zuber, who heads MIT's Department of Earth, Atmospheric, and Planetary Sciences, described herself as a strong supporter of the space program. But she cautioned that any programs that may be developed for space exploration need to be "reality-based."

"It's great to be a dreamer, but the only good space mission is one that's in space, really working," she said.

Zuber enumerated a variety of specific endeavors that a reality-based space program could encompass: development of a sound plan for the International Space Station, further investigation of "dark energy" in the universe, searching for terrestrial planets beyond earth and around other stars, and the quest for life beyond earth.

James H. Crocker, vice president and general manager for sensing and exploration systems, Lockheed Martin Space Systems, saw a crucial continuing role for NASA in providing "access to space."

"We need to remember that one of the things that NASA does best is build capability," he said. "You can't do things in space if you're not in space."

Richard Garriott, vice chairman of Space Adventures, addressed the future of commercial space flight. The key to developing such an industry, he suggested, is to reduce its costs from the current "tens of millions of dollars" to "a mere millions of dollars."

"My challenge to MIT students specifically is to become part of that journey," he said. "And my challenge to government space programs and private, traditional aerospace is to find a way to partner with and capitalize and take advantage of the technologies that this fledgling industry is bringing to bear versus resist it or ignore it."

By contrast, David W. Thompson, chairman and CEO of Orbital Sciences pointed out that another category of space-related industry is well-developed and thriving. He said that satellites, which provide communication, navigation, and imagery services to consumers on earth, now comprise an industry that generated about 60 percent of the estimated $185 billion spent on space-related activities by public and private interests last year.

MODERATOR EDWARD F. CRAWLEY SUGGESTED THAT INTEREST AMONG STUDENTS TO BECOME PART OF A NEW SPACE EFFORT MAY BE LACKING.

"In a somewhat quiet way over the last 40 years, commercial space ventures ... have found markets where customers voluntarily spend between 15 and 25 dollars per month per subscriber for space-delivered commercial services," he said. "These areas I think provide a very strong foundation for growth across all sectors of the space enterprise in the years ahead."

But panel moderator Edward F. Crawley, the Ford Professor of Engineering in the Department of Aeronautics and Astronautics and the Engineering Systems Division at MIT, suggested that the interest among students to become part of a new space effort may be lacking.

"I find in dealing with our students here that they're not really very excited by the current plan," he said. "They sort of think it looks like something their grandfather did or maybe their father did."

MIT lecturer Erika Wagner agreed, but suggested that creating the same kind of spark that influenced those fathers and grandfathers could happen again.

"I think if we want to get the next generation engaged, we have to do amazing things again and we have to take back the story line and talk about what's hard. I think Kennedy had it right. We were going to go into space because it was the difficult thing to do, and that that was how we inspired the next generation, and that challenges are good."

Dick Dahl is a freelance writer who lives in Cambridge, Massachusetts. Some material for this article was provided by David Chandler of the MIT News Office.

EDITORIAL

APOLLO WAS A SHEER CREATIVE EXPRESSION

by David Mindell

The Giant Leaps symposium was exhilarating. An auditorium full of accomplished scientists and engineers was reminded of why we got into the business of technology in the first place. From the president of MIT to our current students, the excitement of human spaceflight, particularly the Apollo program, has had an impact on us all. The panelists were simply legends whose names we all grew up with—Armstrong, Aldrin, Battin, Cohen, Gavin, Kraft, Mueller, Schmitt, and Sorensen.

Apollo was, of course, a product of its time, as Ted Sorensen so clearly articulated when describing its Cold War origins. Yet at that moment when "The Eagle has landed" (or "One small step for man") Apollo rose above that history. There it stands, by itself 40 years later, as a technological accomplishment that has not been superseded by Moore's law, DNA sequencing, or any other breakthroughs since then. We hear that technology is incremental, that it progresses in an ever upward arc of physical parameters. Apollo showed how a perfect storm of politics, management, engineering, and operations can leap ahead of those ordinary rules.

We also hear that engineering is about solving problems to improve the human condition, and undoubtedly that is often true. But Apollo points to another, perhaps deeper motivation for engineering: the sheer creative expression of conceiving and building new technologies.

Like poets or philosophers, engineers' wondrous creations are meditations on the human place in the universe, on the human relationship to machines, on the nature of human experience. The Apollo Program broke new ground in all three.

To the challenges of the future, the Apollo model may not be the way to go. Kennedy's "Man, moon, decade" provided a clear, straightforward challenge with no ambiguity as to its success. Today we face problems (like the future of human spaceflight, as well as energy independence and climate change) that are large, vaguely defined, with a host of stakeholders and non-linear interactions. But the Giant Leaps Symposium showed what aspects of Apollo are relevant to our future: the ambition to tackle a problem that may not be solvable, the values of disciplined engineering, the willingness to take risks to achieve a higher goal, and the creative energies unleashed by an inspired project. Forty years from now, we will be celebrating tomorrow's Apollo project, whose seeds and future leaders are undoubtedly on our campus today.

David A. Mindell, an engineer and historian, is the Dibner Professor of the History of Engineering and Manufacturing and the director of MIT's Program in Science, Technology and Society. His most recent book is "Digital Apollo: Human and Machine in Spaceflight." He may be reached at mindell@mit.edu.

WE ASKED GIANT LEAPS PARTICIPANTS:

WHAT IS THE FUTURE OF SPACE EXPLORATION?

"This idea that you and I can go into space, that we can take a vacation, go to a spaceport. Hop on board a spacecraft and go up and see the blackness of space and the earth falling away below us."

ERIKA WAGNER, LECTURER AND INSTRUCTOR, MIT

"It's a bright future. I feel confident that eventually we will get back to the moon and go to Mars. There are a lot of demands on our country right now, but my fervent hope for my students is that they have that opportunity."

AARON COHEN, APOLLO PROGRAM COMMAND AND SERVICE MODULE MANAGER

"That in the next 50 years we'll be able to visit every planet in our solar system."

JOSHUA JACOBO, GRADE 8, LAWRENCE (MA) FAMILY DEVELOPMENT AND CHARTER SCHOOL

"The next challenge is to go back to the moon. And not just go there and touch it. This time we're going to go with the intent of staying."

WILLIAM GERSTENMAIER, NASA ASSOCIATE ADMINISTRATOR

"For greater distances and worse environments, I think we're going to be doing it robotically for a long time. One of the things you learn in the aircraft or space industry is that providing for the pilot or the crew is a very complicated business. If you can avoid that, things are much simpler. My friends in Houston would not enjoy that comment."

JOE GAVIN, FORMER PRESIDENT OF GRUMMAN CORP., WHERE HE DIRECTED THE APOLLO LUNAR LANDING MODULE DEVELOPMENT

Former astronaut Neil Armstrong, speaking at MIT's June 11 memorial to his former NASA boss, Robert C. Seamans Jr. On the stage with Armstrong are (from left) Carnegie Institution for Science president Richard Meserve, Kistler Aerospace CEO and former Office of Manned Space Flight associate administrator George Mueller, and MIT AeroAstro Apollo Program Professor Lawrence Young. Not pictured, but also on the dais, were Apollo guidance, navigation, and control director Richard Battin, MIT Institute Professor Sheila Widnall, and MIT AeroAstro professor Edward Crawley.

Celebrating the life of
ROBERT C. SEAMANS JR.

by Louis Padulo

As part of the Giant Leaps celebration of the 40th anniversary of the moon landing, AeroAstro hosted a memorial gathering to celebrate the life and accomplishments of Robert C. Seamans Jr.

Robert C. Seamans Jr. was a principal architect of the Apollo Program. Seamans, a former professor of aeronautics and astronautics and dean of engineering at MIT, passed away in 2008. He also served as deputy and then acting administrator of NASA, president of the National Academy of Engineering, secretary of the Air Force, and he was the first administrator of the Energy Research and Development Administration, the precursor to today's Department of Energy. As Ian Waitz said at the start of AeroAstro's memorial for Bob, "More than a year ago we started planning these events and we assumed that Bob Seamans would be an important part of the events, and we expect he would have very much enjoyed being part of the events. And when he passed away, we felt the best way to keep him as a very important part of the event was to join these celebrations with a commemoration of his life."

I always knew that Bob Seamans had a lot of friends. I was proud to be one of them, having worked for Bob at RCA — three years before becoming his son-in-law. I also knew that Bob had a host of professional contacts and quite a few organizations whose "causes" he encouraged and supported. When Bob died last summer, and his wife and five children planned funeral arrangements, my job was to notify friends and contacts of his passing and tell them about the church service on July 2nd. I sat in Bob's study and, using his lists and directories, emailed all his contacts for whom I could find addresses. Recognizing that many friends might be away for the 4th of July or summer holidays, I mentioned that the family hoped to celebrate Bob Seamans' extraordinary life and accomplishments along with his professional and civic colleagues on some future occasion.

Well, I never got as much email in my life as I did in response to that message. In addition to the outpouring of condolences and the overflow crowd that made it to St. John's church in Beverly Farms, Massachusetts, there quickly developed a queue of institutions and organizations offering to host such a Seamans celebration. The common thread in these invitations was: "We'd like to host the ceremony honoring Bob — he loved and helped us a lot, and we loved him."

Had Bob Seamans still been with us, he would have continued to mentor and support all those organizations he cared for, but he would have really gotten his juices flowing by working with the MIT AeroAstro Department to organize a symposium celebrating the Apollo Program and contemplating "next steps" for the future. One of the principal architects of Apollo, Bob would have been a key speaker and panelist in that symposium and would have enjoyed himself immensely, reminiscing with peers and colleagues and helping chart a course for the next generation of students, faculty and citizens.

Thus, when Ed Crawley and Ian Waitz proposed that AeroAstro would honor Bob with a special commemoration ceremony as part of the Giant Leaps Symposium, the Seamans family was thrilled to accept. Of all the organizations so dear to Bob, none were dearer than AeroAstro and MIT. As Ed and Ian pointed out, Bob was a student there, met and worked with Doc Draper, became a professor and a dean of engineering (a high calling), before, between, and after his RCA, NASA, Air Force, ERDA, and National Academy of Engineering appointments.

Generously, MIT's AeroAstro Department offered to not only host the Seamans celebration, but to invite Bob Seamans' "significant other" organizations to participate and contribute to it as well. Many of those organizations did participate and shared their perspectives on Bob and his life. So did a number of AeroAstro graduate students who read passages they selected from Bob's charming autobiography "Aiming at Targets." A video produced by the department (on the DVD included with this issue of *AeroAstro*) permitted some participants unable to attend in person to reflect on aspects of Bob Seamans' contributions. Several people at the ceremony spoke from the floor microphones and, before we knew it, it was over. A raucous, joyous, jazz band led us all, New Orleans style, to a reception and informal mingling of relatives, colleagues and symposium attendees.

On behalf of all those organizations and people with whom AeroAstro shared the occasion, Gene Seamans and her family thank Bob's MIT family for making the ceremony such a memorable celebration of a life well lived.

Louis Padulo, President Emeritus of Philadelphia's University City Science Center, was invited by AeroAstro to help organize and MC the Robert Seamans commemoration. Louis earned his Ph.D. (in EE) at Georgia Tech under B.J. Dasher, an MIT contemporary of Bob's, was an engineering professor at Stanford; served as engineering dean at Boston University while Bob was dean at MIT; and was president of University of Alabama in Huntsville. He is an adjunct professor at Penn State and Princeton where he teaches product design.

Following are excerpts of the many accolades, remembrances, and thoughts about Bob Seamans delivered by his friends, family, and colleagues at the Seamans Memorial event.

DICK BATTIN

APOLLO GUIDANCE, NAVIGATION, AND CONTROL DIRECTOR; AEROASTRO SENIOR LECTURER

1951 was an important year. It was 10 years before the MIT Instrumentation Laboratory would be chosen for the Apollo guidance system. In 1951, the Whirlwind computer, which was MIT's project, had a little over 1,000 words of memory and it consumed so much power that before you could turn it on you had to call the electric utility because it was going to be a big drop. Ten years later we built computers that could fly to the moon. Also in 1951, Bob Seamans became Doctor of Science. He had worked with Doc Draper from 1940 and, modestly, 1951 was when Richard Battin received a Ph.D. in applied mathematics.

Much later, when Bob was a senior lecturer at MIT, he helped me with some freshmen seminars. He would call me up and say, "I'd like to be on your seminar." And he was so attractive to these young teenagers and he was willing to talk to them well into the early evening. Last winter, while he was in failing health, he drove in on a cold and blustery day to my winter lecture on MIT and Apollo. As he said, it was to keep me honest! The world has lost a giant. And he will always be remembered as such.

CHARLES VEST

MIT PRESIDENT EMERITUS AND NATIONAL ACADEMY OF ENGINEERING PRESIDENT (VIA PRE-RECORDED VIDEO)

One of the most amazing things that ever happened to me in my life was I spent a long evening over dinner in the outskirts of Houston with Bob Seamans. And Bob began to reminisce in great detail about the Apollo program, how did it come about, how he experienced it, what it meant, how people reacted. He told me things that just have stuck with me ever since. One was that President Kennedy had been convinced that he should go before the Congress and the American people and announce that America needed to send a man to Mars and back before the decade was out. Bob told me the story of working three days and nights trying to put together, clearly and succinctly, the case for the president that we cannot hit that goal; we need to go to the moon. I've just never forgotten that, because suppose that the president had gotten up in this inspirational speech and set a goal that was not only audacious but couldn't be accomplished. The goal had to be right and Bob played a very major role in doing that.

LARRY YOUNG

MIT AEROASTRO APOLLO PROGRAM PROFESSOR

Bob made countless crucial leadership decisions, which benefited our country in space, in the military, in energy, and then back at MIT as well. What was it that made (Bob) so effective? He had an engineer's viewpoint towards solving tough problems. He was doing systems engineering before it became a buzzword. He had the ability to concentrate on finding the solution rather than argue about the pros and cons of competing approaches. And he was willing to listen, listen to unpopular or even eccentric opinions and form his independent conclusions. A prime example is his treatment and, finally, adoption of the concept of landing on the moon using lunar orbit rendezvous.

The risky, yet energy efficient way to go involved landing a small craft on the moon while keeping the larger return vehicle in lunar orbit. But this involved the single point failure risk of a botched rendezvous. In his wonderful, informal discussions with our class, and again in his book, Bob relates how he understood the criticality of making the rendezvous in far off lunar orbit, but based upon his experiences with Doc Draper and the gunsight development during the war, which also involved having two objects moving quite fast and meeting exactly at a distance, he was sure the lunar orbit rendezvous could be pulled off. And Bob was crucial in bringing NASA to that decision.

GEORGE MUELLER

CEO OF KISTLER AEROSPACE AND FORMER OFFICE OF MANNED SPACE FLIGHT ASSOCIATE ADMINISTRATOR

I was head of the Office of Manned Spaceflight, reporting to Bob. His first assignment was to ask me to review the program and the schedule as he was afraid that we would not be able to meet President Kennedy's goal of a manned lunar landing and return within the decade, without some fundamental changes. I did a thorough review and he was indeed correct. We needed to make some dramatic changes. One change was he introduced the concept of all-up testing. That is to flight test the very first vehicle with all three stages and the two payload stages assembled and active. This was a radical departure from the practice of Marshall and of Houston and met a sizeable resistance. And the very next management meeting in Huntsville, Arthur Rudolph cornered Bob by the models of the Saturn V and the Jupiter and asked him how could one possibly test all the huge stages of Saturn V at the first firing? Bob said, "Talk to George." Arthur went on to try the same argument on me. I simply said, "Why not?" And of course I had to back that up with some thorough and logical details of exactly how we should proceed. With Bob on board I must say all three centers embraced the concept, and best of all, it worked!

EDWARD F. CRAWLEY

FORD PROFESSOR OF ENGINEERING AEROASTRO AND MIT ENGINEERING SYSTEMS DIVISION

(Speaking of lessons he learned from Bob Seamans) Should we rendezvous in low earth orbit or not? (Bob) explained very carefully how he had much earlier than anyone thought at the time, come to the conclusion that LOR (lunar orbit rendezvous) was the right answer. But that he did not think that he could impose that decision on the organization. He hired Joe Shay to go to the manned spaceflight center and convince the organization that this was the right thing to do. Lesson: Don't force your decision on an organization even if you're a boss.

Bob explained to me how John Hubolt had twice risked his career by sending letters around all of the NASA hierarchy directly to Dr. Seamans, to argue persuasively for the LOR approach. Lesson: Have intellectual courage.

He told me of the meeting that he had at the White House when the decision about LOR actually went to the president and in the room were Jack Kennedy, Jerome Weisner, and Bob in the Oval Office. The president looked at Jerry Weisner and said, "Well, Jerry what do you think?" The scientific community was still backing the so-called direct or Von Braun approach in which one capsule would go all the way to the surface of the moon. And Jerry again argued for that approach. And Jack Kennedy turned to Jerry and said, "We should really listen to the people from NASA because they're the people who are going not have to do this and who knows Jerry, you and I may not be around to see it." Lesson: Make sure you listen very carefully to the people who have to execute the work before making a decision.

Bob Seamans (Courtesy Seamans family)

When the results of (NASA's Exploration Systems Architecture Study) started coming out in 2005, this generation's version of the LOR debate, Bob was brought in by NASA to be a graybeard and by coincidence he and Aaron Cohen were at the faculty lunch one Wednesday when the report was actually issued. And we hurried back up to my office, downloaded it from online and found that it looked much like Apollo. Aaron looked at and said, “You know what they’re going to learn from this Bob? Just how hard it is to go to the moon.” And Bob looked at Aaron and said, “And just how lucky we were.”

NEIL ARMSTRONG

FORMER ASTRONAUT AND UNIVERSITY OF CINCINNATI AEROSPACE PROFESSOR

President Kennedy had noticed the remarkable impact (of the first U.S. manned spaceflight) on the public, both here and abroad. And it was confirmation that NASA could be depended upon. And, Bob Seamans was dedicated to making the U.S. preeminent in space. He strengthened his organization. He found ways of attracting superior people to join the effort. He worked with the bureau of the budget and the president and the Congress to strengthen the budgets. Bob was genuinely interested in detail, in addition to getting a cockpit check in Mercury from John Glenn and talking with John Hubolt about lunar orbit rendezvous, he actually rode with me in the Gemini orbital docking simulator to understand the details of how it could really work. That engineer in him would not allow him to manage without understanding those details.

Dr. Robert C. Seamans Jr. was a leader of great ability at a critical time in the space race and we remember him with great warmth, admiration, and respect.

SHEILA WIDNALL

MIT INSTITUTE PROFESSOR

One thing that Bob and I shared was our attachment to another flag, the flag of the secretary of the Air Force. When I was offered the position of secretary of the Air Force, I was wind surfing in Aruba. And I came into the board shop dripping wet to make two phone calls. One was to Chuck Vest and one was to Bob Seamans. Bob was very encouraging and said that I would be great and that it would be great fun and that I should definitely take the job.

After two years (as Air Force secretary), Seamans informed Secretary of Defense Melvin Laird that he wished to extend his tour to complete or initiate several projects. He wanted to place the C-5 contract with Lockheed on a sound basis. He wanted to resolve the F-111 cost and technical difficulties. He wanted to move new programs such as the F-15, the B-1, the AWACS, and the AX and the F-5E to the point where the Air Force could be confident in its policy of "fly before buy." And he wanted to improve military and civilian personnel policies. However he stated that his willingness to stay with DOD depended on the administration's determination to terminate U.S. activities in Southeast Asia. President. Nixon credited Seamans with keeping the Air Force modernization program cost so very close to projected estimates, and for creating an environment in which people serving in the Air Force believed they could realize their potential.

RICHARD MESERVE

CARNEGIE INSTITUTION FOR SCIENCE PRESIDENT

Bob was elected a trustee of the Carnegie Institution in 1974. And we were privileged to have his support and guidance for 34 years.

As I looked back in our file about Bob, I found materials arising from a lecture on energy policy that he gave at Carnegie in 1977, shortly after he left his post as the administrator of the Energy Research and Development Administration, which was the predecessor of the Department of Energy. If people had listened to Bob, we would not be in the energy bind in which we find ourselves. Bob made the following points: He observed that 75 percent of the energy consumption in this country was based on dwindling assets, gas, and oil. And he urged that we get out of the gas and oil cul-de-sac. We're now up to about 80 percent. He noted that there historically had been a long period of transition from one fuel to another, typically about 60 years between peak usages. And he observed that we had less than 60 years to make that transition. He was optimistic about alternative energy supplies, including nuclear power. And he did acknowledge however that the big practical problem with nuclear reactors was the disposal of spent fuel.

He observed the great opportunities in energy efficiency that were possible, citing the prospect for greatly improved automobile fuel economy, the application of new types of building design, the recycling of industrial heat, and effective use of cellulosic materials. He saw that efficiency measures could reduce consumption very significantly over the following years. He saw the problem as extremely difficult, but solvable. Given our current situation, albeit with the new dimension of climate change, we simply should have listened.

PAUL GRAY

MIT PRESIDENT EMERITUS

Bob's deep loyalty to MIT was again evident in 1978 when he accepted my invitation to serve as Dean of the School of Engineering. He both provided effective leadership of the school, a school that represents fully half of the Institute's educational, and research activities. And he contributed wisely to the governance of MIT as a member of the Academic Council. As a distinguished public servant and public citizen, as an engineer and a manager of complex engineering efforts, as a leader of men and women, as a loyal son of MIT, and as a colleague and friend, Bob Seamans "left campground in better shape than he found it," to borrow a phrase from Carl Taylor Compton. May memories of his life continue to inspire all of us who loved him.

SUSAN HOCKFIELD

MIT PRESIDENT

I want to describe only three of the many remarkable ways Robert Seamans served the nation and the world. First, he was a superb engineer. He taught himself to be a great leader of people. In 1968, when he returned from NASA to teach at MIT, MIT's then president, Howard Johnson, hailed Bob's ability to "marshall diverse technological resources for the achievement of major national goals." A quality as rare then as it is today. Bob carried on the finest MIT tradition of bringing to bear first class technical expertise to master the great problems of the day.

Second, he was an enthusiastic and beloved teacher well into his 80s. Yet he deliberately chose not to make teaching his only career because he understood deeply one of the principles that animates MIT right up to today: the transformative power of integrating teaching with front line research.

Third, he demonstrated an unswerving commitment to national service at the very highest level and at great personal cost. Punctuating his autobiography are multiple tales of Bob arranging a few rare days off, only to find himself on a sailboat in a foggy Maine harbor with someone rowing alongside to announce that he was needed in Washington. To MIT, to the space program, and to America's science and technology leadership, Bob Seamans left an incomparable legacy.

WE ASKED GIANT LEAPS PARTICIPANTS:

WHAT INSPIRES YOU?

"Mr. Kennedy. He was the man who made me work 24 hours a day."

CHRIS KRAFT, APOLLO FLIGHT OPERATIONS DIRECTOR

"The Earth. It's been through so much, but it's still spinning."

LAUREN V. GALLOWAY, GRADE 7, BOSTON LATIN ACADEMY

"The determination and brilliance of those in the Apollo program inspires me to follow their example — to work hard in pursuit of a noble goal 'for all mankind,' and never accept that any dream is too big."

HEMANT CHAURASIA, MIT AEROASTRO GRADUATE STUDENT

"People who do things others say are impossible."

JACQUELINE SOEGAARD, MIT FRESHMAN

"Thinking about how technology intersects with politics and society and economics."

ERIKA WAGNER, MIT AEROASTRO LECTURER AND INSTRUCTOR

"How fast technology moves. And once you have the next big idea, everybody just jumps on board and works towards it."

CHELSEA HE, MIT AEROASTRO GRADUATE STUDENT

"(In 1928) we got within 15 feet of Lindberg, and about the same distance from his airplane. From that point on, flying machines were my interest — doesn't matter if it's airborne or in orbit."

JOE GAVIN, FORMER PRESIDENT OF GRUMMAN CORP., WHERE HE DIRECTED THE DEVELOPMENT OF THE APOLLO LUNAR LANDING MODULE

"MIT inspires me."

IART GASHI, GRADE 8, BOSTON LATIN ACADEMY

While Keith Lockhart leads the Boston Pops Orchestra, Buzz Aldrin leads the MIT audience on a tour through the solar system as he narrates Gustav Holst's acclaimed orchestral suite, "The Planets."

The Boston Pops
A SPACE TRIP OF THE IMAGINATION

On October 29, 1918, an intimate group of 250 people gathered in London's cavernous Queen's Hall to hear British composer Gustav Holst premier his seven-movement orchestral suite, "The Planets."

More than 90 years later, in Boston's Symphony Hall, a group eight times that size was treated to the composer's sonic tour of the solar system — narrated by Apollo astronaut and Aero-Astro alumnus Buzz Aldrin.

The event was sponsored by MIT as part of the Giant Leaps Apollo Program 40th anniversary celebration. The packed house of 2,000 comprised invited luminaries; MIT faculty, staff, students, and their guests; and 200 local children invited by AeroAstro for the once-in-a-lifetime experience of taking a journey of the imagination lead by one of history's most famous explorers.

While a video trip through space and time by Dr. José Francisco Salgado of Chicago's Adler Planetarium played on a giant screen, Aldrin lent both depth and drama to movements from the crashing and vibrant "Mars: The Bringer of War" to the ethereal, distant and murky wash of "Neptune." As the second of only 12 people who have walked the lunar surface, Buzz spoke with unique perspective on what he sees in the night

sky: indeed he was the perfect guide to lead listeners, through words, music, and images, to the edge of their celestial neighborhood.

The Boston Pops performance continued with popular favorites for all the aerospace fans in the audience, including the themes from "Star Wars," "Star Trek," and "Close Encounters of the Third Kind," and a "moon-tune sing-a-long" that had the entire audience standing and singing. The Boston Children's Chorus then came to the stage to sing John Lennon's "Imagine" as many in the audience waved blue lightsticks. The evening concluded in classic Pops style with "Stars and Stripes Forever."

WE ASKED

GIANT LEAPS PARTICIPANTS:

HOW SHOULD WE OVERCOME ENVIRONMENTAL CHALLENGES ON EARTH?

"Treat it like we did Apollo — set a goal and keep your eye on it … the future is what we imagine it to be."

LOURDES MAURICE,
CHIEF SCIENTIST FOR THE ENVIRONMENT,
FAA OFFICE OF ENVIRONMENT AND ENERGY

"We should start to think about what is really happening, because if we don't we are going to be lifeless, like other planets."

JOSH BIALKOWSKI, MIT AEROASTRO GRADUATE STUDENT

"By using the different branches of engineering to design new, more efficient and self-sufficient ways to lead our lives so as to decrease our harmful impact on the planet."

JACQUELINE SOEGAARD, MIT FRESHMAN

PRESIDENT BARACK OBAMA, IN A SPEECH TO THE NATIONAL ACADEMY OF SCIENCES, APRIL 27, 2009

"Think about new and creative ways to engage young people in science and engineering — like science festivals, robotics competitions, and fairs that encourage young people to create, build, and invent and to be makers of things."

Visitors to the MIT Museum during the Giant Leaps celebration were treated to a preview of the new MIT/Boston Museum of Science traveling exhibit about aerospace challenges and the young engineers who are meeting those challenges. The exhibit was written by MIT science and technology curator Deborah Douglas and AeroAstro communications director Bill Litant, and designed by Emily Roose and Lana Parks of the Science Museum.

Making the next Giant Leaps:
LOOKING AT THE FUTURE

The first human set foot on the moon more than four decades ago. Since then, we have built an international space station, sent rovers to Mars, and discovered planets orbiting other suns.

Giant Leaps was more than a historical retrospective. It was more than applying lessons learned to today's challenges. It was also a look to the future. And the future of aerospace is in the hands of young people whose interests are still fluid. We want to excite children and teens about air and space and engineering. So, AeroAstro and the MIT Museum partnered with our friends at the Boston Museum of Science to create a traveling exhibit that talks about cool challenges in transportation, while, at the same time, highlights some young people who are tackling those challenges. The exhibit, which takes the form of seven large banners, each featuring a person, or a group of people, premiered at the MIT Museum during Giant Leaps. Over the next year (or more) copies of the exhibit will travel to schools and museums throughout the country to inspire the next generation of giant leapers.

On the following pages appear excerpts from the exhibit banners.

BUZZ ALDRIN

"I'm making sure not to lock the hatch on my way out."

JOB

Air Force fighter pilot, astronaut

FAVORITE ACTIVITIES

Talking and writing about space, deep sea diving, skiing, travelling around the globe (his next goal is to trek around the South Pole!)

Fun facts

The Disney character Buzz Lightyear is modeled after Aldrin.

The MTV Video Music Award statuette of the moonman is called the "Buzzy."

Buzz Aldrin was walking on the Moon

Buzz Aldrin loves flying and exploring. He is best known as the second man to walk on the moon, following in the footsteps of Neil Armstrong in 1969. Aldrin continues ground-breaking work in space research, building on his PhD thesis on orbital rendezvous to design a spacecraft that continuously loops between Earth and Mars. He is still an avid explorer traveling by icebreaker to the North Pole and mini submarine to the wreckage of the Titanic.

Photo Album

Buzz (on the left) was third in his class at West Point

Buzz flew combat missions in Korea as an Air Force ace

Buzz on EVA (spacewalk) during the Gemini 12 mission

The ticker tape parade to welcome the astronauts home was the largest in New York's history

In the cockpit of the Gemini 12 spacecraft

Neil Armstrong, Mike Collins, and Buzz, the crew of Apollo 11, had to work very hard to remain calm when they learned the mission would land on the moon

DAVA NEWMAN

"We need to shrink wrap the astronaut"

JOB

MIT professor of Aeronautics and Astronautics and director, MIT Technology and Policy Program

FAVORITE ACTIVITIES

sailing, scuba diving, nature, listening to music, laughing

Interest

Galatea

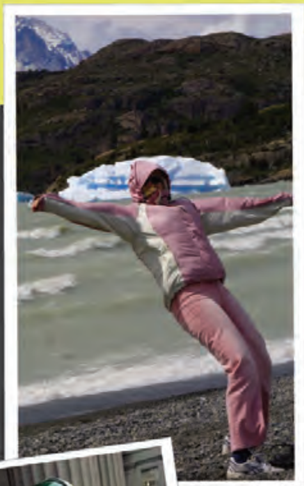
Dava's love of exploration isn't confined to outer space. She and Gui spent a year sailing around the world on their ship Galatea, teaching hundreds of children about living in space and sea.

Dava Newman is making space suits for Mars

Space suits don't need to be awkward and bulky, they just need to apply a constant pressure on the skin. Dava is working on wrapping astronauts in flexible, breathable fabric. Overcoming the challenges involved require understanding of how the body moves, modeling that motion in 3D, and designing embedded electronics to assist motion. Our BioSuit™ System provides a "second skin" that brings together advanced technologies, human modeling, creative design, and aesthetics.

Photos courtesy of Dava Newman

Dava's Photo Album



The 70 knot wind at the Grey Glacier in Patagonia, Argentina

Onboard the Galatea with my partner Gui

Our robotic space suit tester is called M. Tallchief after the ballet dancer

Gui and Dava in Baikonur Cosmodrome for the Soyuz launch in Fall 2008

The MIT BioSuit™

The MIT BioSuit™ in the Rocket Park at Kennedy Space Center

DESIGN/BUILD/FLY

“To invent an airplane is nothing. To build one is something. But to fly is everything.”

OTTO LILIENTHAL, 19TH CENTURY CALCULATION PIONEER

TEAM

Ryan Castonia, *undergrad student*
Carl Engel, *grad student*
David Sanchez, *undergrad student*
Brandon Suarez, *undergrad student*
Adam Woodworth, *grad student*

Photos courtesy of Design/Build/Fly

Photo Album


Getting the plane ready for the next run


This is what a crash landing looks like


Carl likes the kind of aircraft you can ride in, too


Dave also builds solar cars


Ryan (2nd from left) before parachuting


Brandon ready to fly ... on his motorcycle


PAULO LOZANO

"When I was 8 years old, I decided to be a pilot, an engineer, a physicist and rocket scientist. Today I am all four."

JOB

MIT Assistant Professor of Aeronautics and Astronautics

FAVORITE ACTIVITIES

flying, rock climbing, sculling, running, guitar, violin, reading

On Paulo's playlist

Bach
Suite No. 3 in D, II. Air

Boston
"Hollyann"

Caifanes
"No Dejes Que..."

Marillion
"Beautiful"

Paulo Lozano is building tiny rockets

If phones, computers, and MP3 players can get smaller, why not rockets. Current rockets require fuel that is very inefficient, so you need a lot of it to get anywhere. It's like the gas tank of a car taking up 99% of the room. Once Paulo decided to work with ion (electric) rocket engines, he found he could make everything smaller. He's designing satellites that can fit in your hand and maneuver in space with rockets smaller than a human hair.

Photos courtesy of Paulo Lozano

Paulo's Photo Album

Cross country skiing with my family

The Pantheon (in Rome) is one of my favorite buildings

Kayaking

Sitting at my desk at MIT

Kayaking

Rock climbing

SPHERES

"SPHERES is helping us learn how to construct things like telescopes in space so we can learn even more about what is out there."

JENNIFER ALLEN

TEAM

Jaime Garza Ramirez, *graduate student*

Jennifer Allen, *undergraduate student*

Jake Katz, *graduate student*

Jake Katz
grad student

Interests
hiking, cooking, sailing, skiing, radio controlled aircraft, jazz music, do-it-yourself projects

On Jake's Playlist
Louis Armstrong
"A Kiss to Build a Dream On"

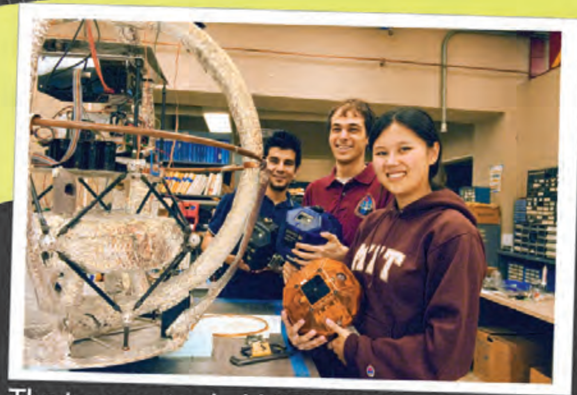
SPHERES is designing satellites that fly in formation

Can you imagine a flock of basketball-sized satellites each collecting light from a distant galaxy, together forming a telescope effectively the size of a football field? The SPHERES team is working on turning this vision into reality. Along the way, they explored sustainable power sources, tested prototypes on NASA's Zero-Gravity Simulator—an aircraft called the Vomit Comet (see photo above)— and were thrilled to have SPHERES fly on the International Space Station.

Photo Album

Astronaut Greg Chamitoff testing SPHERES on the International Space Station

Jennifer exploring a cave



The teammates hold SPHERES next to their electromagnetic formation flight test bed

Jake makes friends with an anteater

Jaime playing Elvis' piano

Jennifer with her dog

Jaime enjoying the Caribbean on St. Barts

Jake practicing a face-up head-first self-arrest with an ice axe

MISSY CUMMINGS

"Anyone with an iPhone can control a robot!"

JOB

MIT Associate Professor of Aeronautics and Astronautics
Director, MIT Humans and Automation Lab

FAVORITE ACTIVITIES

hiking, mountain biking, kayaking, water skiing, snowboarding

Career Highlight

Missy was one of the U.S. Navy's first female fighter pilots. She has written a book Hornet's Nest about her experience.

Missy Cummings is flying a lot of planes (at once)

Flying one airplane at a time can require the concentration of two people. So what if you wanted to fly several at once? Then you'd want Missy on the job. She designs systems that allow one person to control multiple unmanned aerial vehicles or ground robots. These systems run on computers (including iPhones) and are simple enough to use that anyone who is great at video games has the basic skills to command a fleet of robots.

Photos courtesy of Missy Cummings

Missy's Photo Album

From my days as a fighter pilot

Winter hiking at Lake Louise, Banff National Park, Canada

Kayaking is a great way to explore a watershed

With my daughter at Lake Minnewanka, Canada

Most of my work involves interacting with computer displays

At the April 2-3 Women in Aerospace Conference, doctoral candidates joined professionals from academia, industry, and government to present research and to network. The conference will be an annual event. (William Litant/MIT photograph)

MORE LEAPS

Women in Aerospace, Outreach Programs, Gardner Lecture, and Zero G

WOMEN IN AEROSPACE

As part of Giant Leaps focus on the future of aerospace, on April 2 and 3, 2009 AeroAstro and the Department of Earth, Atmospheric, and Planetary Sciences jointly hosted the Women in Aerospace Symposium. Twelve women who are advanced doctoral candidates were nominated as participants by leading academic programs around the country. Also in attendance were professionals from academia, industry, and government. The symposium offered women who we expect to be future leaders a unique forum to present their research to both peers and pros. The opportunities for connection, networking, mentoring, and kindling relationships were unparalleled.

Presentations were:

- **Jacqueline O'Connor**, Georgia Institute of Technology "Investigation of Thermoacoustic Instabilities in Low-Emission Gas Turbines"

- **Ashley Hallock**, Princeton University, "Current Sheet Formation in a Conical Pulsed Inductive Plasma Thruster with Preionization"

- **Briony Horgan**, Cornell University, "Using composition to unravel the north polar region of Mars"

- **Kristina Lemmer**, University of Michigan, "The Use of an Electromagnet in Helicon Plasma for Demonstration of Communication Blackout Amelioration"

- **Sharlotte Kramer**, California Institute of Technology, “Failure of Aerospace Materials: Assessing Stresses Using a Hybrid Interferometric Method.”
- **Heather Knutson**, Harvard University, “Portraits of Distant Worlds; Characterizing the Atmospheres of Extrasolar Planets”
- **Debbie Meduna**, Stanford University, “Terrain Relative Navigation for Robotic Exploration in Remote Environments”
- **Kristin Medlock**, Purdue University, “Dual-Use Ballutes for the Exploration of the Solar System”
- **Sally Bane**, California Institute of Technology, “Spark Ignition: Assessing the Risk of Accidental Explosions in Aircraft”
- **Julie Shah**, Massachusetts Institute of Technology, “Human-Robot Teaming in Shared Physical Workplaces”
- **Deborah Woods**, Harvard University, “The Binospec spectrograph: elements of optical system design”
- **Su Leen Wong**, Cornell University, “Quantifying Crystal Stresses the Drive the Initiation of Fatigue-Induced Defects in Aerospace Alloys”

Our expectations for the event were more than fulfilled. Feedback was so overwhelmingly positive that the event will become an annual event. We know it will grow and evolve, and yet we are committed to maintaining the event’s atmosphere of one-on-one collegiality, camaraderie, and connectivity.

OUTREACH

by the MIT Office of Engineering Outreach Program

During the many activities taking place at MIT to celebrate the 40th anniversary of the Apollo moon landing it was hard not to notice the younger faces in crowds. The MIT Department of Aeronautics and Astronautics teamed up with the MIT Office of Engineering Outreach Programs, to provide exciting opportunities for middle and high school students from Boston, Cambridge, and Lawrence, Massachusetts. Our goal was to influence students to learn more about the history and future of aerospace exploration.

OEOP's Saturday Engineering Enrichment & Discovery Academy, an enrichment program for local public high school students, kicked off its spring 2009 term with it's own commemoration of the first human landing on the moon. SEED Academy highlighted this celebration with speaker Dr. Jeffrey Hoffman, former astronaut and AeroAstro professor of the practice, at its orientation event on Feb. 7, 2009. The Apollo Outreach Committee also contributed to the planning and development of a semester-long Aeronautics and Astronautics curriculum and course for SEED Academy's high school sophomores.

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

We also focused on exposing students to fields related to science and engineering. On April 1, committee members participated in the Aviation/Transportation Education expo at Logan Airport to promote the field of aerospace exploration to more than 1,000 Boston area K-12 students.

On Saturday, May 2, AeroAstro hosted the Sally Ride Science Festival as a part of the Cambridge Science Festival. This day-long event was aimed at encouraging young people to pursue their passion for exploration in science, math, and engineering. Approximately 1,000 middle school students enjoyed the festival which included a motivational talk by Dr. Ride, the first American woman to fly in space; discovery workshops presented by local scientists and engineers; workshops for parents and teachers on ways to support students' interests in science and math; and a street fair with booths, hands-on activities, food and music.

As a special gesture to end the festivities, and as a way to inspire tomorrow's engineers, 200 OEOP students and their families attended the Boston Pops performance, narrated by Apollo astronaut and AeroAstro alumnus Buzz Aldrin.

2009 Lester D. Gardner lecturer Yvonne Brill, a dedicated mentor to young engineers, discusses aerospace careers with AeroAstro graduate students Justin Kaderka, Allie Anderson (center), and Chelsea He. (William Litant/MIT photograph)

THE 2009 LESTER D. GARDNER LECTURE

MEGABYTES FOR THE MASSES

The April 2-3, 2009 Women in Aerospace Symposium was the venue for AeroAstro's annual Lester D. Gardner Lecture. The speaker, Yvonne Brill, is a veteran of 60 years in aerospace engineering and a pioneer in space propulsion. She is a revered mentor and role model for aspiring young women engineers.

Brill's lecture, "Megabytes for the Masses," provided a history of the beginnings and evolution of earth observation and commercial communication satellites. She discussed her experiences in developing onboard rocket propulsion systems that ensure that satellites maintain prescribed orbits and can relay data to earth. She also shared her perspectives on doing pioneering work in space propulsion at a time when there were few women in the field, why she chose engineering, and why engineering is an exciting and rewarding career.

Gardner Lectures, which focus on aerospace history, are funded by a bequest of the late Major Lester D. Gardner, an 1898 MIT graduate who was instrumental in creating the Aeronautics and Astronautics Department's Hunsaker Professorship in Aeronautical Engineering.

ZERO G

by Erika Wagner

Aboard the Zero G flight, Tina Srivastava (left) and Jillian James test microgravity deployment of a solar panel for an undergrad satellite project. (Steve Boxal/Zero Gravity Corp. photo)

Thirty MIT students, faculty, and staff. A Boeing 727-200 called "G Force One." And, a swath of airspace 100 miles long by 10 miles wide. Add to these a pilot trained to fly in 10,000 foot roller coaster-like parabolas and you get one incredible research opportunity. With support from Massachusetts Space Grant, NASA, ESA, and others, MIT took to the Florida skies in June as an adjunct to the Giant Leaps events, offering students the opportunity to conduct research while in a reduced gravity environment. Experiments ranged from studying how microgravity can be used to improve the nanostructural characteristics of aerogels, to lunar-g effects on astronauts' perception of slopes and distances on the moon's surface — a critical task for future exploration. Students examined deployment dynamics of a solar panel for an orbital debris tracking satellite, the first flight of a novel air-ionizing propulsion system, and multi-environment functionality of biosatellite habitat systems. ZERO-G Corp., which operates these flights out of airports across the country, was co-founded by Course 16 alumni Peter Diamandis ('88) and Byron Lichtenberg ('75, '79).

MIT Museum science and technology curator Debbie Douglas explains the Apollo Guidance, Navigation, and Control simulator to BBC science correspondent Tom Feilden. (William Litant/MIT photo)

MUSEUM

In addition to the exhibit detailed in the article beginning on page 35, from June through September MIT Museum hosted the exhibit "MIT Goes to the Moon." The display included rare Apollo-era artifacts that tell the story of the major contributions made by MIT to the American space program. Included were an extremely rare Apollo Guidance, Navigation, and Control system simulator on loan from Draper Laboratory for its first public showing. (See it in use 40 years ago opposite Page One.)

WE ASKED

GIANT LEAPS PARTICIPANTS:

WHAT SHOULD BE HUMANKIND'S NEXT GIANT LEAP?

"To create an efficient vehicle that doesn't run on gas and can hover above the ground."

KAYONE CHITOLIE, GRADE 10, BOSTON LATIN ACADEMY

"An intense surge in space exploration and biological advancements that would better adapt humans to the environments of other planets."

GABRIELLA DE PAZ, MIT FRESHMAN

"To raise the standard of living for everyone on the planet to an acceptable level without doing damage or depleting resources we can't replenish."

WILFRIED HOFSTETTER, MIT AEROASTRO GRADUATE STUDENT

"Teleportation."

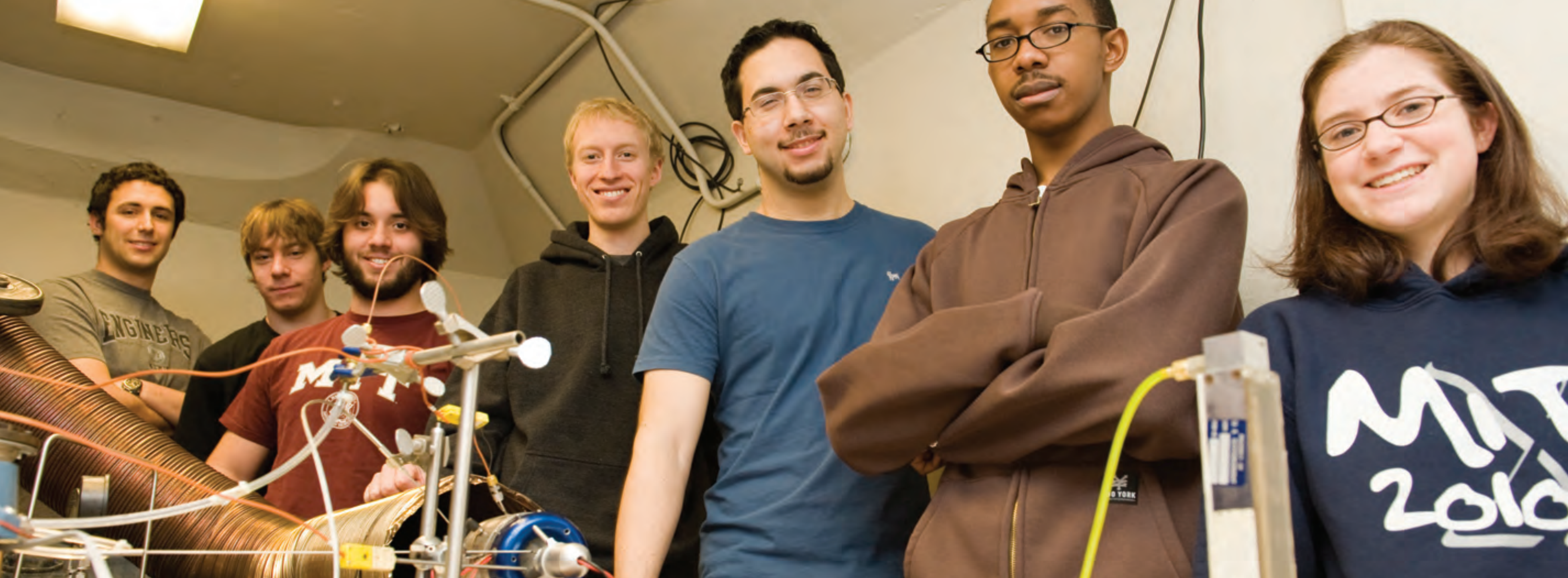
BRENDAN NG, GRADE 6, MARY CURLEY SCHOOL

"To take the excitement we felt during Apollo and push forward. We should look at new frontiers, new ways of doing business, and develop new materials that will keep us as a world leader and help us solve problems we don't even know about today."

WILLIAM GERSTENMAIER, NASA ASSOCIATE ADMINISTRATOR

"Politics in the US is too personal and too confined to the individual, and until we get past that, we're not going to be in the position to make a giant leap any time soon. We need to want to solve the problems of the future as a society."

CHRIS KRAFT, APOLLO DIRECTOR OF FLIGHT OPERATIONS



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

Lab Report

A 2008-2009 REVIEW OF AERONAUTICS AND ASTRONAUTICS DEPARTMENT LABORATORIES

Information provided by the research laboratories and centers

AEROSPACE COMPUTATIONAL DESIGN LABORATORY

The Aerospace Computational Design Laboratory's mission is the advancement and application of computational engineering for aerospace system design and optimization. ACDL researches topics in advanced computational fluid dynamics and reacting flow, methods for uncertainty quantification and control, and simulation-based design techniques.

The use of advanced computational fluid dynamics for complex 3D configurations allows for significant reductions in time from geometry-to-solution. Specific research interests include aerodynamics, aeroacoustics, flow and process control, fluid structure interactions, hypersonic flows, high-order methods, 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.

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

The creation of computational decision-aiding tools in support of the design process is the objective of a number of methodologies the lab pursues. These include PDE-constrained optimization, real time simulation and optimization of systems governed by PDEs, multiscale optimization, model order reduction, geometry management, and fidelity management. ACDL applies these methodologies to aircraft design and to the development of tools for assessing aviation environmental impact.

ACDL faculty and staff include: Jaime Peraire (director), Doug Allaire, Marcelo Buffoni, David Darmofal, Mark Drela, Michalis Frangos, Robert Haimes, Youssef Marzouk, Cuong Nguyen, Karen Willcox, and David Willis.

Visit the Aerospace Computational Design Laboratory at http://acdl.mit.edu/

AEROSPACE CONTROLS LABORATORY

The Aerospace Controls Laboratory researches autonomous systems and control design for aircraft, spacecraft, and ground vehicles. Theoretical research is pursued in areas such as decision making under uncertainty; path planning, activity and task assignment; estimation and navigation; sensor network design; and robust, adaptive, and nonlinear control. A key part of ACL is RAVEN (Real-time indoor Autonomous Vehicle test ENvironment), a unique experimental facility that uses a motion capture system to enable rapid prototyping of aerobatic flight controllers for helicopters and aircraft, robust coordination algorithms for multiple helicopters, and vision-based sensing algorithms for indoor flight. Recent research includes the following:

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

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

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

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

ACL faculty are Jonathan How and Steven Hall.

Visit the Aerospace Controls Laboratory at http://acl.mit.edu/

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 upon satellite, wireless and optical components. Satellite networks are essential for providing access to remote locations lacking in communications infrastructure, wireless networks are needed for communication between untethered nodes (such as autonomous air vehicles), and optical networks are critical to the network backbone and in high performance local area networks.

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

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

CNRG'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.

Visit the Communications and Networking Research Group at http://web.mit.edu/aeroastro/labs/cnrg/

Graduate student Dan Courtney explains the operation of a miniature Hall Thruster ion engine to Space Propulsion Lab visitors during the AeroAstro Department's June Open House, held as part of the Giant Leaps Apollo anniversary observance.

COMPLEX SYSTEMS RESEARCH LABORATORY

Increasing complexity and coupling, as well as the introduction of new digital technology, are introducing new challenges for engineering, operations, and sustainment. The Complex Systems Research Lab designs system modeling, analysis, and visualization theory and tools to assist in the design and operation of safer systems with greater capability. To accomplish these goals, the lab applies a system's approach to engineering that includes building technical foundations and knowledge and integrating these with the organizational, political, and cultural aspects of system construction and operation.

While CSRL's main emphasis is aerospace systems and applications, its research results are applicable to complex systems in such domains as transportation, energy, and health. Current research projects include accident modeling and design for safety, model-based system and software engineering, reusable, component-based system architectures, interactive visualization, human-centered system design, system diagnosis and fault tolerance, system sustainment, and organizational factors in engineering and project management.

Nancy Leveson directs the Complex Systems Research Laboratory.

Visit the Complex Systems Research Laboratory at http://sunnyday.mit.edu/csrl.html

GAS TURBINE LABORATORY

The MIT Gas Turbine Laboratory has had a worldwide reputation for research and teaching at the forefront of gas turbine technology for more than 60 years. GTL's mission is to advance the state-of-the-art in fluid machinery for power and propulsion. The research is focused on advanced propulsion systems, energy conversion and power, with activities in computational, theoretical, and experimental study of: loss mechanisms and unsteady flows in fluid machinery, dynamic behavior and stability of compression systems, instrumentation and diagnostics, advanced centrifugal compressors and pumps for energy conversion, gas turbine engine and fluid machinery noise reduction and aero-acoustics, novel aircraft and propulsion system concepts for reduced environmental impact.

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

Zoltan Spakovszky is the GTL director. Faculty, research staff, and frequent visitors include John Adamczyk, Nick Cumpsty, Elena de la Rosa Blanco, Mark Drela, Fredric Ehrich, Alan Epstein, Edward Greitzer, Gerald Guenette, Jim Hileman, Bob Liebeck, Jack Kerrebrock, Choon Tan, and Ian Waitz.

Visit the Gas Turbine Lab at http://web.mit.edu/aeroastro/www/labs/GTL/index.html

HUMANS AND AUTOMATION LABORATORY

Research in the Humans and Automation Laboratory focuses on the multifaceted interactions of human and computer decision-making in complex socio-technical systems. With the explosion of automated technology, the need for humans as supervisors of complex automatic control systems has replaced the need for humans in direct manual control. A consequence of complex, highly-automated domains in which the human decision-maker is more on-the-loop than in-the-loop is that the level of required cognition has moved from that of well-rehearsed skill execution and rule following to higher, more abstract levels of knowledge synthesis, judgment, and reasoning. Employing human-centered design principles to human supervisory control problems, and identifying ways in which humans and computers can leverage the strengths of the other to achieve superior decisions together is HAL's central focus.

Current research projects include investigation of human understanding of complex optimization algorithms and visualization of cost functions, collaborative human-computer decision making in time-pressured scenarios (for both individuals and teams), human supervisory control of multiple unmanned vehicles, and designing decision support displays for direct-perception interaction as well as assistive collaboration technologies, including activity awareness interface technologies and interruption assistance technologies.

Lab equipment includes an experimental test bed for future command and control decision support systems, intended to aid in the development of human-computer interface design recommendations for future unmanned vehicle systems. In addition, the lab hosts a state-of-the-art multi-workstation collaborative teaming operations center, as well as a mobile command and control experimental test bed mounted in a Dodge Sprint van awarded through the Office of Naval Research.

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

Visit the Humans and Automation Laboratory at http://mit.edu/aeroastro/www/labs/halab/index.html

Students from the Space Systems Engineering capstone class (16.83x) are working in the Space Systems and Gelb labs to build a high Delta-V (~1-2 km/sec) micro-satellite as a means is to provide a low cost orbital transfer vehicle capability for maneuvering throughout the Earth-moon system. The goal is to deliver to the Air Force in January 2011, a flight qualified vehicle for launch as an ESPA-Ring (a device that permits up to six small satellites to be carried along with a larger satellite) secondary payload. The project offers approximately 35 undergraduates and 10 graduates from multiple departments hands-on experience in designing, building, and testing actual flight hardware. (William Litant/MIT photo)

INTERNATIONAL CENTER FOR AIR TRANSPORTATION

The International Center for Air Transportation undertakes research and educational programs that discover and disseminate the knowledge and tools underlying a global air transportation industry driven by technologies. Global information systems are central to the future operation of international air transportation. Modern information technology systems of interest to ICAT include global communication and positioning; international air traffic management; scheduling, dispatch, and maintenance support; vehicle management; passenger information and communication; and real-time vehicle diagnostics.

Airline operations are also undergoing major transformations. Airline management, airport security, air transportation economics, fleet scheduling, traffic flow management, and airport facilities development, represent areas of great interest to the MIT faculty and are of vital importance to international air transportation. ICAT is a physical and intellectual home for these activities. ICAT, and its predecessors, the Aeronautical Systems Laboratory and Flight Transportation Laboratory, pioneered concepts in air traffic management and flight deck automation and displays that are now in common use.

ICAT faculty include R. John Hansman (director), Hamsa Balakrishnan, Cynthia Barnhart, Peter Belobaba, and Amedeo Odoni.

Visit the International Center for Air Transportation at ***http://web.mit.edu/aeroastro/www/labs/ICAT/***

LABORATORY FOR INFORMATION AND DECISION SYSTEMS

The Laboratory for Information and Decision Systems is an interdepartmental research laboratory that began in 1939 as the Servomechanisms Laboratory, focusing on guided missile control, radar, and flight trainer technology. Today, LIDS conducts theoretical studies in communication and control, and is committed to advancing the state of knowledge of technologically important areas such as atmospheric optical communications, and multivariable robust control. Laboratory research volume is approximately $6.5 million, and the size of the faculty and student body has tripled in recent years. LIDS hosts events, notably weekly colloquia that feature leading scholars from the laboratory's research areas. . In addition to a fulltime staff of faculty, support personnel, and graduate assistants, scientists from around the globe visit LIDS to participate in its research program. Currently, seventeen faculty members and approximately 100 graduate students are associated with the laboratory.

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

Visit LIDS at http://lids.mit.edu/

LEAN ADVANCEMENT INITIATIVE

The Lean Advancement Initiative is a unique learning and research consortium focused on enterprise transformation, and its members include key stakeholders from industry, government, and academia. LAI is headquartered in AeroAstro, works in close collaboration with the Sloan School of Management, and is managed under the auspices of the Center for Technology, Policy and Industrial Development, an MIT-wide interdisciplinary research center.

LAI began in 1993 as the Lean Aircraft Initiative when leaders from the U.S. Air Force, MIT, labor unions, and defense aerospace businesses created a partnership to transform the U.S. aerospace industry using an operational philosophy known as "lean." LAI is now in its fifth and most important phase and has moved beyond a focus on business-unit level change toward a holistic approach to transforming entire enterprises across a variety of industries. Through collaborative stakeholder engagement, along with the development and promulgation of knowledge, practices, and tools, LAI enables enterprises to effectively, efficiently, and reliably create value in complex and rapidly changing environments. Consortium members work collaboratively through the neutral LAI forum toward enterprise excellence, and the results are radical improvements, lifecycle cost savings, and increased stakeholder value.

LAI's Educational Network includes more than 40 educational institutions in the United States, England, Italy, and Mexico and provides LAI members with unmatched educational outreach and training capabilities.

AeroAstro LAI participants include Deborah Nightingale (co-director), Earll Murman, Dan Hastings, Annalisa Weigel, and Sheila Widnall. John Carroll (co-director) joins LAI from the Sloan School of Management, and Warren Seering and Joe Sussman represent the Engineering Systems Division.

Visit the Lean Advancement Initiative at http://lean.mit.edu/

MAN VEHICLE LABORATORY

The Man Vehicle Laboratory optimizes human-vehicle system safety and effectiveness by improving understanding of human physiological and cognitive capabilities, and developing countermeasures and evidence-based engineering design criteria. Research is interdisciplinary, and uses techniques from manual and supervisory control, signal processing, estimation, sensory-motor physiology, sensory and cognitive psychology, biomechanics, human factors engineering, artificial intelligence, and biostatistics. MVL has flown experiments on Space Shuttle missions, the Mir Space Station, and on many parabolic flights, and developed experiments for the International Space Station.

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

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

MVL faculty include Charles Oman (director), Jeffrey Hoffman, Dava Newman, and Laurence Young. They teach subjects in human factors engineering, space systems engineering, space policy, flight simulation, space physiology, aerospace biomedical engineering, the physiology of human spatial orientation, and leadership. The MVL also serves as the office of the Director for the NSBRI-sponsored Graduate Program in Bioastronautics, the Massachusetts Space Grant Consortium, NSBRI Sensory-Motor Adaptation Team, the MIT-Volpe Program in Transportation Human Factors, and the MIT Portugal Program's Bioengineering Systems focus area.

Visit the Man Vehicle Laboratory at http://mvl.mit.edu/

THE PARTNERSHIP FOR AIR TRANSPORTATION NOISE AND EMISSIONS REDUCTION

The Partnership for AiR Transportation Noise and Emissions Reduction is an MIT-led FAA/NASA/Transport Canada-sponsored Center of Excellence. PARTNER fosters breakthrough technological, operational, policy, and workforce advances for the betterment of mobility, economy, national security, and the environment. PARTNER combines the talents of nine universities, three federal agencies, and 53 advisory board members, the latter spanning a range of interests from local government, to industry, to citizens' community groups. During 2008-09, PARTNER continued to expand its research portfolio. New research projects include Noise Exposure Response: Annoyance; Noise Exposure Response: Sleep Disturbance; Sound Structural Transmission; Environmental Cost-benefit Analysis of Ultra Low Sulfur Jet Fuels; Environmental Cost-benefit Analysis of Alternative Jet Fuels; Objective Measures to Support Airspace Management; Metrics for an Aviation CO_2 Standard; Near-Term Operational Changes; Isotopic Analysis of Airport Air Quality; and International Collaborative Emissions Studies. New reports resulting from PARTNER research were released including studies of en route traffic optimization to reduce environmental impact, land use management and airport controls, large eddy simulations of contrails, and aircraft emissions-related pollutant health risk prioritization.

MIT's most prominent role within PARTNER is developing research tools that provide rigorous guidance to policy-makers who must decide among alternatives to address aviation's environmental impact. The MIT researchers collaborate with an international team in developing aircraft-level and aviation system level tools to assess the costs and benefits of different policies and R&D investment strategies.

Other PARTNER initiatives in which MIT participates include exploring mitigating aviation environmental impacts via the use of alternative fuels for aircraft; studies of aircraft particulate matter microphysics and chemistry; and a study of reducing vertical separations required between commercial aircraft, which may enhance operating efficiency by making available more fuel/time efficient flight levels, and enhancing air traffic control flexibility and airspace capacity.

PARTNER MIT personnel include Ian Waitz(director), James Hileman (associate director), Hamsa Balakrishnan, John Hansman, Thomas Reynolds, Karen Willcox, Malcolm Weiss, Christoph Wollersheim, William Litant (communications director), Jennifer Leith (program coordinator), and 10-15 graduate students.

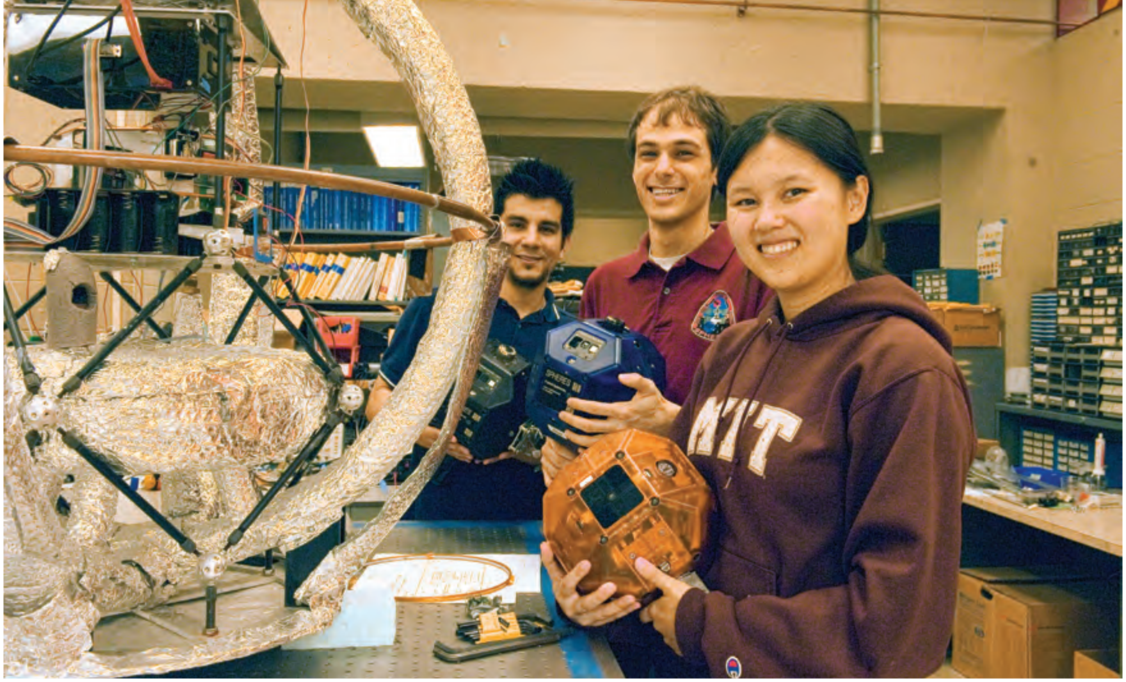
Visit The Partnership for AiR Transportation Noise and Emissions Reduction at http://www.partner.aero

SPACE PROPULSION LABORATORY

The Space Propulsion Laboratory, part of the Space Systems Lab, studies and develops systems for increasing performance and reducing costs of space propulsion. A major area of interest to the lab is electric propulsion in which electrical, rather than chemical energy propels spacecraft. The benefits are numerous, hence the reason electric propulsion systems are increasingly applied to communication satellites and scientific space missions. In the future, these efficient engines will allow exploration in more detail of the structure of the universe, increase the lifetime of commercial payloads, and look for signs of life in far away places. Areas of research include Hall thrusters; plasma plumes and their interaction with spacecraft; electrospray physics, mainly as it relates to propulsion; microfabrication of electrospray thruster arrays; Helicon and other radio frequency plasma devices; and space electrodynamic tethers.

Manuel Martinez-Sanchez directs the SPL research group. Paulo Lozano is a key participant.

Visit the Space Propulsion Laboratory at http://web.mit.edu/dept/aeroastro/www/labs/SPL/home.htm



In the Space Systems Lab, AeroAstro students (from left) Jaime Garza Ramirez, Jacob Katz, and Jennifer Allen hold SPHERES microsatellites as they stand next to the electromagnetic flight formation test bed. (William Litant/MIT photo)

SPACE SYSTEMS LABORATORY

Space Systems Laboratory research contributes to the exploration and development of space. SSL's mission is to explore innovative space systems concepts while teaching researchers to be conversant in this field. The major programs include systems analysis studies and tool development, precision optical systems for space telescopes, microgravity experiments operated aboard the International Space Station, and robotic operations for Mars and beyond. Research encompasses a wide array of topics that together comprise a majority of space systems: systems architecting, dynamics and control, active structural control, thermal analysis, space power and propulsion, microelectromechanical systems, modular space systems design, micro-satellite design, real-time embedded systems, and software development.

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

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

The Electromagnetic Formation Flight testbed is a proof-of-concept demonstration for a formation flight system that has no consumables; a space-qualified version is under study. The MOST project studies multiple architectures for lightweight segmented mirror space telescopes using active structural control; its final product will be a ground-prototype demonstrator. Multiple programs research the synthesis and analysis of architectural options for future manned and robotic exploration of the Earth-Moon-Mars system, as well as real options analysis for Earth-to-Orbit launch and assembly. SSL continues to lead the development of methodologies and tools for space logistics. In 2007, SpaceNet 1.4 was accredited by the NASA Constellation Program as an approved software tool for modeling lunar exploration missions and campaigns. SSL contributed several important studies to the Constellation Program Integrated Design and Analysis Cycles. Together with the Jet Propulsion Laboratory, SSL is editing a new AIAA Progress in Aeronautics and Astronautics Volume on Space Logistics that summarizes the current state of the art and future directions in the field.

Jointly with Aurora Flight Sciences, SSL is developing prototypes for automated asset tracking and management systems for ISS based on radio frequency identification technology. Innovative exploration logistics container concepts were tested at the Mars Desert Research Station in Utah in February 2008.

SSL personnel include David W. Miller (director), John Keesee, Olivier de Weck, Jeffrey Hoffman, Edward F. Crawley, Daniel Hastings, Annalisa Weigel, Manuel Martinez-Sanchez, Paulo Lozano, Alvar Saenz-Otero, Paul Bauer (research specialist), SharonLeah Brown (administrator and outreach coordinator), Brían O'Conaill (fiscal officer), Marilyn E. Good (administrative assistant), and Deatrice Moore (financial assistant).

Visit the Space Systems Laboratory at http://ssl.mit.edu/

TECHNOLOGY LABORATORY FOR ADVANCED MATERIALS AND STRUCTURES

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

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

- nano-engineered hybrid advanced composite design, fabrication, and testing
- fundamental investigations of mechanical and transport properties of polymer nanocomposites
- characterization of carbon nanotube bulk engineering properties
- carbon nanotube synthesis and governing mechanisms
- composite tubular structural and laminate failures
- MEMS-scale mechanical energy harvesting modeling, design, and testing
- durability testing of structural health monitoring systems
- thermostructural design, manufacture, and testing of composite thin films and associated fundamental mechanical and microstructural characterization
- continued efforts on addressing the roles of lengthscale in the failure of composite structures
- numerical and analytical solid modeling to inform, and be informed by, experiments
- continued engagement in the overall issues of the design of composite structures with a focus on failure and durability, particularly within the context of safety

In supporting this work, TELAMS has complete facilities for the fabrication of structural specimens such as coupons, shells, shafts, stiffened panels, and pressurized cylinders, made of composites, active, and other materials. A recent addition includes several reactors for synthesizing carbon nanotubes. TELAMS testing capabilities include a battery of servohydraulic machines for cyclic and static testing, a unit for the catastrophic burst testing of pressure vessels, and an impact testing facility. TELAMS maintains capabilities for environmental conditioning, testing at low and high temperature, and in hostile and other controlled environments. There are facilities for nano and microscopic inspection, nondestructive inspection, high-fidelity characterization of MEMS materials and devices, and a laser vibrometer for dynamic device and structural characterization.

With its, linked, and coordinated efforts, both internal and external, the laboratory continues its commitment to leadership in the advancement of the knowledge and capabilities of the composites and structures community through education of students, original research, and interactions with the community. There has been a broadening of this commitment consistent with the broadening of the interest areas in the laboratory. This commitment is exemplified in the newly formed NECST Consortium, an industry-supported center for developing hybrid advanced polymeric composites. In all these efforts, the laboratory and its members continue their extensive collaborations with industry, government organizations, other academic institutions, and other groups and faculty within the MIT community.

TELAMS faculty include Paul A. Lagacé (director), Brian L. Wardle, and visitors Antonio Miravete, and Luis Rocha.

Visit the Technology Laboratory for Advanced Materials and Structures at http://web.mit.edu/telams/ and the Nano-Engineered Composite aerospace STructures Consortium at http://necst.mit.edu

WIRELESS COMMUNICATION AND NETWORK SCIENCES GROUP

The Wireless Communication and Network Sciences Group 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 lab.

The lab is engaged in the development of a state-of-the-art apparatus that enables automated channel measurements. The apparatus makes use of a vector network analyzer and two vertically polarized, 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 underway to analyze the vast amounts of data collected during an extensive measurement campaign that was completed in early 2009.

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

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

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

Moe Win directs the Wireless Communication and Network Sciences Group.

Visit the Wireless Communication and Network Sciences Group at http://wgroup.lids.mit.edu

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, the aeroelastic dynamics of airport control tower configurations for the Federal Aviation Authority, and the less anticipated live tests in Olympic ski gear, space suits for tare evaluations related to underwater simulations of weightless space activity, racing bicycles, subway station entrances, and Olympic rowing shells for oarlock system drag comparisons.

In its more than 70 years of operations, Wright Brothers Wind Tunnel work has been recorded in hundreds of theses and more than 1,000 technical reports.

WBWT faculty and staff include Mark Drela and Richard Perdichizzi.

Visit the Wright Brothers Wind Tunnel at http://web.mit.edu/aeroastro/www/labs/WBWT/wbwt.html

THANK YOU

Prior to the Giant Leaps Boston Pops performance, many members and friends of the department gathered with Apollo participants and Giant Leaps speakers for the Jerome C. Hunsaker Dinner at Symphony Hall. It was an opportunity to share food and fellowship and to thank many of the people who have so generously given to support AeroAstro, especially those who have supported our initiative to significantly increase the number of endowed fellowships for graduate student education and research.

In grand MIT tradition, on May 17, 2009 unnamed students presented their tribute to Giant Leaps, AeroAstro, and the anniversary of the moon landing. On that Sunday morning, the Cambridge, and Boston communities awoke to discover a hack lunar module residing atop the Great Dome. (William Litant/MIT photo)

We recognized several people in attendance, including Professor Emeritus Y.T. Li for his fellowship gift which has supported many graduate students in the department throughout the years; Arthur and Linda Gelb for their support of the AeroAstro Gelb Laboratory, a wonderful venue for hands-on undergraduate education, and also for their very generous graduate fellowship fund; Dan Schwinn and Caterina Bandini for recently establishing the Avidyne Fellowships and for other gifts to the department over the last several years.

We announced new gifts to the department, including the David and Patricia Vos Foundation Fellowship that will focus on supporting exceptional international graduate students. David is a graduate alumnus of the department who established the company AthenaTI, which was recently acquired by Rockwell-Collins. We thanked John Langford, John Tylko, and Javier deLuis for establishing the Aurora Flight Sciences Fellows Program. Aurora has a history that is closely interwoven with the department and we have many active research relationships with them. It was a pleasure to announce the Jack and Vickie Kerrebrock Fellowship established by many friends and admirers, most notably Daniel Fink, David Thompson, and Professor Edward Crawley. We also thanked several others who were in attendance for their generous gifts to the department including William Poduska, Professor Larry Young, Joseph and Dorothy Gavin, John Miller, and Claude Brenner.

Finally, we recognized the sponsors of Giant Leaps. We thanked The Charles Stark Draper Laboratory, represented at the dinner by James Shields, Darryl Sargent, and Eli Gai. Draper Labs provides the most significant research and fellowship support to the department of any of our relationships (currently supporting 16 Draper Fellows, and a variety of research activities — 50 Draper Fellows MIT-wide). We are pleased to continue the fine tradition of this relationship and reaffirm our commitment to working with one another. The Lockheed Martin Corporation was also a significant sponsor of the events, as were the Orbital Sciences Corporation and The Boeing Company.

To these people and companies, and to all of you who have contributed to the department throughout the year in amounts large and small, we very sincerely thank you. Your gifts and sponsorship represent significant investments in the future of aerospace, most especially through supporting and inspiring those who will carry it forward: our students.

This DVD includes videos presented at the MIT AeroAstro Apollo anniversary events and an edited version of the June 11, 2009 **GIANT LEAPS** Symposium. A multiple DVD set of the entire Symposium and a DVD of the Robert Seamans Jr. memorial observance are available at no charge by contacting giantleaps@mit.edu or writing Communications Director, MIT AeroAstro, 37-395, 77 Massachusetts Avenue, Cambridge, MA 02139 USA.