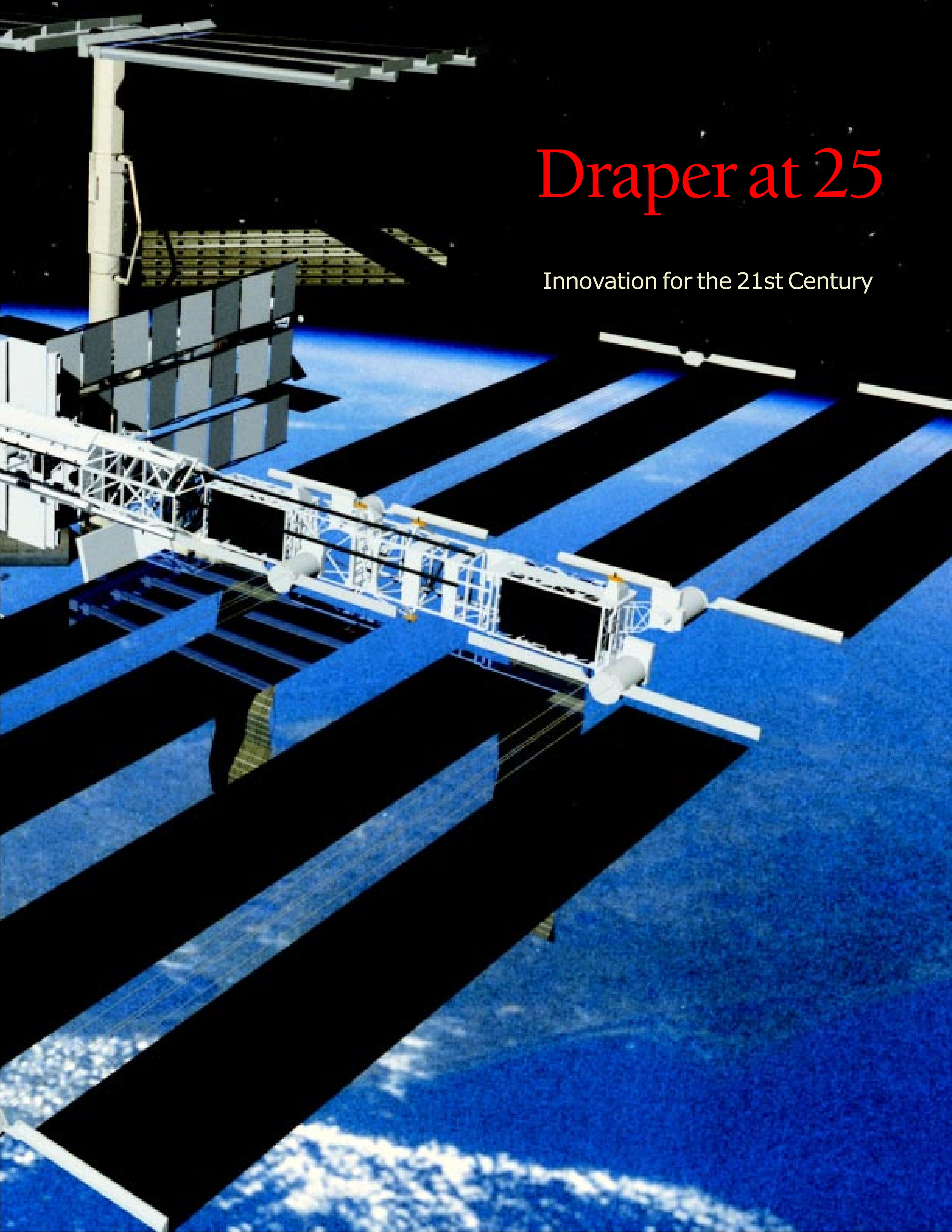
Draper at 25

Innovation for the 21st Century



Our Cover:
For the International Space Station (ISS) Alpha program, Draper is exploring how best to control the flexible, unwieldy and variable structure of the ISS.

Draper at 25

Innovation for the 21st Century

By Christopher Morgan
with Joseph O'Connor and David Hoag

This replica medal of the Draper Prize accompanied Colonel Kenneth Cameron, USMC, astronaut and former Draper Fellow, aboard Space Shuttle flight STS-37 in 1991.

Cameron presented the medal to then-President Ralph Jacobson, saying "It flew in *Atlantis* and, in fact, it's been 93 orbits and 2-1/2 million miles to come back home to you."

Introduction

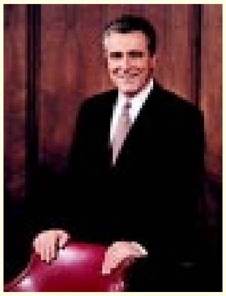
By Vincent Vitto
President and CEO, Draper Laboratory

On July 1, 1973, Draper Laboratory was separated from The Massachusetts Institute of Technology (MIT) and became an independent not-for-profit research and development corporation. This souvenir history commemorates the 25th anniversary of our independence. It reflects on the triumphs and trials that have made the Laboratory what it is today, and provides a view of Draper in the 21st century. It describes the conflicts of the late 1960s and early 1970s that led to the divestment from MIT. It chronicles the successes of the Apollo and Fleet Ballistic Missile (FBM) programs, and shows how the Lab prevailed through the difficult post-Cold War years and is now positioned for the future.

This history honors over six decades of engineering achievements dating from the early days of the MIT Instrumentation Laboratory and the legacy of Doctor Charles Stark Draper. Many of you worked with him; others know him by reputation. His legacy and genius continue to inspire us today. Doc Draper and this Laboratory have contributed fundamentally to the nation's ability to control its ships, submarines, airplanes, space vehicles, and missiles.

These achievements rest on a set of strong core competencies, which allowed the Laboratory to design, build, and test the early gyroscopes, accelerometers, and inertial systems during the formative years of the Instrumentation Lab. Today, Draper continues to build reliable hardware, precision instruments, fault-tolerant computers, and reliable software and sensors. We build complex systems that work and that are deployed to serve the national interest.

The technologies have changed significantly during the past 25 years, but the engineering expertise and sense of adventure at Draper remain powerful constants. As the next millennium approaches, Draper will continue to apply its traditional engineering competencies in guidance, navigation and control, as well as its developing expertise in such fields as microelectronics, robotics, autonomous systems, information management, and biomedical engineering. We hope you'll enjoy this look back at where we've been, and the brief look ahead to Draper in the 21st century.



“History has a joking way of forgetting the events that make a big noise ...and remembering the events that are quiet, unnoticed, even mysterious, in the eyes of contemporaries . . .

If you want to play the game of locating such unnoticed yet great events in our own period, you might bet on the invention of the non-precessible gyroscope perfected by Charles Stark Draper at MIT.”

– *Journalist Joseph Alsop*
New York Herald Tribune, 1949,
commenting on the coming era of
the guided missile

One of the buildings housing the MIT Instrumentation Lab in 1957

Birth of the Laboratory

The Lagoon Nebula in the Constellation Sagittarius is a large star-forming region in the Milky Way Galaxy.

Some nebulae serve as "space laboratories" for the study of how stars are born.

1932
Charles Stark Draper, Research Associate at MIT, founds new Instrument Lab.

1942
The Lab's Mark 14 Gunsight proves its worth in battle during World War II.

1953
SPIRE guides the first coast-to-coast flight without the aid of a pilot.

1954
Lab develops SINS, the first self-contained submarine navigation system.

Prolog

The Birth of a Laboratory

Draper Laboratory's roots reach back to the late 1920s and early 1930s, when Charles Stark Draper began teaching aircraft instrumentation at MIT, all the while dreaming of ways to improve instrument accuracy. He was an accomplished pilot, and often performed daredevil acrobatics to make a point about the workability of a theory. The technique underscored the point to his sometimes-startled passengers.

Draper wanted more control over his plane and was determined to get it. In the early 1930s, he began teaching in MIT's Aeronautical Engineering Program, and founded the MIT Instrument Lab. During World War II, Draper's lab was known as the "Confidential Instrument Development Laboratory" (CID). Later, the name was changed to the MIT Instrumentation Laboratory.

The Mark 14 Gunsight

One of the Laboratory's important early successes was the Mark 14 gunsight. It was developed under contract to the Navy during World War II, and was a direct outgrowth of Doc Draper's deep interest in fire control systems. First used during a 1942 battle aboard the *USS South Dakota*, it enabled anti-aircraft gunners to shoot down numerous Japanese Kamikazes. One glowing World War II newspaper headline read, "Wizard MIT Gyro Gunsight Ends [Enemy] Air Mastery Over Sea."

The 'Shoebox' Gunsight

Anti-aircraft guns of 1939 couldn't cope with fast flying planes. Draper displaced the fixed sight of the gun by placing the computing 'shoebox' directly on the gun, enabling the gunner to hold the reticle on a moving target.

The Mark 14 was called "Doc's shoebox" because the experimental model was shaped like a small rectangular box. The Mark 14 was designed to work while mounted on a gun on the deck of a rolling ship. It was the first of Doc's designs that used the "disturbed-line-of-sight" principle. The gyros, springs, and linkages of the Mark 14 caused the optics to "disturb" the line of sight so that the gun operator, while tracking the target, would actually be pointing the gun at the target's future location, where the bullet would arrive later.

The Mark 14 brought the art of gunnery to an unheard-of level of effectiveness under battle conditions. The *Boston Herald American* later remarked that the Mark 14 gunsight had "saved countless thousands of American lives."

At the conclusion of World War II, the Instrumentation Lab continued to design gun fire control systems using the disturbed-line-of-sight approach, both for the Navy and the Army Air Corps. The Navy work included the development of the GUNAR and X-1 systems. The Army Air Corps work included the A-1 Gun/Bomb/Rocket sights, Dummy Gun, and Black Warrior.

1957
Lab begins developing Polaris guidance system for Navy.

1957
Sputnik launched. Lab accelerates work on Thor missile guidance system.

1957
Lab begins development of FLIMBAL, a new, floating-sphere system for inertial guidance.

1959
Mars Probe design begins. These concepts will be used later in Apollo.

1961
Titan II is successfully tested. Inertial system inspired by Lab design.

1968
First Poseidon (C3), Polaris successor, flown with Lab-designed guidance.

...es Gunsight That Stoppe...

...the most closely guarded military secrets of the war—a gyroscopic ... of Sperry which has made our fleet relatively invulnerable to at... ...d today with the permission of the Navy.

...ad eclipsed seapower as a naval ...eapon and this impression was ...ngthened in certain quarters ... the British naval craft 'Re... and 'Prince of Wales' we... dive bombing and tor... ...ttacks," Morgan conti... ...hips were not e... ...dern anti-aircr... ...he day of ... passed,' ... ...ists.

aircraft guns was a match for sky raiders. Before they could strike, ... Japanese planes were shot ... by the South Dakota in her ...ajor engagement on Oct. ... Representing the cul... American ingenuity ...ill, the South ...with the lat... ...ers fire

Institute of Technology, who had been collaborating in the study of rate gyroscopes for several years, started work on the problem in 1940. In June of that year Dr. C. Stark Draper, director of the instrument laboratory of MIT, made a complete mathematical analysis of the conditions to be met.

By Sept. 1940 Dr. Draper had developed the principal features of a sight which would meet the conditions. At first it seemed impossible to obtain the characteristics indicated by Dr. Draper's analysis ... the automatic ... lead angles re... ...opic mounting ... frictionless but ...anism rep...

...gotten Men

...W YORK, Jan. 29 (INS)—... unsung heroes of Amer... phenomenal wartime avia... development Tuesday held ...dals and awards in recogni... ...n of their work by Lt. Gen. ...ames H. Doolittle as "the for... ...otten men of aviation."

... Doolittle, speaking at the vic... ...tory dinner of the Institute of ... Aeronautical Services, said the ... work of the recipients and their ... colleagues "gave us air supre... ...macy and victory" and called ... for peacetime continuation of ... research and development as ... essential to national security.

... Honored were civil aeronau... ...tics administrator Theodore P. ... ...of. Charles S. Draper ... ...sachusetts Institute of ... U. S. A. A. F. Capt. ... ...ous of Berkeley, Cal.; ...arry Wexler of Fall ... Navy Com. John ... of Washington, ... pilots Robert T. L... Elliott Merrill, ... and Richard Hutto... ...ton, N. Y., a Grum...

WINS AERONAUTICS AWARD

Prof. C. S. Draper of M.I.T. Ge... Sylvanus Albert Reed Pri...

Charles S. Draper, Professor of Aeronautical Engineering in charge of Instrumentation at Massachusetts Institute of Technology, has won the Sylvanus Albert Reed award for 1945 "for application of the gyroscope to computing gunnery sights and to other computing devices." It was announced yesterday by the Institute of the Aeronautical Sciences, Inc., 2 East Sixty-fourth Street, donor of the award. ... Hugh ... Dryden, Assistant

...War Role, ... Millions

...eace, they educate men for ...spect of our national econ... ...n which higher education is ...rtant. In war, they are ready... ...s centers for housing and train... officers and specialized per... ...nnel. Their faculties are the most ...eadily available source of experts ...or the numerous emergency boards, committees and expanded technical services.

"Their laboratories and staffs become productive centers for research and development in new instrumentalities of offensive and defensive warfare.

"The most widely used and effective new weapon of this war was radar, which received its principal war development, especially in the microwave version, at the Massa...

(Continued on Page Twelve)

MIT TASKS IN WAR

PLAYFAIR

(... First Page)

... training was ...ute's course in ... engineering. ...-war staff ... granted ... a wide ...

The lengthy list of war contributions of the Institute listed by President Compton included the work of Prof. Robley D. Evans of the radioactive laboratories in developing methods for the preservation of whole blood for the troops overseas; superhigh voltage x-ray units for the examination of castings and munitions; research in fuel, insulation, liquid oxygen, chemical warfare; and the testing of models of military airplanes.

"The war gave great impetus to ...er developments in machine ...ulations and as a consequence ...e have opportunities in this field of a magnitude beyond anything we have yet undertaken," Dr. Compton said.

50 P. C. MORE STUDENTS

In its enormous war program, M. I. T. adopted a policy that would accept no profit for the work it undertook for the government. In fact, the Institute made a 'substantial over-all out-of-pocket contribution.'

"This contribution," he said, "was made freely and gladly and was entirely proper since the war was costly to the entire nation and to every patriotic element in it."

Turning to problems of transition from war to peace, Dr. Compton said that student applications, including a large number of veterans, indicate that by next spring the Institute's enrolment will have increased 50 per cent above the normal stabilization registration of approximately 3000.

... doubling its en... ...ers, the Institute, at the ... of the Navy, also trained ...aval construction and engineer... a considerable number of naval ...fficers from China, Turkey and ...razil.

Next to radar, the war achievements of which were of incalculable value, the M. I. T. development most extensively used in the war, Compton said, was the gunsight ...oped by Prof. C. Stark Draper ...aff, which introduced the ... angle in firing ... whether tanks ... was particu... ...Japanese ...

...s Gunsight ... Jap Planes

...ark 51 director ... utilize the ... control of ... ...uad mounts and ... guns.

"This move enab... ...an ships to reach ... enemy planes ... could go into ..." Morgan declare...

THEY PUT LIFE IN AERONAUTICS

Engineering Specialists Are Honored at Dinner.

Calling the aeronautical engineers of the United States "the forgotten men of aviation," Lieut.-Gen. James H. Doolittle paid tribute to their great contribution to the winning of the war and pleaded for "the continuation of our wartime research organizations and our wartime rate of development" at the Honors Night victory dinner of the Institute of the Aeronautical Sciences last night in the grand ballroom of the Waldorf-Astoria.

The Awards.

The Daniel Guggenheim Medal to Theodore P. Wright, CAA administrator, for outstanding contributions to the development of civil and military aircraft, the presentation made by Dr. J. C. Hunsaker, chairman of the National Advisory Committee for Aeronautics; the Sylvanus Albert Reed Award to Prof. Charles S. Draper of M. I. T. for application of the gyroscope to computing sights for gunnery and to other computing devices, by Dr. Hugh

TUESDAY,

Doolittle ... Air Re... Key to ...

Calls for F... If Need... by Aero...

Future s... States dep... sive conti... war-time ... Lieutenan... little sai... tute of ... tory di... nautic... for the ...

...s' Directed U. S. Gu... ...mikaze Pilots

... (AP) ... In recognition ... device, Nor... ...with the...

Wizard M. I. T. Gyro Gunsig... Ends Air Mastery Over Sea

Dr. Draper Invented, Sperry Firm Made It

The Birth of Inertial Navigation

Draper's early work on fire control led to his first experiments in inertial navigation, described in detail in a 1940 MIT doctoral thesis by Walter Wrigley, one of Draper's early students. Draper built on the ideas of Wrigley and others who had done earlier conceptual work. The Cold War evolved after World War II, and Draper was presented with a series of challenges and opportunities to refine and improve the art of inertial navigation. That process began with systems to navigate aircraft, ships, and submarines.

New Projects in the 1950s

The Laboratory began a series of new projects during the early 1950s to explore the still young science of inertial navigation. One such project was the Marine Stable Element System (MAST), which was to provide precision vertical and azimuth references in ships and boats. Some of MAST's technology would later be incorporated into missile guidance system designs.

The SPIRE Flight

At the same time the MAST system was under development, a parallel effort reached its climax on a cold morning in February 1953, when an Air Force B-29 bomber took off on a top-secret mission from Hanscom Air Force Base in Bedford, Massachusetts. It traveled 2250 nautical miles to Los Angeles in 12.5 hours and made aviation history. For the first time, a plane had flown from coast to coast with the pilot aboard acting essentially as a spectator.

Draper was aboard the plane that day with seven of his engineering associates from the Instrumentation Lab. They cheered as the 2,700-pound Space Inertial Reference Equipment (SPIRE) system located at the back of the B-29 automatically directed the plane's flight using the first working implementation of "inertial navigation" for a cross-country trip.

Amazingly, SPIRE did its job with no information from the outside world other than the initial coordinates at the Bedford airstrip. SPIRE used three single-degree-of-freedom gyros to establish an inertial reference coordinate system. An onboard analog computer was used to transform the navigation state in inertial coordinates to an earth-centered, geodetic coordinate frame for navigation purposes.

The plane's windows could have been painted black, since it was not necessary to look outside. The system worked so well that the safety backup pilot onboard had

The ABCs of Inertial Systems

Inertial navigation was Doc's answer to how one could fly a plane autonomously over long distances without seeing the ground and without relying on measurement help from the ground. As he once put it, "an inertial system does for geometry – angles, distance, and speed – what a watch does for time."

With Doc's incentive and drive, the Laboratory has over the years developed the necessary precision accelerometers and gyros and applied them to the inertial guidance of vehicles. In these systems, the gyros measure changes in vehicle direction or orientation; the accelerometers measure changes in vehicle velocity.

The accelerometers sense these velocity changes in much the same way a blindfolded passenger senses the acceleration, braking, and turning of an automobile – but with much greater accuracy. However, a blindfolded passenger would be far less able to keep track of the changes in direction of motion than a gyroscope can in an inertial system. Since the accelerometers can measure only velocity changes and consequent position changes, the initial value of these parameters must be provided by some other source. Similarly, gyros can only sense changes in direction or orientation. Again, an initial value must be obtained by some alignment process.

Practical inertial systems demand extremely accurate accelerometers and gyroscopes. The development of such instruments has been one of the Laboratory's conspicuous successes. However, even tiny errors in these instruments can, in time, cause the system-indicated attitude, velocity, and position to drift away from the truth in the same way that a clock drifts. For longer missions, they must be periodically reset or corrected.

The accelerometers and gyros make their measurements while self-contained in a local inertial frame and require no physical or electromagnetic contact with external references. This inspired Doc's characterization of inertial navigation as "astronomy in a closet."

There are two distinctly different classes of inertial systems applications. One is the guidance of spacecraft or missiles, in which the inertial guidance system manages the direction and duration of rocket burns so that the final unpropelled coasting phase of the payload is left on the desired trajectory required by the mission. The other is the navigation of vehicles such as aircraft, submarines, and surface ships at relatively slow velocity near the surface of the earth. In this case, the inertial navigation system must provide continuous accurate measures of vehicle position, velocity, and orientation under the influence of the more or less random water and wind motions, as well as those of pilot-commanded propulsion and steering.

– David Hoag

Dave Hoag ***(on the right)*** **and Ralph Ragan examining Polaris hardware in 1961.**

to touch the controls only once during the 12.5-hour flight to make a planned course correction. He joked afterwards, "You can celebrate, but I've just lost my job."

Once in Los Angeles, Draper and his colleagues drove to a top-secret conference on inertial guidance being conducted by the Federal government and the University of California. There, to the astonishment of all, Draper described the historic flight he had just made, giving credibility to the enormous potential of inertial guidance. Characteristically, he had timed the flight to coincide with the conference, demonstrating his talent for garnering publicity, a talent he would use effectively throughout his career.

SPIRE was the forerunner of today's modern inertial navigation systems for commercial aviation. It was also a personal triumph for Doc. Just a few years earlier, many scientists had ridiculed the idea of inertially navigating a plane. SPIRE proved them wrong. The SPIRE flight was the culmination of years of groundwork done by the Lab. A significant predecessor to SPIRE was FEBE (named after Phoebus, the sun god), the first celestial-aided inertial navigation system, demonstrated in 1949. It used stars as reference points to improve navigational accuracy.

Ballistic Missiles

A few years after the SPIRE flight, the ballistic missile burst onto the scene, an occurrence that would dramatically accelerate the development of inertial guidance systems. The ballistic missile required an order of magnitude of improvement in guidance accuracy. Radio guidance had been used in the earliest ballistic missiles, which relied on ground-based radars to track the missile's flight path and ground-based computers to compute steering commands sent to the missile via a radio link. The main drawback to radio was its susceptibility to interference or jamming. Doc Draper knew the ultimate answer was inertial navigation, which offered a superior, nonjammable system to control ballistic missiles autonomously without broadcasting their positions.

The Lab was well positioned to pursue missile guidance system design, and Draper quickly stepped up to the challenge. In 1954, the Lab developed an inertial guidance mechanization that was to serve many generations of U.S. strategic weapons, including the Air Force's Atlas, Thor, and Titan, and the Navy's Polaris, Poseidon, and Trident missiles.

Thor and Titan

In 1957, the Soviets launched both a multistage ballistic missile and the first man-made satellite, Sputnik, intensifying the so-called "missile gap" debate in the United States. These events accelerated the development of the Air Force's Thor intermediate range ballistic missile (IRBM) project, for which Instrumentation Lab inertial guidance design and consulting support were provided to industry. The single-stage Thor had a 1500-mile range for launch against targets in the Soviet Union from England. This IRBM concept filled a strategic gap until longer-range ballistic missiles could be built and launched from the United States.

The Titan II inertial system, built by industry and based on a prototype Instrumentation Lab design, was tested successfully on July 25, 1961. In August 1962, the Defense Department announced that the Titan II guidance system would be modified for use in the Titan III rocket. The Titan III provided an early heavy-lift booster for U.S. space program Earth orbit payloads.

Photograph: **Shown are CBS TV's Eric Sevareid and Doc Draper in 1957, shortly before the flight of SPIRE, Jr., a refinement of the original SPIRE system. The SPIRE, Jr. flight received national media attention.**

The earlier 1953 SPIRE flight from Massachusetts to Los Angeles marked the first time that a plane had flown from coast to coast without the aid of a pilot.

SPIRE was the forerunner of today's modern inertial navigation systems for commercial aviation.

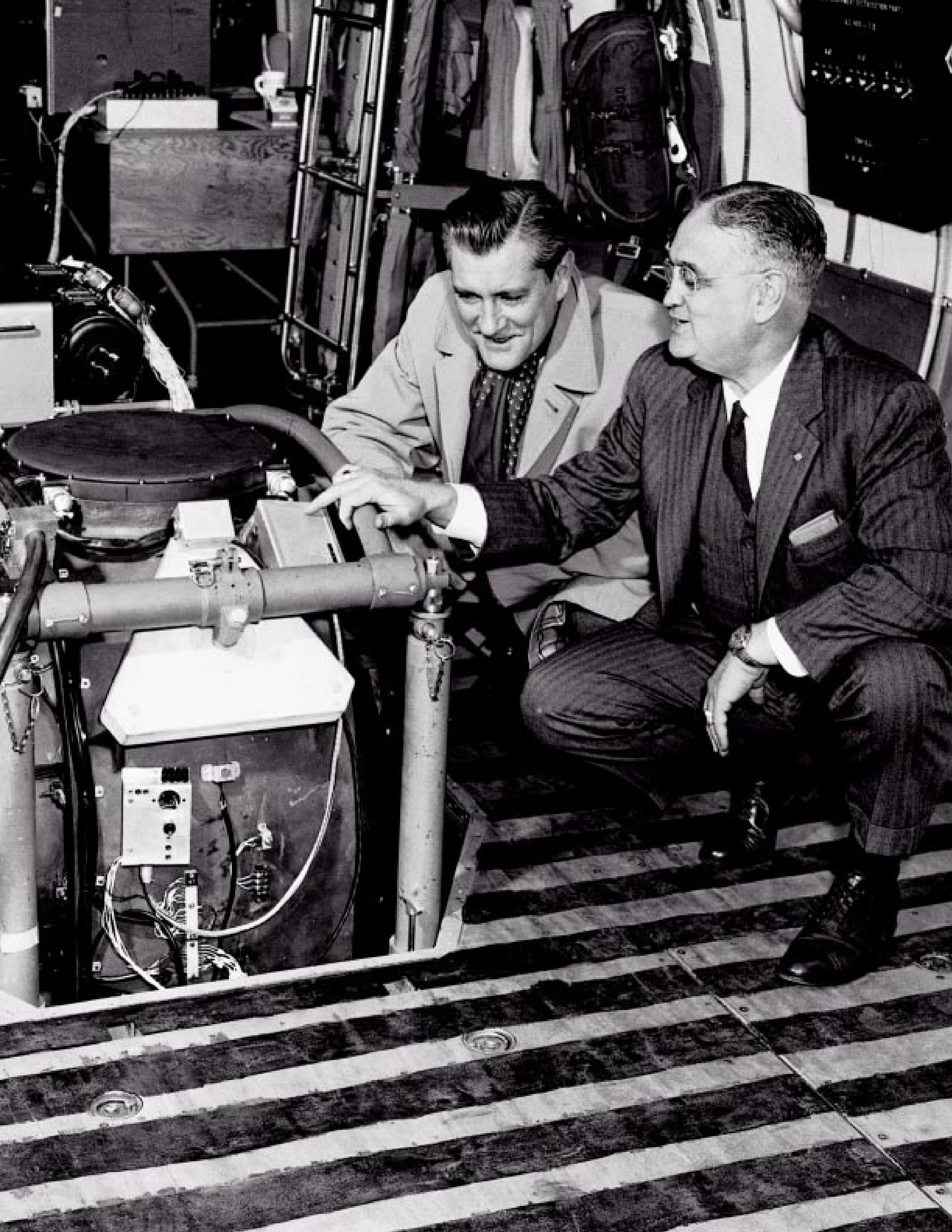
Laboratory Innovation: the FLIMBAL

Also in 1957, the Laboratory began developing a new technology designed to eliminate the three-axis mechanical supports, called gimbals, that decouple the motion of the vehicle from the stable platform on which the inertial instruments are mounted. The new design, called the Floating Inertial Measurement Ball (FLIMBAL), would place all the inertial instruments and the associated electronics of a self-contained all-attitude system inside a floating sphere, hydrostatically centered in a close-fitting outer support structure, which provides a "womb-like" environment for the inertial sensors.

To demonstrate what a missile could do in terms of accuracy, the Air Force adopted the FLIMBAL concept and applied it to the SABRE system. SABRE could align itself (one of the most difficult accuracy challenges) and guide a missile through boost and reentry.

The FBM Program and the Polaris Guidance System

Because of the Laboratory's early work on inertial navigation, the Navy invited it to take part in discussions centered on the feasibility of its use in navigating submerged missile-carrying submarines and guiding their underwater-launched missiles. On the first issue, Doc informed the Navy that a completely self-contained submarine navigation system would not only be feasible, but already existed and had been tested in the Laboratory's Ship Inertial Navigation System (SINS) in 1954.



Draper as Design Agent

The design of the Polaris Mark 1 missile guidance system began a unique role for the Laboratory and a unique relationship with the Navy's Special Projects Office (SP), which has continued for over 40 years and through five generations of system designs.

SP was organized outside of the normal Navy management structure specifically to manage the Polaris program, which had been accorded the highest possible national priority. The hallmarks of SP and of the entire Polaris/Poseidon/Trident team have been, and continue to be, an absolute dedication to the good of the program and the nation; continuity of leadership; and a virtually unheard-of spirit of teamwork and cooperation among the military, civil service, and contractors.

Photograph: **The first submerged launch of Polaris in 1960**

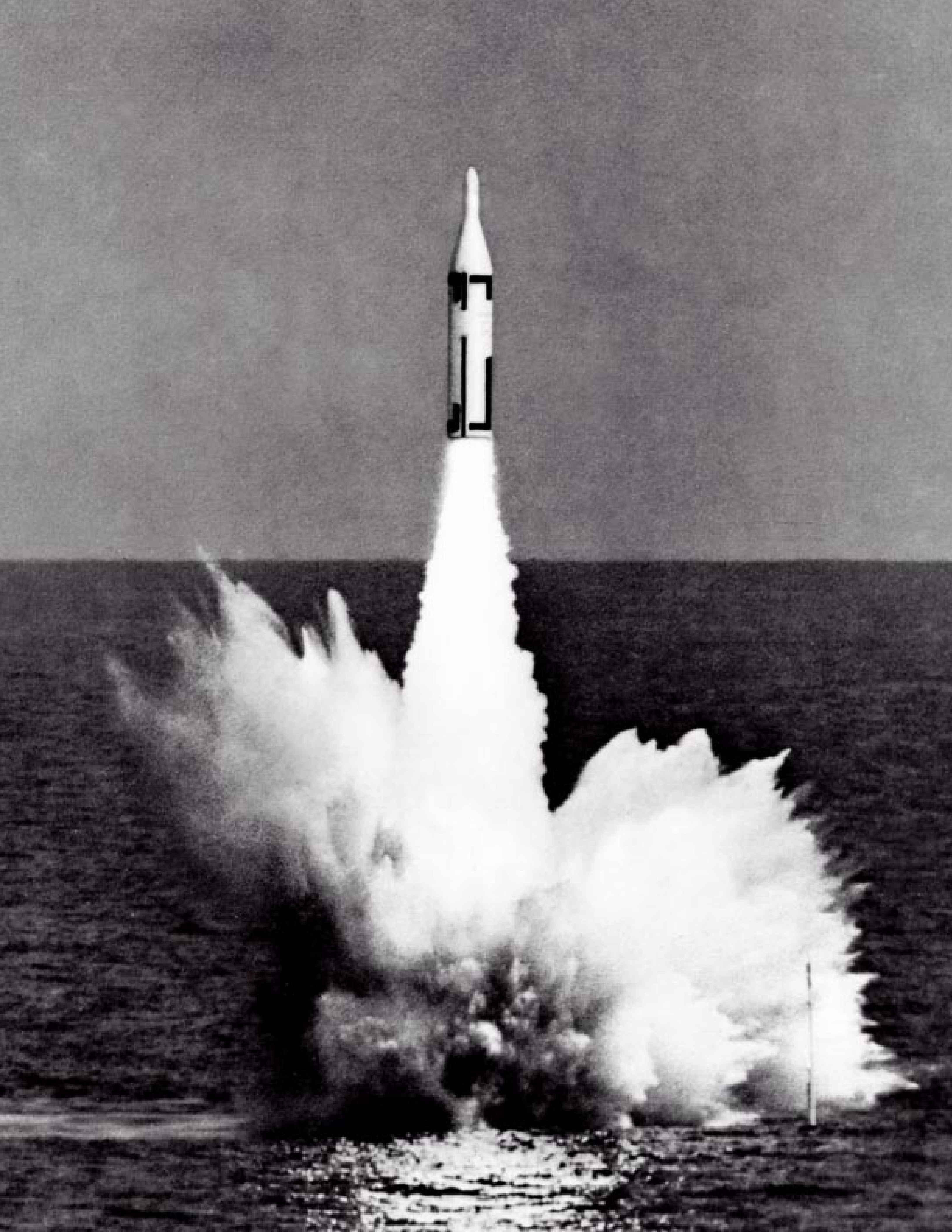
Draper has acted as design agent for all the various generations of FBM guidance systems. In this role, the Laboratory completes the design of the system working with the industrial members of the guidance team. Then the Lab builds prototype systems in-house that are used in the flight test program. Simultaneously, the Lab subcontracts with industry for preproduction systems that are also tested in flights from Cape Canaveral. Following the flight test program, Draper authenticates the drawings, specifications, and processes that have been modified during the preproduction program, so they can be used by the Navy to procure production guidance systems directly from industry.

The design agent role lets Draper create the best, most affordable design, one that can be replicated by industry, and one that Draper will continue to test and support. Because the Laboratory is not-for-profit, it can act as an unbiased, neutral advisor to its sponsors, and can address the needs of the Department of Defense (DoD), National Aeronautics and Space Administration (NASA), and other government sponsors both for major national initiatives and smaller research projects. In this way, the Laboratory can develop nonproprietary system designs that incorporate critical advanced technologies and produce the associated data packages needed to support a subsequent competitive procurement.

" Quite honestly, I think that teamwork, more than anything else, is the major contributor to our success.

We can't afford to have an adversarial relationship with our contractors. We have to have teamwork, or we won't get the job done."

– Rear Admiral Glenwood Clark, USN, in 1982



With respect to the second issue, as was previously mentioned, the Laboratory already had begun work on inertial guidance of ballistic missiles.

In 1957, the Navy decided to issue a contract to the Lab to design, model, test, and document an all-inertial guidance system for the Polaris missile. Thus began the first phase of the long and successful relationship between the Lab and the Navy that continues to this day.

The extraordinary urgency of the proposed Fleet Ballistic Missile program was evident from a memorandum from Chief of Naval Operations Admiral Arleigh Burke sent to Rear Admiral William F. (Red) Raborn on December 2, 1955. It read in part, "It is quite evident that we must move fast on this fleet ballistic missile, and that our present schedules for shipboard launching are not good enough . . . If more money is needed, we will get it. If [you need] more people, those people will be ordered in." The memorandum was known informally as Raborn's "hunting license." Three days later, Burke told Raborn, "Give me a ballistic missile which is seaworthy. And, for God's sake tell me what's been done after you've done it, and not what you will do." In response, the Laboratory placed its highest priority on FBM development.

The Polaris program provided a dramatic new level of deterrence capability for the United States. The new, nearly invulnerable platform could roam the world's oceans unseen and launch submerged missiles to their targets.

After witnessing the first successful sea launch of the Polaris missile from a submerged submarine under the control of Draper's inertial guidance system, Raborn told Draper, "Stark – again our country owes you a debt of gratitude."

Mars Probe

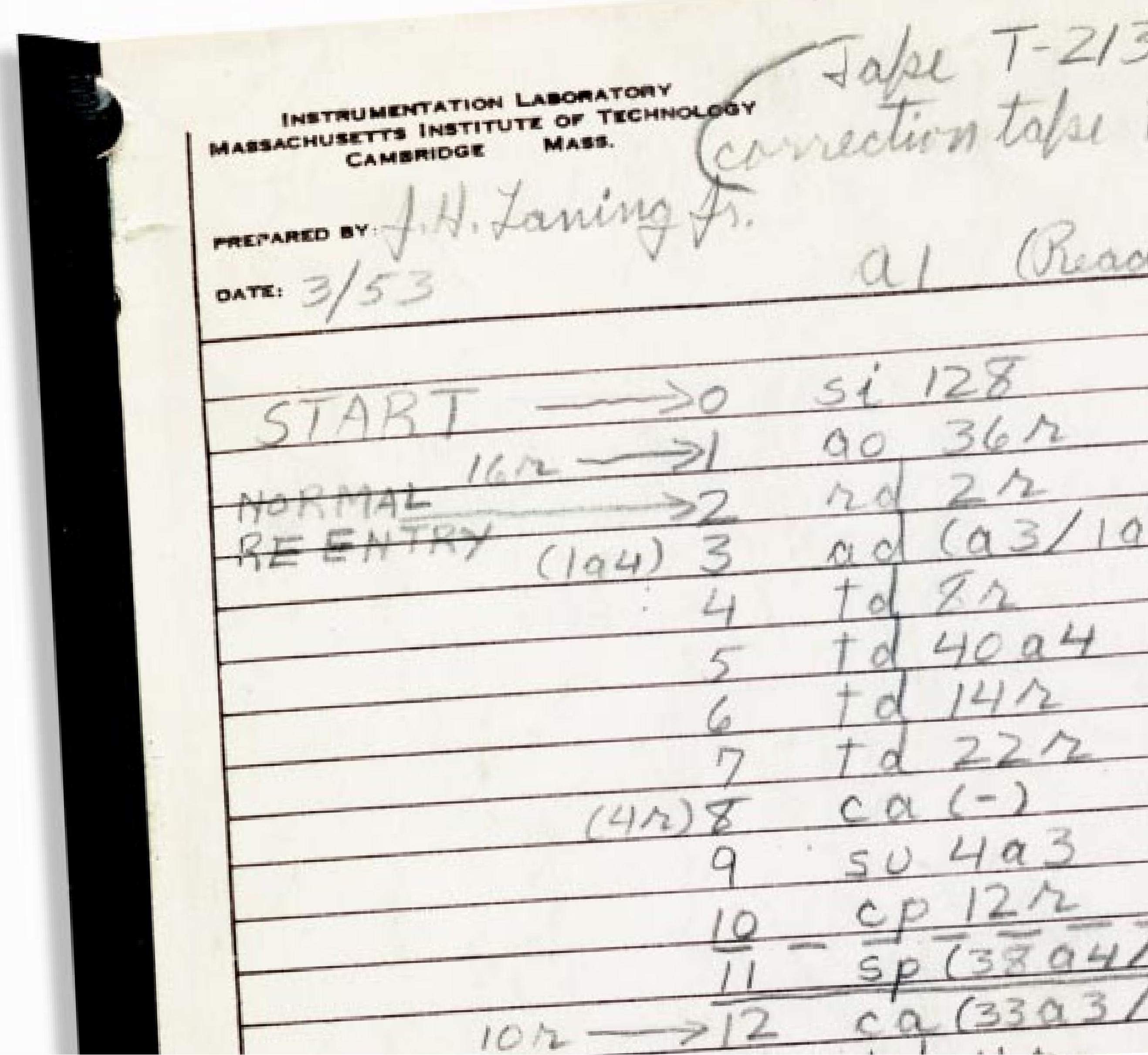
In the late 1950s, under contract to the Air Force Ballistic Missile Division, the Lab began work on a preliminary design study for a Mars space probe. The proposed autonomous spacecraft was intended to take close-up, high-resolution photos of Mars. It featured a low-power, highly-reliable computer for space flight guidance and navigation. Although the probe was never launched, the team that worked on it gained valuable experience and developed technology that would later help position the Lab for work on the Apollo manned-space program during the 1960s.

Dr. Hal Laning

World's First Algebraic Compiler

Seen here is the original manuscript for the first compiler program ever written to translate mathematical notation into a usable program for a computer. The effort, which began in the summer of 1952 by Dr. J. Halcombe Laning and carried forward with the assistance of Neal Zierler, culminated at the end of 1953 in an operational program which was used in a limited number of engineering studies by the Instrumentation Lab on the MIT Whirlwind Computer.

The significance of the program lies in the fact that it demonstrated for the first time that such translation from mathematical symbolism to computer code was indeed practical. By setting this precedent it influenced the development of subsequent languages such as Fortran (which was released in April 1957).



INSTRUMENTATION LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
CAMBRIDGE MASS.

Tape T-21…
correction tape …

PREPARED BY: J. H. Laning Jr.

DATE: 3/53

a1 (Rea…

START → 0 si 128
16r → 1 ao 36r
NORMAL REENTRY → 2 rd 2r
(1a4) 3 ad (a3/1…
4 td 8r
5 td 40a4
6 td 14r
7 td 22r
(4r) 8 ca (-)
9 su 4a3
10 cp 12r
11 sp (38a4…
10r → 12 ca (33a3…

“I predict that inertial guidance principles will be used in all the guidance systems of the future.”

– *Doc Draper*

The Laboratory has, over the years, developed the necessary precision accelerometer and gyros and applied them to the inertial guidance of vehicles. As Doc Draper once put it, “An inertial system does for geometry - angles, distance, and speed - what a watch does for time.”

Doc in 1968 on the roof of the Lab testing the Apollo celestial sightings.

1901
Charles Stark Draper born in Missouri October 2, 1901.

1922
Receives degree in Psychology from Stanford, comes east to MIT.

1926
Begins working at MIT as Research Associate under Sloan fellowship.

1938
Receives Ph.D. in physics from MIT, and is appointed Associate Professor.

1942
Navy first uses Draper-designed Mark 14 gunsight in battle at sea.

Charles Stark Draper

Founder of Draper Lab

"In any assessment of the importance of individual contribution to national defense, we cannot but think of von Neumann and the bomb; Rickover and the atomic submarine; and Schriever and the management of the ICBM program. But no person has so clearly dominated in engineering science as has Draper in automatic control and guidance."

– General L.I. Davis, U.S. Air Force, 1963

Charles Stark Draper was the 20th century's key figure in developing and applying inertial navigation. He did more than any other individual to make inertial guidance practical. "I've been accused of being both the mother and the father of inertial navigation," he once joked. The press called him "Mr. Gyro," but the staff at the Lab referred to him simply as "Doc." The story of Draper and the story of Draper Lab are, in many ways, one.

Draper's early work on fire control were crucial first steps leading to his first experiments in inertial navigation, which had been described in detail in a 1940 MIT doctoral thesis by Walter Wrigley.

Draper built on the ideas of Wrigley and many other developments during the first half of the century, but it is his indelible stamp that most clearly marks the development of inertial navigation.

Former MIT President Howard Johnson once called Draper "an authentic genius." Former Draper Laboratory President Robert Duffy, in a memorial tribute to Draper in 1987, referred to him as "a complex genius . . . a modern Renaissance man, self-described as a 'greasy thumb' mechanic." Draper was a master at capturing center stage and energizing those around him. He became a living legend and won over 75 awards and prizes in his lifetime. He combined the genius of the inventor, the savvy of the developer, and the fire of the educator, and led his research laboratory into the real world, where development mattered as much as research, where accountability meant the difference between success and failure.

The world was changing rapidly during the Lab's early years in the 1930s, and World War II was imminent. Draper and his Laboratory responded quickly to the war's demands, and to the Cold War that followed. Throughout his five-decade career, Draper used his salesmanship and the Lab's technical skills to win new contracts and see them to completion. He forever changed the concept of the engineering research lab.

Draper was born in Missouri on October 2, 1901. He grew up with a love of planes and automobiles. In 1922, he completed his requirements for an undergraduate degree in psychology at Stanford University, and drove east to Cambridge, Massachusetts, with a group of friends, all bent on enrolling at Harvard. But once in Cambridge, Draper separated from his friends on a whim and began to explore the nearby MIT campus and its offerings. Fascinated, he immediately enrolled there.

Four years later he received an undergraduate degree in Electrochemical Engineering. In 1926, he began working as a Research Associate under a Sloan fellowship to

1951
Becomes head of MIT Department of Aeronautical Engineering.

1953
Flies SPIRE to Los Angeles: first coast to coast flight without aid of pilot.

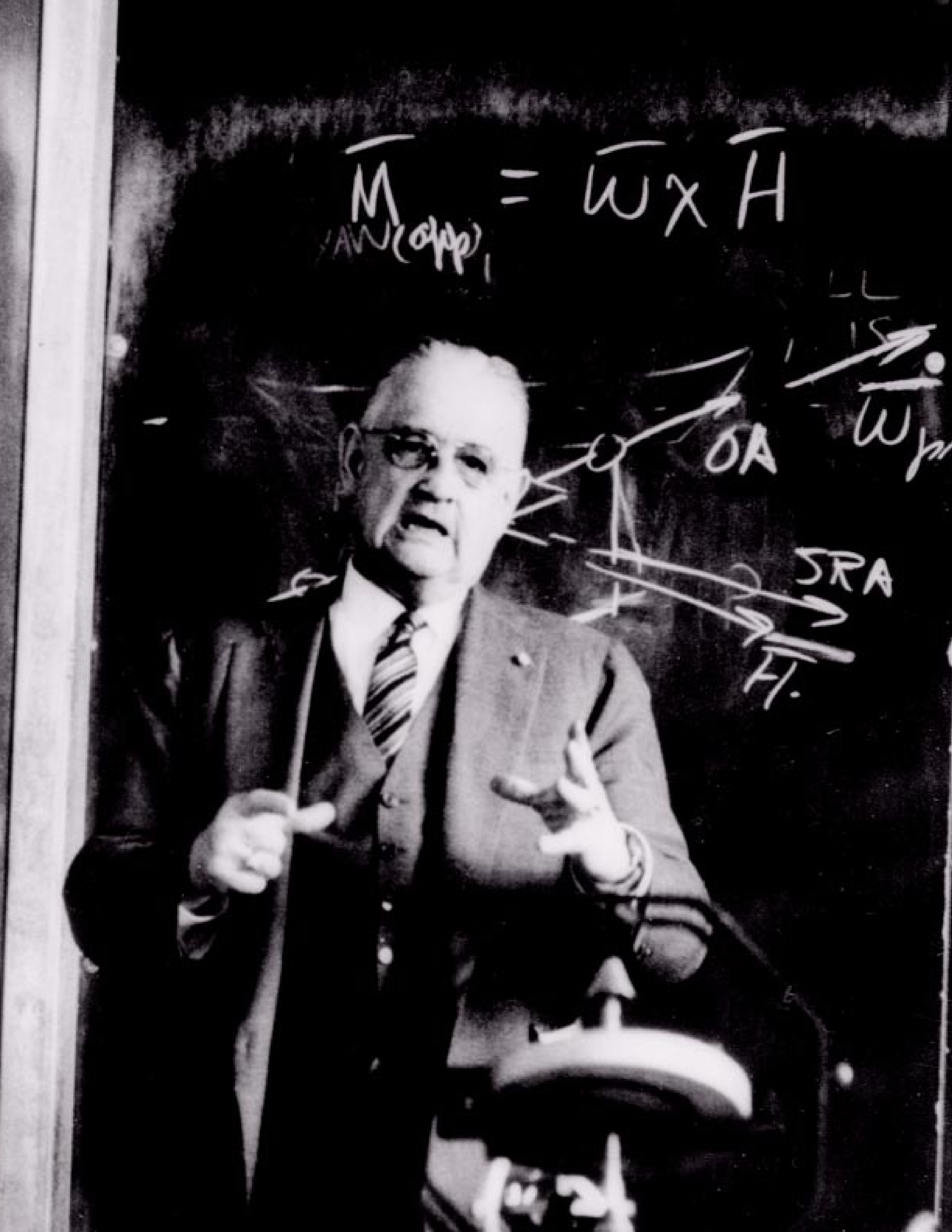
1961
Chosen as one of *Time Magazine's* "Men of the Year," January 2.

1970
Is "retired" as Director of Lab, but reinstated soon thereafter.

1987
Dies at 85, having received more than 75 awards during his lifetime.

Draper was always himself, even in formal situations. Once, while having his photograph taken with the Holy Father in Rome, he told a surprised Pope Paul VI,
"You and I are in the same business – celestial navigation."

The equation on the blackboard is an expression of gyroscopic precession and applies to the single degree of freedom gyro which Doc Draper developed to a very high performance.


M = ω x H
OA
SRA

study automobile and aircraft engine flame spectroscopy. This led to a fascination with the possibility of flying by instruments, a passion that would direct the course of his life.

He received a Master's degree in 1928. He continued on and, according to legend, took more courses for credit than anyone else in the history of MIT. By 1938, a frustrated MIT faculty committee insisted that he stop taking courses and finish work on his Ph.D. in physics. He agreed, earned his degree, and was appointed an Associate Professor in the same year. By that time he had been going to college for over 20 years! Draper was appointed a Full Professor in 1939, and in 1951 he became Head of the Department of Aeronautical Engineering (later called the Department of Aeronautics and Astronautics).

"I've been accused of being both the mother and the father of inertial navigation," he once joked.

Draper was an entertaining lecturer and a colorful presence at MIT. Wearing his oversized French beret, he drove around the campus in a Morgan sports car, looking more like a *bon vivant* than an academic. His down-to-earth attitude appealed to the popular press. A *Boston Herald* article once described him as "a gray-haired man with the square build of a baseball catcher – which he was – and the mashed and flattened proboscis of a prize-fighter – which he was. How did he break his nose? 'I didn't break it,' he said, 'It was broken for me. Five or six times.' " The article, a paean to Draper's career, demonstrated his flair for a good quote. From the beginning, he knew the importance of public relations and the 'photo op.' The Draper Lab archives reveal countless images of Doc Draper cradling his inventions (often small gyroscopes) in his hands.

Draper may ultimately be remembered as much for his contributions to engineering education as for his contributions to inertial navigation.

Draper called his laboratory "an Athenian democracy, where talent ruled." He fostered discussion and debate among his staff and listened carefully to all sides of each issue, sensing that the better solution would evolve out of the process. But, as Robert Duffy noted, "If it wasn't Doc's preferred solution, it didn't always survive. He could be ruthless."

The Draper Personality

Draper was gregarious and nearly always surrounded by people, but when on the brink of a new idea, he could be impatient and irritable. He enjoyed celebrations and held lavish Christmas parties every year. Writer Elizabeth Sherman, in her article "The Man Who Set the World Straight," said that Draper pursued his scientific goals aggressively: "He fostered cutthroat competition among his colleagues, but kept a productive balance through his unique blend of psychological subtlety, intellectual flexibility, and ready humor. He was pugnacious and down-to-earth. He despised affectation and ignored divisions of class and rank."

His picture appeared on the cover of *Time* magazine on January 2, 1961. That and his work on the Apollo mission helped make him a public figure. His reputation continued to grow until the late 1960s, when campus unrest began at MIT in protest of the Vietnam War, focusing on the Institute's role in developing military weapons. Seeming to bear no personal animosity toward the demonstrators, Draper often spoke to them personally or joked with them, and, in some cases, even took them to dinner to try to reason with them, but to no avail. These events, begun in the late 1960s, led to the renaming of the Laboratory as The Charles Stark Draper Laboratory and, finally, the Lab's divestiture from MIT in 1973. In 1970, Doc Draper was "retired" as head of the Laboratory, but the scrappy Draper immediately told the *New York Times*, "I was fired."

Draper was later reinstated and remained an important presence at the Lab until his death in 1987 at the age of 85. During his career, Draper received more than 75 awards, including election to the National Academy of Science, the National Academy of Engineering, and the French Academy of Sciences.

Draper led his research laboratory into the real world, where development mattered as much as research, where accountability meant the difference between success and failure.

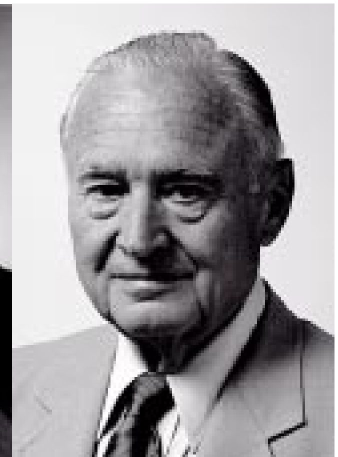
He ultimately may be remembered as much for his contributions to engineering education as for his applications to inertial navigation. He counted among his students some of the most famous names in aviation and space. In 1956, Air Force Chief of Staff Nathan F. Twining told Draper that his contribution to the "superiority of United States weapons ranks with any in the history of arms. But of possibly greater significance is the value received by the many Air Force officers who have worked under your leadership and guidance while undergoing graduate training at the Massachusetts Institute of Technology."

Today, there is an endowed chair in Draper's name and a series of graduate fellowships established in his honor at MIT. Most significantly, the Draper Prize has been permanently endowed in his name. The Prize consists of a gold medal and an honorarium ($450,000 in 1997). It is administered by the National Academy of Engineering, and it recognizes living engineers for innovative engineering achievements and their reduction to practice in ways that have led to important benefits and significant improvements in the well being and freedom of humanity.

The Draper Prize Recipients

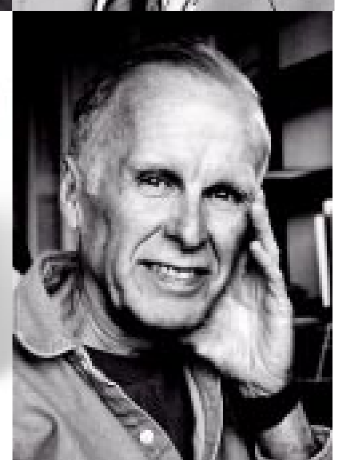
Dr. Robert N. Noyce
1989

Jack S. Kilby
1989

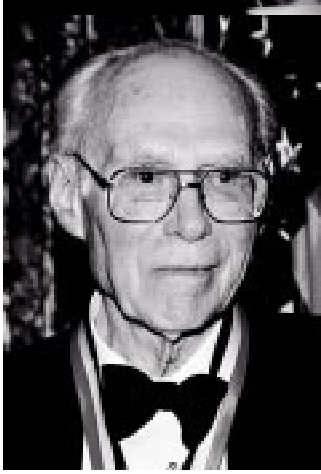


Dr. Hans J.P. von Ohain
1991

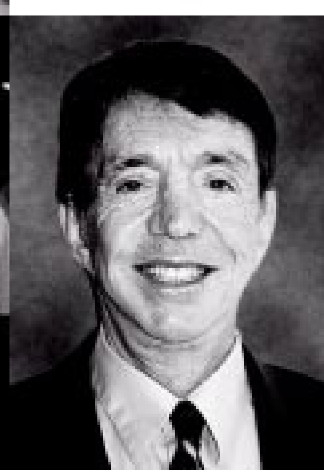
Sir Frank Whittle
1991



John Backus
1993



Dr. John Pierce
1995



Dr. Harold Rosen
1995

Dr. Vladimir Haensel
1997

The Charles Stark Draper Prize

The Charles Stark Draper Prize was established and endowed by Draper Laboratory in 1988 in tribute to its founder. Administered by the National Academy of Engineering, the international prize is the engineering profession's highest honor, and it is given for engineering achievements and their reduction to practice in ways that have contributed to the welfare and freedom of mankind.

The prize can be awarded for achievement in any engineering discipline. In 1997, the Prize carried an honorarium of $450,000, its largest ever.

The first Draper Prize was presented by President George Bush in 1989 to Jack S. Kilby and Robert N. Noyce, the engineers who independently co-invented and developed the monolithic integrated circuit. The second prize was awarded in 1991 to Sir Frank Whittle and Hans J. P. von Ohain for the independent engineering innovation and development of the turbojet engine. In 1993, the third prize was awarded to John Backus for the development of FORTRAN, the world's first higher-level computer language. The fourth prize was awarded in 1995 to John Pierce and Harold Rosen for their inventions in communication satellite technology. In 1997, the Draper Prize was awarded to Vladimir Haensel, inventor of "Platforming," a trademarked revolutionary chemical engineering process essential in producing clean fuel for transportation and in supplying materials for the modern plastics industry.

Excerpt from a letter from President William Clinton which was read on February 20 ,1996 at the presentation of the 1995 Draper Prize to John Pierce and Harold Rosen.

"This prestigious award honors those engineers who, often against great odds, explore a new world of possibilities. Pioneers like Pierce and Rosen have taken that exploration further by transforming scientific knowledge into improvements in communication, mobility, education, environment, security and entertainment - enriching our lives, broadening our minds, and increasing our opportunities to prosper."

- President William J. Clinton
February 20 , 1996

1961
President John F. Kennedy commits the nation to put a man on the moon by the end of the decade.

1961
Lab receives first major contract awarded by NASA for the Apollo project.

1964
NASA Administrator James Webb and Doc confer with President Johnson during the Apollo space program.

1968
Apollo 8 crew orbit the moon.

1969
Apollo 11 makes historic first manned moon landing.

The Apollo Program

The Apollo 11 astronauts landed on the moon in 1969 using the vitally important onboard guidance, navigation, and control (GN&C) systems designed by the Instrumentation Lab for both the Command Module and the Lunar Module . The MIT guidance systems were so essential to the Apollo mission that *The New York Times* referred to Draper simply as the man who "guided the astronauts to the moon."

David Hoag, the Lab's Apollo Technical Director during the 1960s, says in his history of the Apollo program at the Instrumentation Laboratory, "The guidance equipment for the [Apollo] mission was created out of first principles, prolific imagination, and a lot of hard work. It is significant that the Lab's suite of hardware and software on these spacecraft safely led a team of astronauts on an audacious trip to the moon and back." Indeed, Draper's designs successfully guided eight Earth-orbital missions and nine lunar missions without a failure.

"When [Doc Draper] told us at NASA that he would 'go along and run' the Apollo mission navigational system, he wasn't just kidding.

He wrote us a letter explaining that he'd be the logical choice, since he knew more about the new system than anybody else.

And I think he was mad when we didn't take him up on it."

— Dr. Robert Seamans, former Deputy Administrator of NASA

Shortly after President John F. Kennedy urged the nation in 1961 to "commit itself to achieving the goal, before this decade is out, of landing a man on the Moon," Draper met with the NASA management staff. He later recalled, "I was invited to Washington for a conference with Mr. James E. Webb, then the Administrator of NASA. After some preliminary explanations of the mission plan being considered for Apollo, Mr. Webb, Dr. Hugh Dryden (Technical Director), and Dr. Robert C. Seamans (Deputy Administrator) asked the Lab's Program Manager Milton Trageser and me if guidance for the mission would be feasible during the 1960s decade. 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.' " The Lab soon received the first major contract awarded by NASA for the Apollo program.

The Apollo guidance computer managed all onboard guidance, navigation, and control functions.

Several hundred MIT Instrumentation Laboratory engineers and technicians worked on Apollo. They were primed for the job because of two important prior projects: the Mars Probe prototype and the Navy Polaris project. As the Apollo mission operation and spacecraft details evolved, the Lab's responsibilities also evolved to include the onboard GN&C flight systems for both the Command/Service Spacecraft Module and the Lunar Lander Spacecraft Module.

For Apollo, the Lab borrowed, with minor modifications, the configuration of the inertial measurement unit (IMU) designed earlier for the Polaris missile. The computer design expanded on ideas from the earlier Mars Probe. It was a general-purpose real-time digital control computer having 36 K 16-bit words of fixed

1969
NASA programs now represent over 50% of Lab's work.

1970
Apollo 13 crew rescued. Lab plays key role.

1971
Lab writes emergency software so that Apollo 14 computer can ignore faulty switch.

The Lab's Mission Support to Apollo

During missions, Lab engineers with specialized knowledge stood watch in the back rooms of Mission Control in Houston.

In Cambridge, the Lab had its own mission support center in direct communication with the Houston flight controllers, where the Lab's Apollo design staff were quickly available to help resolve mission problems. They could employ, when needed, the special simulators used earlier during the design phases.

Those were exciting times. The Lab staff was caught up in the emotion of the 1968 Christmas Eve flight of Apollo 8, waiting anxiously for it to reappear from its passage behind the moon to confirm that the astronauts, while out of Earth's view a quarter million miles away, had used the guidance system successfully to achieve lunar orbit.

The Lab-developed equipment and software had no failures in eight unmanned and manned Earth orbital missions and in nine manned lunar missions.

"Houston, we h

As millions watched the world-wide coverage of the Apollo 13 mission, an onboard mechanical problem threatened the safety of the crew and the mission.

Rescue was accomplished using an Instrumentation Lab -designed program in the Lunar Module guidance computer.

" Good people bring good people with them. And that is what happened at the Instrumentation Lab [during the Apollo program].

Draper has received a lot of credits, a lot of plaudits and as far as I am concerned, it is all very justifiable."

- Dr. Aaron Cohen
  Director of NASA's Johnson Space Center 1986-93

ave a problem..."

For the most part, the flight program experience was remarkably consistent with expectations.

But not all went smoothly; events were sometimes punctuated with surprises. Some of these compromised mission objectives and even endangered the crew. The astronauts and their flight controllers performed remarkably well under the stress of facing the unexpected.

Instrumentation Lab engineers participated in the resolution of many of these problems and, in some cases, their support was critical.

Several events are notable:

The Apollo 11 Lunar Module computer sending alarms to the crew during the first lunar landing due to being overloaded, caused by a switch left in the wrong position, but still able, in spite of this, to complete the landing program for the astronauts. . .

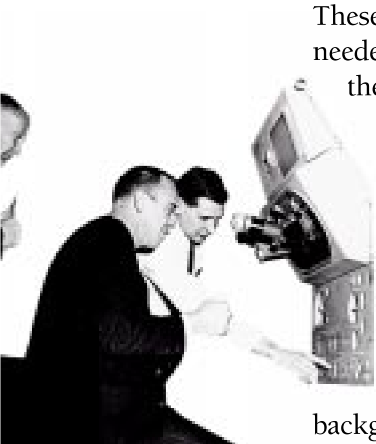
The realignment of the Apollo 12 guidance system in Earth orbit after an upset caused by two lightning strikes shortly after liftoff. . .

The remarkable rescue of Apollo 13 by using a little tested program in the Lunar Module guidance computer to push the disabled Command/Service module onto a safe return trajectory to earth. . .

The emergency transmission to the Apollo 14 Lunar Lander crew of a manual keystroke sequence developed hastily in Cambridge so that the computer would ignore erratic commands from a faulty switch on the main panel that would otherwise have aborted the landing.

memory, and 2 K words of RAM operating at a 12-microsecond cycle time. Although pushing the state-of-the-art in the early 1960s when the design had to be frozen, it had very modest capabilities indeed compared with today's computer technology. Although general purpose in its processing function, it was necessarily unique in the more than 200 input and output specialized ports needed to interface with the IMU, the optical systems, the radar systems, the displays and controls, and the various spacecraft rocket thrusters and attitude reaction jets. The latter connections were necessary to accomplish the digital autopilot functions assigned to the computers and their software for both vehicles. (Although digital autopilots are common now, these were the first ever to fly.)

These digital autopilot designs were only one class of many computer programs needed. Every mission phase required compact and accurate algorithms to manage the guidance and navigation functions. They had to be optimized to use available data and fit in the small computer storage available. Sometimes, necessarily, programs had to operate simultaneously as in a multiprocessor and still be able to service interrupts, all without interfering with each other.

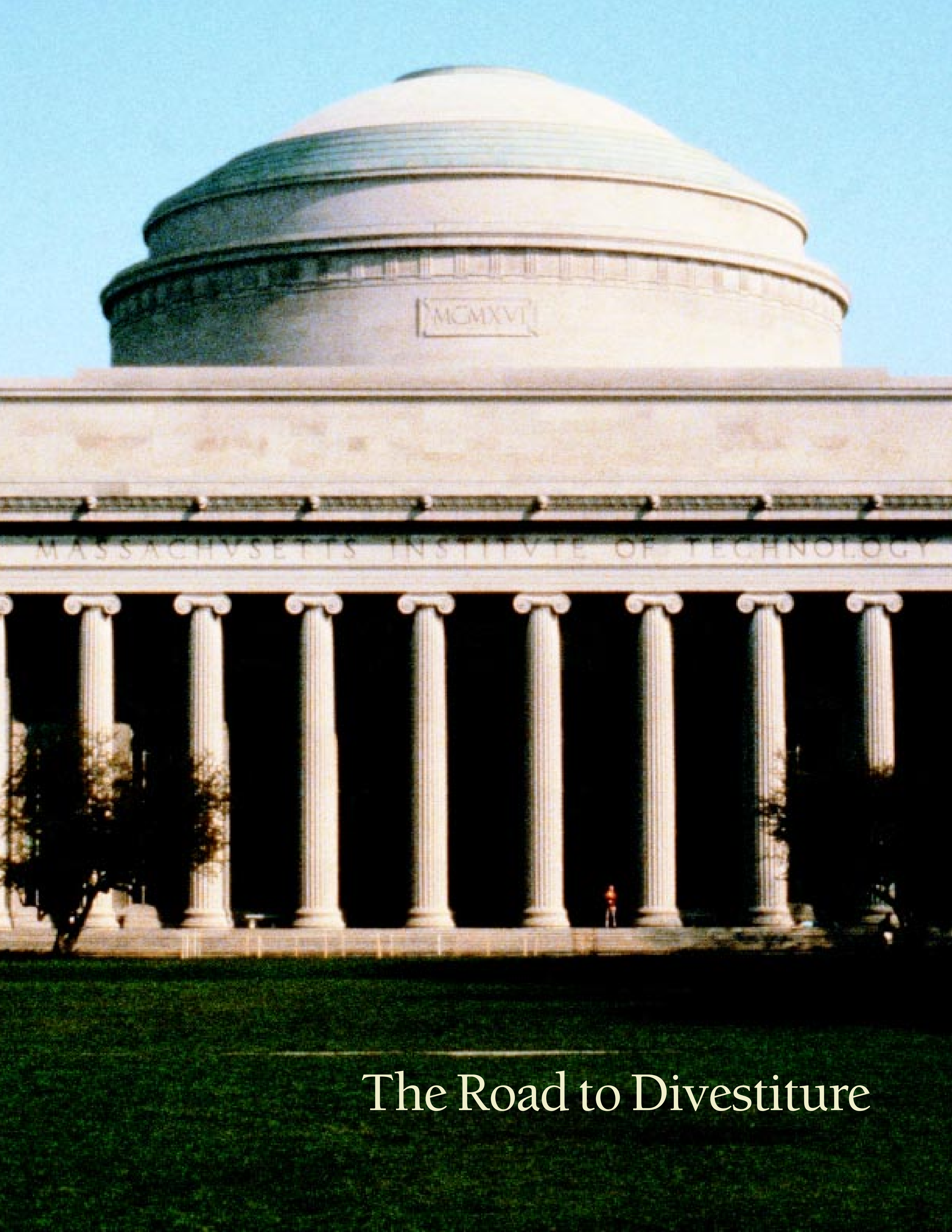


In1965 MIT Instrumentation Lab engineer Ain Laats demonstrated the Apollo computer operation to Astronauts John Glenn and Alan Shepard.

Although the IMUs and digital computers in the Command Module and Lunar Lander were identical, the displays and controls and the optical systems in each spacecraft configuration were necessarily custom designed. The optical systems were used by the crews to align the IMUs and to make navigation measurements of the directions to Earth or moon relative to the background stars. The capability for self-contained onboard navigation was considered necessary in case the USSR interfered with the ground-tracking radars and/or communications necessary for the primary ground-based mission navigation. Local navigation at the moon was augmented in the computer using data from a landing radar and a rendezvous radar.

The Lab's focus on the program was about equally divided between the hardware and the computer software. The software design was particularly difficult because of the limited computational resources that were available, the ever-evolving spacecraft design, the differences in the mission operation procedures for various phases of the flight, and the two different spacecraft configurations. Negotiating the physical, electrical, and functional interfaces with North American Aviation for the Command Module and with Grumman for the Lunar Lander so that the equipments and functions would all work in harmony also required intense effort. All during the design and development phases, the Lab was assisted by industrial support teams who would later manufacture to the drawings released by the Lab.

The Apollo computer's capability and reliability were highly respected by Apollo astronauts. David Scott, commander of Apollo 15, said in 1982, "With its computational capability, [the Apollo Guidance Computer] 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."



The Road to Divestiture

In April of 1969, Doc went into the streets outside the Lab to personally discuss the issues with the students.

March, 1969
Unrest at MIT focuses on defense research on campus.

April, 1969
Pounds panel begins review of MIT's defense ties to special laboratories.

Fall, 1969
MIT limits defense research on campus and begins a year of trial.

The Road to Divestiture

At the peak of the Apollo program, all signs pointed to a continued and successful association between MIT and its Instrumentation Lab. Employment at the Lab exceeded 2,000 people, half of whom were working on NASA contracts. But only a few short years later, the two became separate entities. The dramatic story of the Laboratory's divestiture is still fresh in the minds of many Draper employees who lived through it.

Even while the world celebrated in July 1969 as two Americans stepped onto the Moon's Sea of Tranquillity, guided to their destination by the Lab's onboard systems, the Laboratory's military programs began to catch the attention of anti-war students and faculty. The Laboratory soon became embroiled in a series of tumultuous events.

Early Political Unrest

The first major appearance of unrest at MIT occurred on March 4, 1969, when students and faculty conducted a research stoppage to protest military research on campus and the possible "misuse of scientific and technical knowledge."

The stoppage was organized by several faculty and students who formed the Science Action Coordinating Committee (SACC) to oppose defense research on campus. Unlike the SDS (Students for a Democratic Society), they rejected violence in favor of peaceful demonstrations, including sit-ins, to focus on ending weapons development at the Institute. Their efforts attracted large groups of people, both organized and unorganized, who met to debate this subject.

The activists focused on the Laboratory's Navy Poseidon ballistic missile program, specifically, its multiple independent reentry vehicles (MIRV) capability, which would allow a single missile to deliver multiple warheads. SACC claimed that MIRVs would stimulate further escalation of the arms race. They also alleged (inaccurately) that the Deep Submergence Rescue Vehicle (DSRV) program was actually a cover for developing new military weapons.

In *The University and Military Research*, Sociologist Dorothy Nelkin notes, "The students planned to march to the Instrumentation Lab on April 15, but Doctor Draper and Rene Miller, Head of the Department of Aeronautics and Astronautics, met the students and invited a group of them for lunch; the march turned into an open-air discussion."

Howard Johnson was President of MIT at the time, and the pressure on him to respond intensified. In a recent interview, he recalled, "There was a philosophical question about whether [missile guidance] work should be done on the campus. This was easy to resolve during wartime, but much more difficult in peacetime.

January, 1970
The Instrumentation Lab is renamed Charles Stark Draper Laboratory.

May, 1970
MIT President Howard Johnson announces divestment in two stages.

May, 1970
Albert Hill is named Chairman of the Board.

July, 1971
Robert Duffy joins Draper Laboratory as Vice President.

July 1, 1973
Laboratory becomes independent, not-for-profit corporation.

The concept of a university is based on open research. I remember in my early days at MIT being surprised to see that some students' theses were classified, and wondering what was in them. That is a very complicated question for a university."

Pounds Panel

On April 21, Johnson met with the SACC group, who demanded a moratorium on all research related to tactical and strategic weapons. He rejected this demand, instead convening a community committee under the leadership of William Pounds, then Dean of MIT's Sloan School. It consisted of students, faculty, and representatives from campus research organizations, as well as from Lincoln Laboratory and the Instrumentation Lab. David Hoag and Philip Bowditch were the Instrumentation Lab's representatives on the committee.

Howard Johnson

The panel was given six months to review the Institute's relationship to these laboratories and the appropriateness of its sponsorship. The panel would have a major influence on the future of military research at MIT.

During the study, MIT stated it would not accept any new classified projects, but that existing military projects could continue. The Pounds panel conducted both public and private sessions, 20 formal meetings in all. Many panel members also met in Washington with senators and members of NASA and other government agencies. Interestingly, many of the student activists did not want to separate the laboratories from MIT, but instead wanted to stop or limit the military research being done there or to redirect those efforts toward peaceful ends.

Nelkin notes, "There were many who objected to any changes at all in the research orientation of the laboratories. Draper himself referred to the Pounds panel investigation as an 'inquisition,' and many people in the Instrumentation Lab and in the Department of Aeronautics felt threatened by the procedure."

After intense deliberation, the Pounds panel issued its final report in the fall of 1969 and submitted it to Johnson. The panel assumed the laboratories would remain part of MIT. They concluded that there should be a more balanced research program at the laboratories and better educational interaction between the laboratories and the campus. They recommended intensive efforts to reduce classification and clearance barriers in the laboratories. To this end, they recommended that a standing committee on the special laboratories be established to give the President advice on reducing research on weapons systems.

In response to the Pounds Panel Report, the Executive Committee of the MIT Corporation said, "It would be inappropriate for the Institute to incur new obligations in the design and development of systems that are intended for operational deployment as military weapons . . . This is not to mean that with its unique qualities, the Institute should not continue to be involved in advancing the state of technology in areas which have defense applications." This policy would ultimately result in the separation of the Laboratory from MIT.

A Year of Trial and Angst

Johnson declared that the 1969-70 academic year would be a year of trial to determine whether or not the two major MIT laboratories, Lincoln and the Instrumentation Lab, could continue to serve their sponsors while still adhering to the new policy promulgated by the Executive Committee. Johnson announced that the name of the Instrumentation Laboratory would be changed to The Charles Stark Draper Laboratory on January 1, 1970.

It was a year of angst, marked by heavily attended campus meetings, which were noisy and disruptive. Debate raged as to whether the work of these Laboratories, both current and proposed, was appropriate to a university.

In early November 1969, a group of activists blocked access to the President's office at MIT and attempted to block access to the Lab's principal places of business. The Cambridge police tactical squad cleared the streets and by 9:45 a.m. the Laboratory was reopened. Thereafter, there were regular demonstrations in front of the Laboratory. Some were peaceful, others were aggressive efforts to prevent people from coming to work.

Sheehan Panel

The standing committee recommended by the Pounds panel was established, headed by Professor John Sheehan, an MIT chemical engineer famed for synthesizing penicillin. Known informally as the "Morals Committee," the committee's charter was to review all research proposals issuing from the MIT Instrumentation Laboratory and the Lincoln Laboratory to determine whether or not they violated the guidelines of the new policy.

At that time, the Trident I missile development was getting underway, and the Laboratory was preparing to design the guidance system for the new missile, a role that was considered key to the Laboratory's future. The decision about releasing the proposal to work on that program was delayed because there was doubt that it would meet the new campus standard.

The Final Decision

In May 1970, when the year of experiment was over, Howard Johnson announced MIT's decision. Lincoln Lab's programs were in compliance with the new policy against operational weapons development, but Draper's were not. MIT would therefore take steps to divest Draper Laboratory, but would do so in a responsible way. As a first step, the Lab would become a separate, independent division of the Institute with its own Board of Directors reporting to Howard Johnson and the MIT Executive Committee. That Board would determine the most appropriate way to carry out the divestiture. Although some MIT officials, fearing the financial and public relations impact, attempted to reverse the decision and keep the Instrumentation Lab a part of MIT, their efforts failed.

Robert Duffy

The new Board of Directors would be headed by MIT Vice President for Research Dr. Albert G. Hill, and would consist of MIT senior officials plus representatives from industry, banking, and foundations.

Albert Hill and His Task Force

It took three years to plan and implement the divestiture, which officially occurred on July 1, 1973. Robert Duffy, who was to become the independent Lab's first President, referred to Hill as "the master of the transition. He was a 'damper' between Doc Draper and the very vocal minority of the faculty who wanted the labs to be divested."

Joseph O'Connor

Productivity at the Laboratory remained amazingly high during its three years as a division of MIT. Joseph O'Connor, currently the Secretary to the Corporation, feels strongly that no one could have done the job the way Hill did it. "He set up a five-man task force, including David Driscoll, currently Draper's Vice President for Finance and Administration and Treasurer, MIT Comptroller Paul Cusick, Michael Wall, a consultant and entrepreneur, attorney Fred Robbins from Goodwin, Proctor and Hoar, and myself. We were given the essential freedom to examine fully all of the complex issues attending the separation of two organizations that had been together so long."

Hill and his divestiture team kept the employees fully informed about their progress toward divestiture, and explained the options being considered, which included having the Lab become an employee-owned venture, using the employee retirement fund as capital; becoming an operating division of a large defense contractor; and (the option that was finally chosen) becoming an independent, not-for-profit corporation.

Much of Hill's effectiveness had to do with his style. When he became Chairman, he appointed Doc Draper as President pro tempore. Hill and Draper were roughly the same age, they had been through similar career experiences, and they got along well. Hill had been a significant contributor to the work of the MIT Radiation Lab, which developed radar during World War II, and also had served at the Institute for Defense Analysis in Washington, a think tank consisting of academics serving the DoD. He understood Doc Draper's reaction to the demonstrations: "Draper was not pleased with the situation, because underneath it all he was a great teacher and he loved MIT—and here was his love putting him in this horrible position."

Managing the Divestiture

John Kirk

Separating the Lab from MIT was a complex, involved process, requiring extensive negotiation and cooperation between the parties. To its credit, says O'Connor, MIT did not rush things, especially when dealing with the sensitive issues of employee status and benefits. In the end, all benefits were preserved. In addition, Draper employees continued to enjoy access to the activities of the MIT community, including cultural and academic activities, the medical department, libraries, and athletic facilities.

In 1971, Hill asked Robert A. Duffy, a USAF Brigadier General, if he would consider becoming Vice President of the Draper Division and President Elect of the proposed separate corporation. Duffy agreed and retired from the Air Force. He became President and Chief Executive Officer two years later in 1973. Duffy managed the operations of the Laboratory while Hill ran the task force and led the Board. It was an effective combination.

David Driscoll

Once an enlisted man, Duffy was the ideal choice for Draper. With his easy-going style, he could deal effectively with all members of the Laboratory community, as well as policymakers. He had been at the Instrumentation Lab while in the military under a one-year training program. He had managed several Air Force ICBM guidance system development programs, and so knew Draper Lab as a sponsor, as a student, and as an employee. John Kirk, a Naval Academy graduate with two earlier tours of employment with the Laboratory as a technical manager, agreed to become Vice President after having served as technical advisor to Generals Westmoreland and Abrams in Vietnam. With these two positions filled, the leadership that would be needed to guide the Laboratory when it became independent was in place.

One of the most important tasks of the divestiture was to novate the government contracts from agreements between the government and MIT to agreements between the government and Draper Lab. David Driscoll led this work. It was a delicate exercise, important to both the Lab and to its sponsors. In the end, all the contracts were successfully novated.

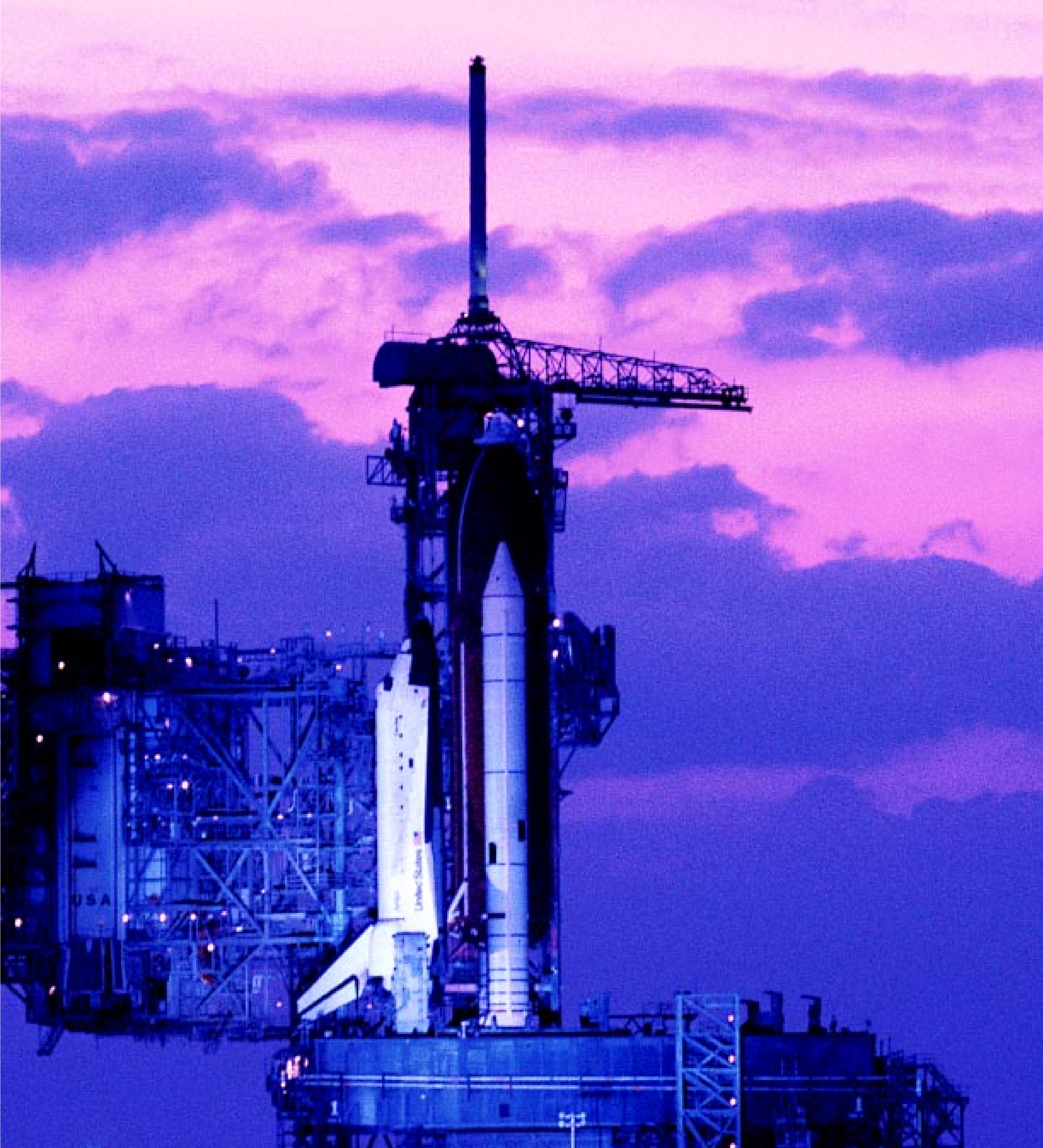
Dr. John Foster, Jr.

Dr. John Foster, Director of Defense Research and Engineering, strongly believed that the Lab was important to the DoD mission, and he was the key government official involved in bringing about a successful outcome of the divestiture process. His support and cooperation were important to the independent Laboratory's success. He later became a member of the Draper Board and continues to be affiliated with the Lab.

The Benefits of Independence

The benefits to Draper of divestiture were substantial. Decision-making was now easier without the involvement of the Institute hierarchy. The Laboratory could add the staff necessary to run an independent corporation, receive a fee on its contracts to provide reserve funds, and still reduce the cost to the government of doing business. Its not-for-profit status allowed the Laboratory to continue its traditional role as an objective designer of systems that advanced the state-of-the-art and served to meet important national needs in the areas of GN&C. At the same time, the Laboratory retained close ties to its parent institution, MIT.

The Independent Laboratory



1970
Laboratory delivers ICAD for first Deep Submergence Rescue Vehicle (DSRV).

1971
Lab receives contract for NASA Space Shuttle avionics work.

1972
Lab pioneers digital fly-by-wire system for NASA.

1973
Skylab begins two years of space experiments.

1976
555 Technology Square completed and dedicated.

1979
Trident I missile is deployed, featuring Draper guidance system.

The Independent Laboratory

The work required to effect the divestiture was now complete, and Draper Laboratory became officially independent on July 1, 1973. Two days prior to this, the Laboratory held a party at MIT to celebrate with guests from both MIT and the Laboratory in attendance. The atmosphere was harmonious and confident. Dr. Hill invited the entire assembly to gather for refreshments at Rockwell Cage, remarking that the ceremonial foods were symbolic of the affluence of the new Corporation: hot dogs and beer.

The Duffy Building

Hill recognized that one of the independent Laboratory's most pressing needs was to replace its existing quarters. He placed a high priority on building a new facility that would not only replace an outdated plant spread across fourteen buildings in Cambridge, but would also symbolize a bright future for the fledgling corporation. The Board decided that the Laboratory should remain in Cambridge and as near to MIT as circumstances would permit. The search for a new facility began in earnest.

Photograph: **Draper Lab provided designs for the Space Shuttle avionics system, for its onboard flight control system, and for its back up flight control software.**

Several developers submitted proposals. The Board accepted one from Cabot, Cabot & Forbes, who proposed a new 450,000 square foot building in Technology Square, to be designed by Skidmore, Owings & Merrill of Chicago. In August 1974, the Laboratory entered into a long-term lease arrangement that would permit occupancy until the middle of the next century.

Ground was broken in September 1974, and the finished building at 555 Technology Square was dedicated on September 10, 1976. By mid-January the Laboratory was fully moved in and functioning normally. Employees no longer needed a shuttle bus to visit colleagues. Mail service was improved, and parking was no longer a problem. Sixteen years later, in 1992, the Draper Board voted to honor retiring Director Robert A. Duffy, the Lab's first Chief Executive Officer, by designating 555 Technology Square the Robert A. Duffy Building.

The Lab's Mission

The independent Laboratory had three principal objectives: to pioneer in science and technology, to contribute to the national interest, and to promote the transfer of technology through education – and they remain principal objectives for the Laboratory today. These goals reflected a strong continuity with the Lab's past. Business would continue uninterrupted, and the policies, procedures, and philosophy that had made the Lab a success remained in place.

1982
Albert Hill retires after 12 years; Kenneth McKay named Chairman of the Board.

1983
First flight of Air Force Peacekeeper missile, with Lab-designed guidance.

1983
Lab begins full-scale development of Trident II guidance system.

1983
Nuclear Free Cambridge initiative defeated by vote of 60% to 40%.

1984
Hill building completed and dedicated.

1984
Lab begins development of micro-mechanical technology work.

Nearly all the Lab's programs were the result of sponsor satisfaction with the Lab's past work. Existing and new programs fell into five major categories: 1) continuing NASA programs; 2) the continuing FBM program for the Navy; 3) the MX missile program for the Air Force; 4) the development of DSRVs for the Navy; and 5) a variety of other programs that advanced the state-of-the-art of GN&C technology. The acquisition of new programs was supported by the development of advanced technologies within the Independent Research and Development (IR&D) program.

Continuing NASA programs

By the early 1970s, Apollo had ended as a general program, but NASA had initiated a series of new missions that enabled the Lab to continue to apply its technical expertise. These programs and the Draper role are defined in what follows.

Digital Fly-by-Wire Flight Control System

Among the programs that evolved from Apollo was one dedicated to developing a digital fly-by-wire flight control system. Dr. Donald C. Fraser, former Draper Executive Vice President, commented recently on the beginnings of this early 1970s program: "Digital fly-by-wire was a proposed method for controlling an aircraft using a computer system wherein the pilot would not be mechanically connected to the aircraft's control surfaces. The program came into being when Astronaut Neil Armstrong asked the Lab if it could take the Apollo computer and control system and adapt it for use in a former Navy F-8 jet. As it turned out, we could, and we did so with great success. In the process, Draper pioneered digital flight control – the basis for controls in all modern aircraft."

The first-ever successful flight test of an aircraft completely under the control of an electronic digital fly-by-wire flight control system took place in May 1972.

The digital fly-by-wire program enabled Draper to demonstrate high reliability for critical aircraft control systems using reasonable-cost components. The Lab also pioneered in redundancy management for flight control systems, advancing the state-of-the-art of fault-tolerant computing. In that technique, several computers work on a task simultaneously. If any one of the computers fails, the others can take over – a vital capability when the safety of an aircraft is at stake. Draper Laboratory developed ways for redundant computers to "vote" about what to do in any situation. Subsequently, the scope of fault-tolerant system designs was expanded to include redundant flight control sensors and actuators.

The Space Shuttle

The Lab was asked to provide designs for the Space Shuttle avionics system beginning in 1970. This grew into responsibility for the design of the Space Shuttle's on-orbit flight control system as well as for its backup flight control software. The former controlled the vehicle attitude and thrust vector during the orbital phase, and the latter provided the Shuttle with controls to land in the event the primary system failed. The Laboratory also verified the GN&C software, and certified that the dynamics of the payload on each flight interacted safely with the Shuttle's control system and its remote manipulator arm. The Shuttle's redundant computer management and fault-tolerant system technology had been demonstrated by the Lab's digital fly-by-wire flight control system experiments on the NASA F-8 aircraft.

Skylab

Skylab, adapted from an upper stage of the Saturn Apollo launch vehicle, went into Earth orbit on May 14, 1973. Three manned flights to Skylab employing Apollo Command Modules were launched over a two-year period, each with a team of astronauts who conducted science and engineering experiments. Draper developed the algorithms used for Skylab's guidance and control package.

Astronaut Janice Voss, a former Draper Fellow, was a mission specialist on board Space Shuttle flight STS-57.

The FBM Program

Trident I

After divestiture, the Lab was free to pursue its long-standing FBM development work. In 1971, the Navy's SP had given the Lab overall design and development responsibility for the guidance system for the Trident I missile. The Trident I grew out of the nation's need to create a greatly improved missile-carrying nuclear submarine with a new long-range missile that would match the increasing strides of the Soviet Union. Unlike Poseidon, the new design would use a star-tracker system to improve accuracy. The first test flight of the Trident I occurred in January 1977, and it was deployed in October 1979.

Paul Dow, retired Senior Vice President and Vice President of Guidance Programs, notes that the Navy "has a philosophy of cradle-to-grave responsibility . . . All of the contractors working on the Navy FBM program have had that type of responsibility. The Navy SP Office itself has that kind of responsibility: the team stays together, from the initial concept of the design through flight tests and deployment, *"One of the things Draper Laboratory has done, and our relationship with Draper has done over the years, is provide a unique model for a relationship with industry.*

It is a relationship that shares the best attributes we, the government, can bring to bear, the Laboratory can bring to bear, and industry can bring to bear. I think that kind of model is one we will be using in good stead."

– *Rear Admiral John T. Mitchell, Director of the Navy's Strategic Systems Programs, 1992*

Draper Lab had overall design and development responsibility for the guidance system of the Trident I missile. Unlike Poseidon, the new design used a star-tracker system to improve accuracy.

and supports the system while it's in the field. It gives people a real sense of responsibility during the early phases of the program, and throughout the design and development. They know they're going to be called to account if there are problems."

In June 1974, the Navy's SP, urged by the DoD to commit to much higher accuracy for the next generation missile beyond Trident I, asked the Laboratory to assemble a team to take on this task under an Improved Accuracy Program (IAP), which was organized so as not to interfere with the ongoing Lab design responsibilities for the Trident I. The IAP program evolved concepts that strongly influenced subsequent guidance system designs.

Photograph:
The Air Force selected the Draper-developed MPMS/AIRS design as the inertial measurement unit for its PeaceKeeper missile.

The Peacekeeper Missile Program

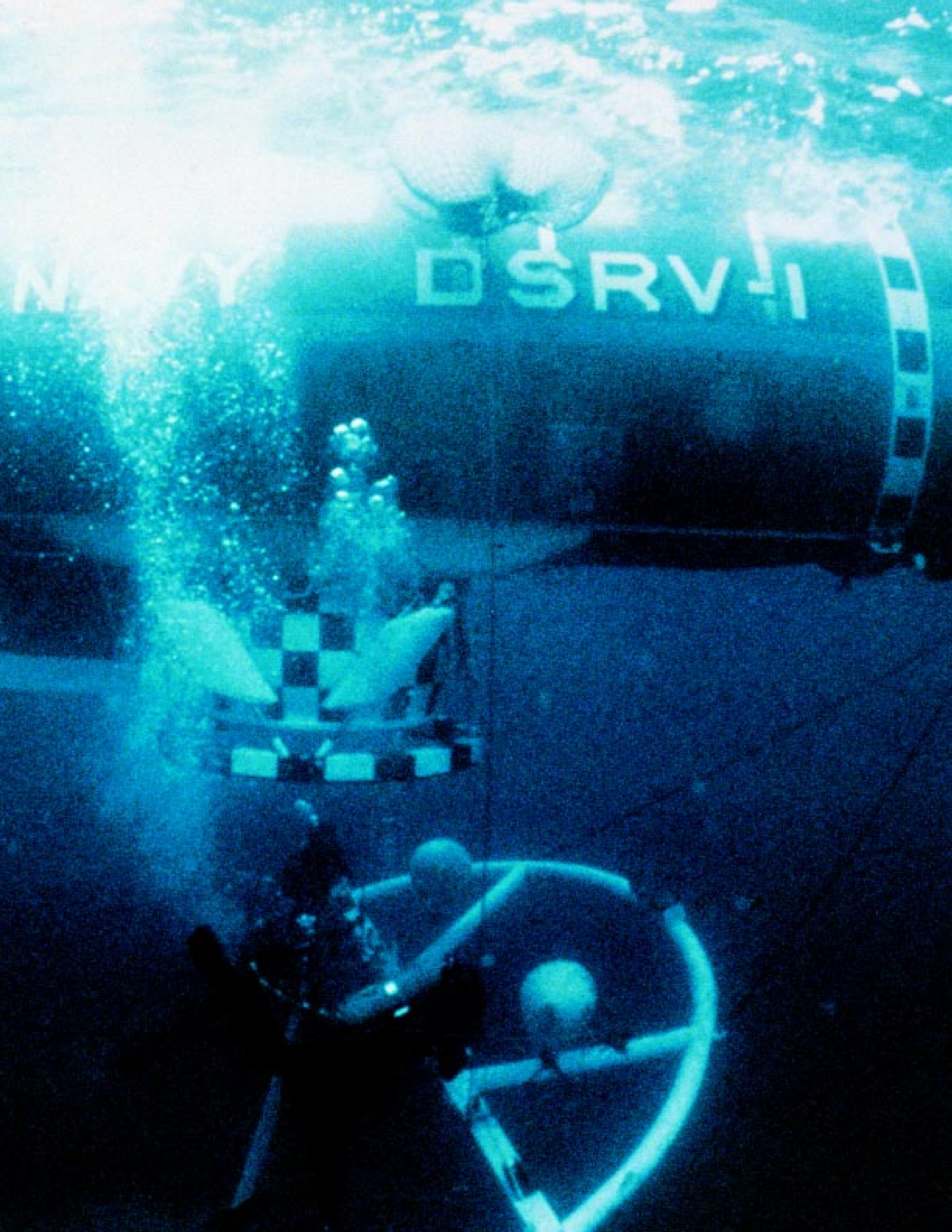
In the early 1970s, the Air Force funded the Missile Performance Measurement System (MPMS)/Advanced Inertial Reference System (AIRS), which would demonstrate the Lab's FLIMBAL capability using the latest Third-Generation Inertial Instruments. The MPMS/AIRS was flown as an instrument package on a Minuteman III in July 1976.

The AIRS FLIMBAL guidance system

The Third-Generation Inertial Instruments were the Third-Generation Gyros (TGGs) that were initially developed by Draper with NASA funds and used in the Lincoln Experimental Satellites (LES 8/9). At the time, they were the lowest noise and most accurate gyros ever built. The Specific Force Integrating Receiver (SFIR)-7 was the next evolutionary step in the Pendulous Integrating Gyro Accelerometer (PIGA) lineage. The SFIR-7 was eventually replaced by the SFIR-J, a less radical departure from the PIGA design.

In the same period, the Air Force began developing a new ICBM with improved accuracy (over the Minuteman) and the ability to carry up to 10 MIRVs. This missile, called MX, with its high-accuracy and large payload, was a counterforce weapon capable of going after opponents' nuclear forces.

The Air Force selected the AIRS as the IMU for this new missile. The Draper-developed MPMS/AIRS design was transferred to Northrop, which took it, with extensive Draper support, through an Advanced Development Program to Full-Scale Engineering Development, and ultimately, through production. MX was later renamed Peacekeeper by President Reagan. The first flight of a Peacekeeper missile was in 1983, and its initial operational capability was achieved in 1986.


DSRV-1

Deep Submergence Rescue Vehicles (DSRV)

In 1963, all hands were lost in the sinking of the U.S. Navy nuclear submarine *Thresher* off the coast of New England. The inquiry into the disaster led to the establishment of the Deep Submergence Systems Project Office to provide the Navy with an advanced submarine rescue capability. The Navy selected the Laboratory to develop the GN&C system for a DSRV that could navigate accurately and maneuver precisely to mate with a disabled submarine and rescue the crew. Draper met the challenge and delivered the Integrated Control and Display (ICAD) system for the first of two DSRVs, which was launched in 1970. For almost 30 years, the Laboratory has provided continuous on-site support for the DSRV systems at the Submarine Rescue Unit in San Diego and engineering and logistical services in Cambridge. This initial DSRV project laid the foundation for the Lab's successful business in ocean systems, which continues today.

The Lab's DSRV program laid the foundation for future ocean systems programs.

Other Programs

Strategic Defense Initiative

During the late 1970s and early 1980s, the Lab supported the Strategic Defense Initiative ("Star Wars"), developing innovative technology for precision pointing and tracking of large earth and space structures for surveillance, communications, and beam weapons. These efforts were performed under various contracts with the Defense Advanced Research Projects Agency (DARPA), the military services, and the National Laboratories. Significant advances in large optical systems, actively controlled structures, and beam alignment and stabilization were accomplished that exploited, among other things, the ultra-precise, low-noise features evolving from the Lab's gyro developments.

Early Contributions to Strapdown Inertial Sensing Systems

The Lab initiated the development of strapdown inertial navigation systems in the early 1970s. This technology represented a departure from the earlier approach to inertial sensing that had relied on gimbaled platforms to isolate inertial components from vehicle rotations. Instead, the inertial components were "strapped" onto the airframe to be guided, using an associated computer to transform the sensed information into an inertial coordinate frame.

The "Nuclear Free Cambridge" Referendum

After becoming independent in 1973, Draper began to develop outreach activities consistent with being a responsible corporate citizen of Cambridge. The Lab learned later, as described in what follows, that its early efforts in this direction were inadequate, failing to counter grossly inaccurate perceptions of the nature of the Lab and its work by many of the citizens of Cambridge.

The newly independent Laboratory faced the continuing challenge of dealing with a number of groups who opposed its work. One such group, known as Ailanthus, meaning "tree of heaven," began demonstrating in 1973, and continued to do so for years on a regular basis – sometimes in an orderly and peaceful way, sometimes not. Their activities often resulted in inaccurate and unfair characterizations of the Lab.

Photograph: **Dedicated in 1984 in honor of the Lab's first chairman, Dr. Albert G. Hill, the Hill Building added 170,000 s.f. of office and lab space to the physical plant.**

In 1983, "Nuclear Free America," a national grass-roots organization announced plans to designate Cambridge as a "Nuclear Free Zone." The plan was aimed directly at Draper Lab because of its work in developing guidance systems for strategic missiles. The group organized and conducted a successful signature campaign to have a referendum question added to the Cambridge ballot in November 1983, which if enacted, would have transformed the City of Cambridge into a nuclear-free zone and directly threatened the ability of Draper to continue its work in Cambridge.

In the late Spring, the Massachusetts Supreme Court ruled that a vote by the City Council to keep the Nuclear Free Zone issue off the ballot was invalid, and ordered that the question be included. Conventional wisdom was that in Cambridge, the measure would pass overwhelmingly. Nevertheless, the Draper Board decided that the Laboratory should publicly oppose the initiative for three reasons: 1) to let employees know that their work was of national importance, and that their right to continue it should be defended; 2) to underscore the Laboratory's belief in what it was doing; and 3) to show that similar efforts in other parts of the country would be difficult and expensive for proponents.

Draper immediately began a campaign to defeat the Nuclear Free Zone initiative. It was vigorous and professional. Citizens Against a Research Ban (CARB), a political action group, was founded with broad-based membership that included academics, doctors, lawyers, labor leaders, and CEOs. The campaign was supported by funds that came from all parts of the country. In addition, the employees of the Laboratory took an active role in collectively protesting the referendum, engaging in the debate, and rallying to help defeat it.

Prominent local, national, and international figures, including Speaker of the House Tip O'Neill and MIT President Paul Gray, ultimately opposed the initiative in public. The effectiveness of the campaign was demonstrated by the overwhelming defeat of the Nuclear Free Initiative by a vote of 60% to 40%. The outcome of the campaign was reported across the country and around the world. The people of Cambridge had indicated their unwillingness to give public officials the right to limit academic research.

During the campaign, the Laboratory learned to its dismay that many in Cambridge were either indifferent or hostile to it because they did not understand the nature of the institution or its work. As a result, Draper formalized and expanded its community outreach program, which continues today. All evidence suggests the City and its residents now hold the Laboratory in high regard.

The Lab developed a unique fault-tolerant strapdown inertial reference unit (SIRU) that consisted of six gyros and six accelerometers arranged in a dodecahedral array. The system could handle the degradation in performance of any two gyros or accelerometers, and up to three catastrophic failures.

Another strapdown guidance system developed in the 1970s was the Low-Cost Inertial Guidance Subsystem (LCIGS). This cost-effective system, featuring a modular design, was the first inertial navigation system to incorporate embedded microcomputer control and processing. The LCIGS was a proof-of-concept system that was flight tested to demonstrate its utility for guiding bombs, but it was never fielded.

Photograph: **The Berlin Wall, 1989**

Independent Research & Development

Taking advantage of its newly independent status following divestiture, Draper established an IR&D program supported in part by fees imposed on its contracts. This program funded research into novel concepts proposed by Lab engineers that had both near- and long-term promise and were relevant to sponsors' needs. These initial IR&D programs embraced nearly all of the Laboratory's competencies at that time.

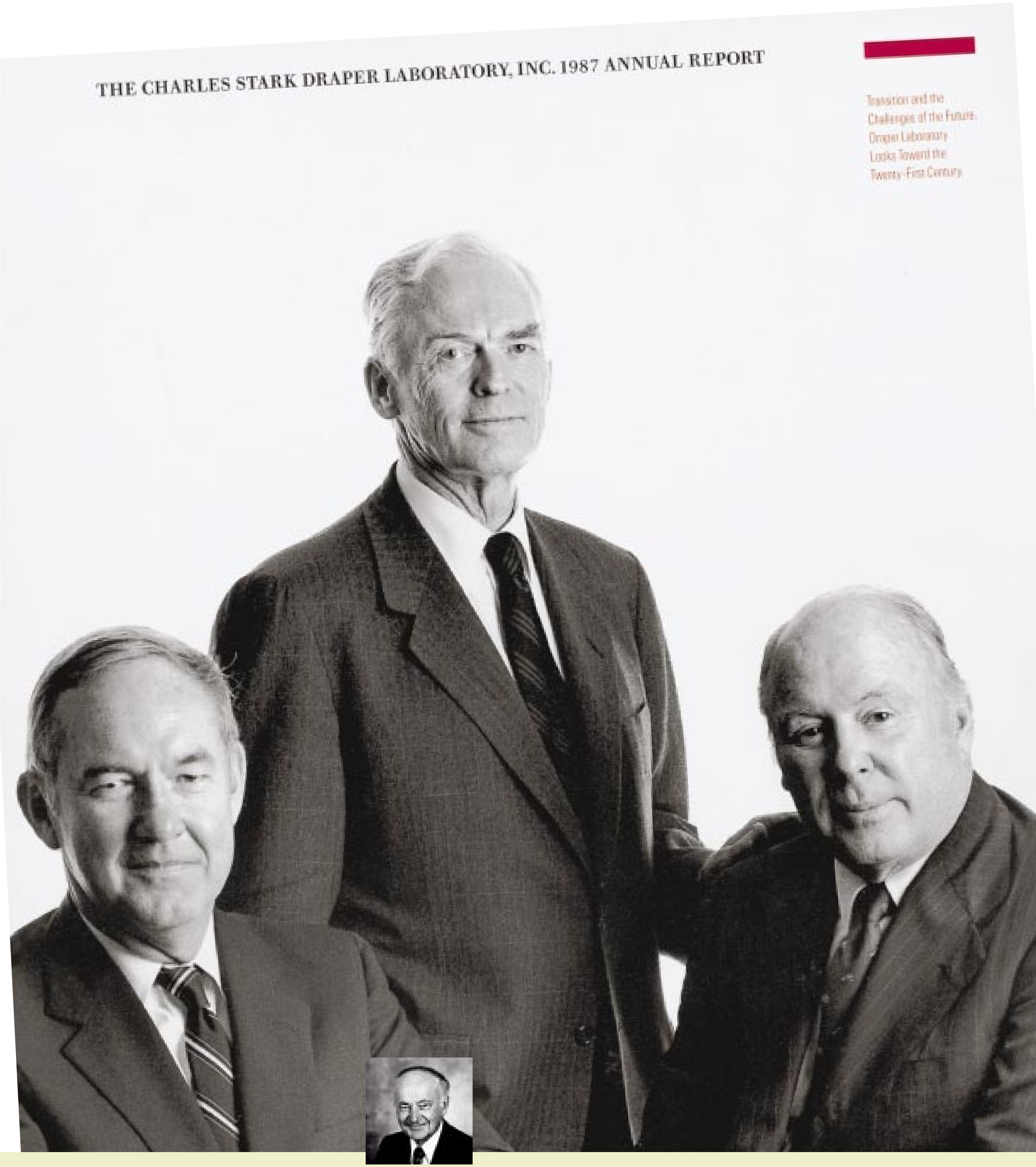
The Lab Expands

Contrary to the predictions that it would not survive, the Laboratory thrived, growing in size and revenues throughout the 1970s and into the 1980s. As a result, the Lab was running out of space once again. In 1981, the Lab purchased two acres of land across the street from 555 Technology Square and constructed a new facility to be dedicated as the Hill Building in honor of the Lab's first Chairman, Albert Hill. It came on-line in 1984, adding 170,000 square feet of office and laboratory space to the Laboratory's physical plant.

At the building dedication, President Robert Duffy said, "Al Hill kept us alive and gave us a transition which kept MIT and the Laboratory friends. That is a key element to the strength of the Laboratory today." When told the new building would be named after him, Hill said, "I could be neither happier nor more surprised."

The Hill building symbolized the continuing, steady growth of the Laboratory, but that growth was not to continue indefinitely.

Weathering the Storm



The 1987 Annual Report highlighted the change in leadership with Jacobson, McKay, and Duffy.

1987
Robert Duffy retires as President and CEO; Ralph Jacobson is named his successor.

1987
Joseph Charyk is named Chairman of the Board.

1988
Draper Prize is established in memory of Lab's founder.

1989
Defense spending decreases; Trident II program winds down.

1989
The Berlin Wall falls.

Weathering the Storm

As 1987 drew to a close, the Lab was soon to face several major new challenges. The Trident II development program, which had been spectacularly successful in meeting its design objectives on time and within budget, was beginning to wind down. Defense spending would soon begin to decline, in large part because the Cold War was rapidly drawing to a close. Draper was caught in the middle of the maelstrom. As one employee put it, "The hurricane hit us at high tide."

At the same time, the Lab went through a change in leadership. Robert A. Duffy retired after 14 years of service as President and CEO, and the Board of Directors, under Chairman Dr. Kenneth G. McKay, named Ralph H. Jacobson, U.S. Air Force Major General (Ret.), as the new President and CEO.

Duffy's Legacy

Albert Hill said, "Duffy was exactly who we needed to lead the Laboratory. His importance was threefold. First of all, he knew the technical problems better than he ever admitted; secondly, he wore a uniform, and this helped us with the military; and thirdly, Duffy is very charismatic. I have never seen anyone in my life who knew more about internal operations of a big organization."

Jacobson also lauded Duffy's role: "He played a major role in getting this country the guidance systems it needed for ballistic missiles and in winning the Cold War." Former Draper Chairman Lew Allen later noted, "The versatile and day-to-day leadership of the Laboratory by Bob Duffy, in which the characteristics, policies, and nature of the Laboratory were formulated, and the practices of excellence, particularly in the guidance and control systems associated with the Trident, were carried through [by him] with great excellence."

Tough Choices

Planetary rover prototypes were developed under a joint venture with MIT, funded through Draper's IR&D program.

When Jacobson took over at Draper, the time for making tough choices was rapidly approaching, and he would call on experience he gained during a distinguished career in the Air Force. He had been Director of Special Projects, Office of the Secretary of the Air Force, and had held previous positions in the Space Program. Jacobson's military duty also included a tour of duty in Southeast Asia. Although a graduate of the Naval Academy, he had taken his commission in the Air Force.

He said in a recent interview, "After I arrived at Draper and had been there for a few months, we saw the end of the Trident development program, and I began to

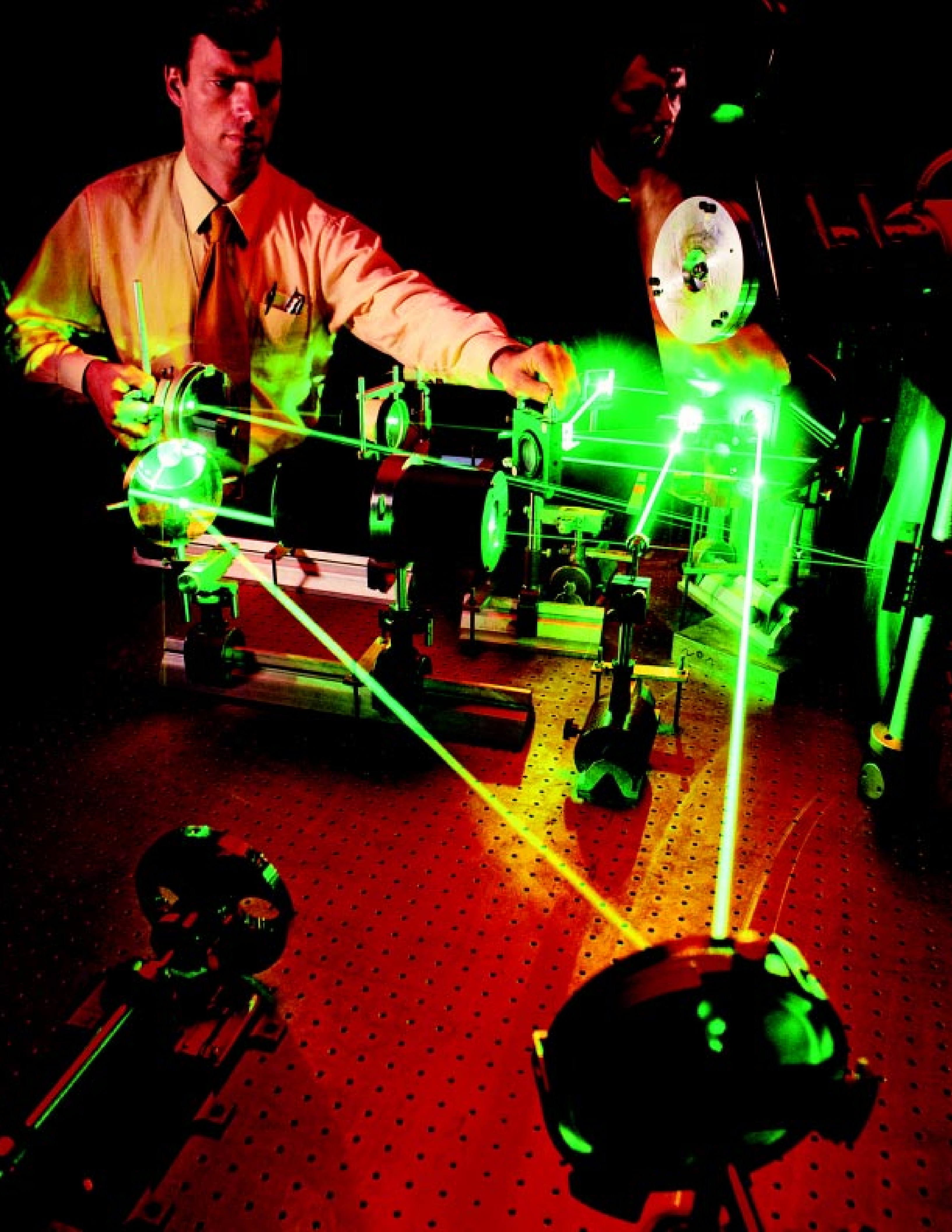
1990
Lew Allen, Jr. is named Chairman of the Board.

1990
Draper board formulates a 5-year plan to "redefine the Laboratory".

1994
Omnibus contract facilitates DOD contracting with Lab.

1995
Robert Hermann is named Chairman of the Board.

1997
Ralph Jacobson retires as President and CEO; Vincent Vitto is named successor.



understand that we would have to have more business elsewhere. I began an effort to diversify, but our efforts didn't keep pace with the decline of the defense budget. Further complicating the situation was the passage of a new law called the Competition in Contracting Act that made it more difficult for government customers to continue to contract with the Lab on a sole source, noncompetitive basis."

Reducing the Workforce

The net result was that Draper was forced to begin cutting its workforce in 1989 due to reduced contract funding. The number of full-time employees dropped from slightly over 2000 in 1988 to 1104 in 1995. During those years, management achieved over 60% of the reduction by voluntary means, primarily through early retirement programs and attrition. The remainder was regrettably achieved through involuntary layoffs.

Jacobson says, "I have to hand it to the employees. They kept doing their work, though of course there was a lot of nervousness. What pulled us through those hard times was the superior engineering achievement of the staff. In a period like that, they could have just thrown up their hands. They did not. They had pride in their technical work, and kept doing it well."

Photograph:
Draper Laboratory engineer William Johnson adjusts optics for a spinning mirror, 24 inches in diameter. Invented and tested under IR&D funds, the full-scale optical device was the critical aperture-sharing component for an Army laser beam control system.

The Allen Board

In 1990, the Draper Board, headed by Lew Allen, worked closely with Jacobson and the rest of the management team to institute a five-year plan that would accomplish "the difficult task of redefining the Laboratory so that its considerable talents and experience would be positioned to keep it a strong and objective technical contributor in the post-Cold War era."

The Lab expanded its Company-Sponsored Research (CSR) program, supplementing the IR&D program with its uncommitted revenues. The purpose was to intensify the search for new applications for Draper technology that also would serve the national interest. Dr. Allen and the other Directors made this commitment because they strongly believed that the Laboratory was a national asset that should be preserved.

The process of redefining the Lab was painful, and in many respects foreign to the Draper culture. But steadily, if slowly, new sponsors were attracted and the base of support broadened, in part because of the expanded CSR and IR&D programs.

Draper's 25-Year Involvement in Education

The 1972 Articles of Organization for the Laboratory emphasize that one of the Lab's main responsibilities is "to engage in educational activities in the sciences and allied subjects."

Education always has been a vital part of Draper's charter. Its heritage is rooted in the formative years of the MIT Instrumentation Laboratory where the Lab's founder, Dr. Charles Stark Draper, was renowned as much for his pioneering work in engineering education as for his teaching. He believed that the best way to learn was by doing.

In 1973, at divestiture, the Laboratory and MIT formally agreed to continue the education of selected graduate students seeking advanced degrees by offering real-world research opportunities in Laboratory programs. These research assistants, known as Draper Fellows, work on substantive projects that provide thesis material in partial fulfillment of graduate degree requirements at MIT and other area institutions. Over the past 25 years, 725 MIT graduate students have completed degree programs as Draper Fellows.

The 1987 Annual Report highlighted many of the students working at the Lab.

In 1996, Draper Laboratory initiated the Solomon J. Buchsbaum postdoctoral fellowship, a two-year program awarded to scholars studying GN&C; autonomous vehicles; computer science; and a variety of related fields. This fellowship honors the memory of Sol Buchsbaum, a member of the Laboratory's Board of Directors, 1986-93.

For more than four decades, the Lab has been conducting a Cooperative Education Program with Northeastern University, with the Lab as technical partner and the University as academic partner. More than 2000 students have benefited from the program, including many senior Draper staff members.

During fiscal year 1997, Draper sponsored more than $2 million in on-campus research, through which MIT and other university investigators collaborated with Draper staff. The Laboratory also launched a new MIT-Draper Technology Development Partnership, designed to leverage MIT students' creativity and innovation in high-risk, high-payoff projects of significant size and scope.

The relationship between Draper and technical education is vital and irreplaceable. By continually advancing the leading edge of the areas in which it works and involving students, the Laboratory ensures that technical education will be state-of-the-art. These students, in turn, constitute a source of high-quality replenishment to satisfy Draper's future technical staff needs.

Students who come to Draper to satisfy part of their academic requirements operate as active members of research teams. Pictured with their technical staff leader David Kang are several students who participated in the Planetary Micro-Rover Project.

Jacobson says, “We focused on diversifying and reorganized to a matrix-based organization to achieve more flexibility in deploying our more limited engineering resources.”

In part because of the long relationship between the Navy and Draper, the Navy was extremely supportive of the Laboratory during the downsizing.

The Omnibus Contract

Photograph: Among its responsibilities for NASA's Space Shuttle Program, Draper verifies the GN&C software and certifies that the dynamics of the payload on each flight of the Space Shuttle interact safely with its control system and its remote manipulator arm.

Through strong support from its main sponsor, the Navy SP, the Omnibus Basic Ordering Agreement (BOA Contract) was awarded to the Laboratory in 1994. For any potential sponsor, the Omnibus contract significantly shortens the normally lengthy process associated with sole-source contracting.

It took a major effort over 18 months on the part of SP to receive approval to award the BOA. The first contract provided for a ceiling of $210 million over a three-year period. Jacobson was pleased that the contract was signed, but was quick to point out that, unlike most other contracts received by the Laboratory, the Omnibus contract does not provide funding. It does, however, provide easier access to Draper Laboratory's long-standing capabilities in GN&C by all defense agencies.

Jacobson's Heritage

Chairman Robert J. Hermann said upon Jacobson's retirement in 1997, “Ralph Jacobson served with distinction as Draper Laboratory's chief executive for more than 10 years. Those were indeed difficult years! Although the sharp drop in Draper's funding compelled Jake to reduce staff, he did it as sensitively as possible, and worked to counter the drop over the years by fostering innovative internal research projects and motivating staff, leading up to diversification in both program and sponsor mix. He secured the Omnibus contract, which made it easier for sponsors to access the Laboratory's capabilities. Fittingly, those initiatives produced an upturn in the Laboratory's fortunes in Draper Fiscal Year 1996, which continued in 1997, giving Jake the opportunity to witness the success of his efforts.”

Draper sponsored the winning entry in the 1996 International Aerial Robotics Competition, held at DisneyWorld's EPCOT center. The vehicle, developed under IR&D funding, used differential GPS fixes and real-time image processing.

The result was also a tribute to Lew Allen and the Board of Directors for acting on their conviction that Draper Laboratory should be preserved, and for their foresight in committing to the expanded CSR program, which was essential to the transition.

Draper in the 90s

1987
Work begins on Space Station Freedom program for NASA.

1988
DARPA commissions Lab to develop autonomous Unmanned Undersea Vehicle (UUV) systems.

1990
Trident II (D5) deployed on time and on budget with Draper guidance system.

1990
Lab starts integration of Global Positioning System (GPS) into A-10 aircraft.

1992
Guidance Technology Center established to foster contributions to GN&C technology.

1993
Lab forms alliance to transfer MEMS technology to automotive market.

Draper

in the 90s

On March 23,1990, the *USS Tennessee*, the first Trident II-equipped strategic nuclear submarine, embarked on her initial operational patrol from Kings Bay, Georgia. It marked the addition to the nation's strategic deterrent triad of the most advanced weapons system, the Trident II missile, featuring a guidance system designed and developed by Draper Laboratory.

The Trident program demonstrated the Laboratory's breadth and depth of capabilities as perhaps no other program of recent memory. It also marked the end of one era at Draper and the beginning of another. Today, Draper is responding to a vastly different geopolitical landscape.

Draper Chairman Robert J. Hermann said recently, "Draper's customers have changed over the past decade in response to changes in the world situation. A reduced threat to security has meant less money spent on intercontinental ballistic missiles, on strategic guidance, and on targeting systems. Today, Draper is turning its attention more and more to issues surrounding information – security, privacy, data management, communications, storage."

Photograph: Draper's expertise in ocean systems technologies spans from autonomous vehicles and combat submersibles to nuclear submarines.

This chapter updates the Laboratory's ongoing programs and highlights some of the new sponsored programs at Draper. The programs are described under several categories: Strategic Missile Systems, Space Systems, Ocean Systems, Information Systems, Global Positioning Systems, Microelectromechanical Systems, and Biomedical Engineering. A relatively new organizational unit, the Guidance Technology Center, whose work is also described, was created to ensure that Draper's international reputation in the field is maintained.

First generation of Draper-developed strategic-grade, interferometric fiber-optic gyro.

Strategic Missile Systems

Trident II

Draper developed and tested the MK 6 guidance system for the Trident II missile, a three-stage FBM whose accuracy and reliability greatly surpass that of the Trident I. The Laboratory continues to provide operational support to the Trident's guidance systems today, as it has for all previous generations of FBM programs.

Incorporating many of the technologies developed during the Improved Accuracy Program, the MK 6 design demonstrated a major advance in FBM guidance system performance. The Draper-developed size 10 PIGA achieved the performance of the Peacekeeper SFIR accelerometer in little more than half the volume and weight. The spherical stable member and close-gapped gimbal design dramatically reduced misalignments and thermal gradients to improve accuracy. The distributed digital

1995 Shuttle/Mir docking utilizes Draper guidance and control technology.

1995 Lab begins development of guidance for competent munitions.

1996 Draper tasked to develop GN&C for the first fully reusable unmanned launch system.

1996 Bosnia C^4I system allows command center personnel to communicate rapidly.

1996 Flight tests demonstrate feasibility of Lab's GPS/Micromechanical IMU.

1997 Seawolf begins sea trials with first-ever submarine digital autopilot.

control system also enhanced system performance and power requirements. The result was a system that significantly exceeded the program's very aggressive accuracy goals. In parallel, a fly-along Three-Axis Instrumentation (TAI) system was developed. TAI was the first strapdown inertial navigation system with sufficiently high precision to be used in performance monitoring the Navy Strategic Missile boost performance.

Trident II exemplifies Draper's importance to the Navy's FBM program. The Laboratory is proud of the fact that the first flight test of the Trident II system occurred on the exact day the Lab had promised six years earlier. It was done within budget and it met its mission requirements. The Trident II missile has been called the most successful weapons development program in the country's history.

Photograph:
The Draper MK6 guidance design for the Trident II missile demonstrated a major advance in FBM guidance system performance.

The Navy's appreciation for Draper's role is reflected in a citation that reads in part: "The unprecedented reliability and accuracy demonstrated by the MK 6 guidance system attest to your uncompromising commitment to excellence and dedication to this worthwhile project, and for the significant contributions of many of your employees. All who have been involved in this effort may be proud of their participation in bringing into being and ensuring the continued viability of a family of weapons which has been the world's major deterrent to nuclear war."

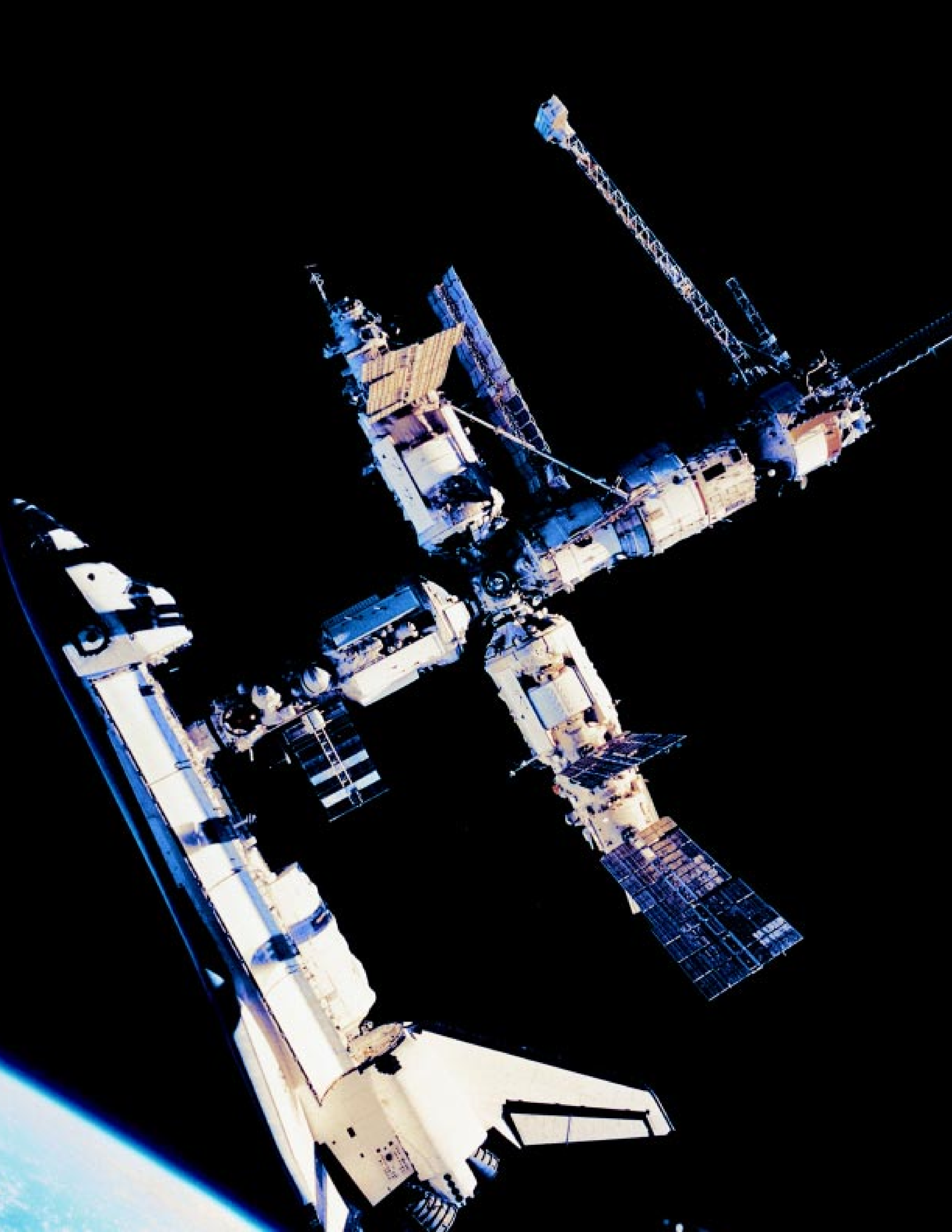
Draper and the team of industrial subcontractors are looking forward to providing tactical engineering support for the MK 5 and MK 6 Trident guidance systems for the duration of the Trident systems' deployed lives.

The Lab has recently revised the mission and control processor software that resides in the Trident II's MK 6 electronics assembly. The revised software was proved during a recent successful flight test. The inertial instrument team is evaluating an improved 10-PIGA accelerometer configuration, scheduled for introduction into the fleet after the year 2000.

The Guidance Application Program was established by the Department of Defense to ensure the maintenance of technologies unique to strategic guidance. During a multiyear effort as part of the Surveillance Evaluation Program, Draper will develop improved Trident II surveillance tools.

Peacekeeper and Minuteman USAF Strategic Guidance Systems

In addition to its Navy work, Draper provides ongoing engineering support to the Air Force for the strategic guidance systems of the Peacekeeper and Minuteman missiles by monitoring design integrity and supporting test flights. The Peacekeeper's guidance system features several Draper enabling technologies, including a floated ball gimbal carrying high-performance gyroscopes and accelerometers. The Minuteman guidance system also incorporates Draper's instruments.



Currently, Draper is supporting the Air Force in the Guidance Application Program. Draper's activities focus on advanced instruments, including an interferometric fiber-optic gyro and a thrust-axis accelerometer.

Space Systems

The Space Shuttle

Draper has continued to support NASA on the Shuttle program since flights resumed in 1989 following the tragic explosion of the *Challenger.*

Today, Draper retains responsibility for the Shuttle's on-orbit flight control and powered flight guidance designs. In order to ensure flight readiness, Draper screens payloads to be deployed from the Shuttle to ensure that there will be no adverse dynamic interactions that might damage either the payload or the Shuttle during deployment/retrieval. Draper also provides the support and modifications necessary for special missions, such as the one recently made to service the Hubble telescope, and all missions to *Mir* and to the forthcoming International Space Station (ISS) during its construction. The first docking of the Space Shuttle and the Russian Space Station *Mir* on June 29, 1995, successfully demonstrated work begun a year earlier by Draper to redesign the Shuttle's on-orbit flight control system for that mission.

" Using the Shuttle's jets to control a large structure attached to the payload bay is like trying to balance a twenty foot long flexible slinky on the palm of your hand.

The control inputs have to be inserted at just the right time to keep the system stable, without causing the system to vibrate uncontrollably or to collapse."

- Darryl Sargent *Associate Director of Space and Missile Programs at Draper*

Space Station

Draper has been a part of NASA's Space Station program since 1987, when it performed systems engineering and system architecture work for the Space Station Freedom program, an early Space Station proposal. More recently, the Lab has begun working on the ISS Alpha program, scheduled to fly in late 1998 or 1999. The Lab is exploring how best to control the flexible, unwieldy and variable structure of the ISS. The dynamic nature of its payloads means that its controls will be in constant flux.

Timeliner Software

Draper has developed a real-time process control language, called Timeliner, for use by the astronauts aboard the ISS. It will automate procedures and control experiments on board the ISS. Timeliner is easy to use, accepting commands expressed in an English-like language. It was initially developed in the early Shuttle days by Draper software engineers to run simulations, and has been used in developing the


KISTLER
aerospace

Shuttle control system. Since then, many significant enhancements have been made, including advanced human interfaces for general application to any process control system. Draper now licenses Timeliner for commercial use and a patent will be issued soon.

Beyond the Shuttle

The Shuttle continues to be an important part of NASA 's manned space program, as it transports astronauts and equipment on space missions. But today, the agency is also looking beyond the Shuttle to develop unmanned vehicles for use in launching satellites and for space exploration. There are currently two experimental launch vehicle programs: the X-33 and the X-34. Draper Laboratory is applying its knowledge of autonomous GN&C to both projects.

The X-33 is an unmanned reusable launch vehicle that will demonstrate technologies required for single-stage-to-orbit. According to NASA, the purpose of X-33 is to demonstrate that cheap, low-risk, and routine access to space is possible. The X-33 is scheduled to make its maiden flight in March 1999 from Edwards Air Force Base in California.

The X-34 is smaller than the X-33, and is a technology demonstration program aimed at developing low-cost reusable propulsion and autonomous entry and landing capability. NASA plans to fund the initial research and to have industry develop the ultimate vehicle.

In addition to X-33 and X-34, Draper is under contract to supply the fault-tolerant computer, based on its Fault-Tolerant Parallel Processor (FTPP), to NASA's X-38 and Crew Return Vehicles (CRV). The X-38 is an experimental vehicle, a precursor to the CRV, which will be designed to return astronauts from the Space Station in the event of an emergency.

" Draper is providing the guidance, navigation, and control algorithms and software, as well as integrating the avionics, for the Kistler K-1, the world's first fully re-usable, unmanned, two-stage to orbit launch vehicle.

It is a very real, private enterprise effort to put up re-usable launch vehicles. It will bring down the cost of launching satellites into space."

- Warren FitzGerald, ***Director of Space and Missile Programs at Draper***

Commercial Space

The Lab also is supporting Kistler Aerospace Corporation, a privately financed commercial enterprise, in developing the K-1, the world's first fully reusable unmanned, two-stage-to-orbit launch vehicle. Draper is providing the GN&C algorithms and software, as well as integrating all vehicle avionics. The Lab began work on the project in 1996, and the first test flight is planned for 1999. This new technology is important because it will enable the cost-effective launching of payloads to various orbit inclinations and the delivery of communication satellite constellations to low-earth orbits. Draper's Director of Space and Missile Programs

Warren FitzGerald notes, “For the space industry, Kistler is a very real, private enterprise effort to put up reusable launch vehicles. The hardware is being built. The engines, Russian NK-33 and NK-43, have been purchased and have been test fired successfully. Kistler will bring down the cost of launching satellites into space because all the K-1 hardware will be recovered, unlike current booster rockets.”

After the first stage separates, it reignites, flies back to the launch site, and lands within a relatively small recovery area. To complicate matters, the first stage drops by parachute during the last leg and is subject to wind shifts. FitzGerald notes: “The orbital vehicle, as the second stage, continues into orbit, deploys its satellite payload, goes to sleep to save power, spends 24 hours in orbit, comes back above the launch site, wakes up, calculates where it is, reenters, and lands near the launch site. Because it is a reusable atmospheric reentry vehicle, it can’t be allowed to burn up or get damaged in the process of returning to the Earth. The Draper software engineers are using their experience with the Shuttle in designing the software algorithms for reentry in the K-1.”

Ocean Systems

Deep Submergence Rescue Vehicle

As mentioned earlier, the Navy’s first DSRV was designed in the late 1960s and delivered in 1970. It featured the Draper-designed DSRV ICAD system. In 1987, Draper upgraded the ICAD system, replacing older, obsolete technologies with reliable state-of-the-art equipment designed to last for several more decades. Draper also provided engineering and technical services to support the *USS Dolphin* research submarine, the submarine rescue ships (ASR-21 and ASR-22), and the Navy’s unmanned vehicle detachment. In 1997, Draper completed overhauls of the two Deep Submergence Rescue Vehicles, *Mystic* and *Avalon*, and an integrated navigation system upgrade for the *USS Dolphin* was delivered and has completed its initial sea trials successfully.

Unmanned Undersea Vehicles (UUV)

In 1988, DARPA, recognizing Draper’s expertise in ocean systems development, contracted with the Lab to develop and build two fully autonomous Unmanned Undersea Vehicle (UUV) systems for use in a series of naval mission demonstrations. The mission packages were provided by industrial sources and integrated into the vehicles for at-sea operations. The rugged, reliable UUVs featured Draper-designed fault-tolerant processing technology and a robust vehicle control architecture. Initial mission demonstrations included tactical acoustics, UUV-to-submarine laser communications, and deep water mine countermeasures. The final Advanced Mapping and Minehunting Technology (AMMT) demonstrations were completed in June 1996. The AMMT program demonstrated totally autonomous shallow water mine reconnaissance and identification, imaging of targets of interest, generation of real-time bathymetric maps, and long-range acoustic transmission of images and data in near real-time. During the course of the mission demonstrations, which took place from 1990 to 1996, the Draper UUVs successfully completed some 247 dives with over 725 hours of submerged fully autonomous operation. The vehicles and related support equipment were transferred to the Naval Oceanographic Office in 1997 for use in unmanned oceanographic projects.

Seawolf

The Seawolf (SSN-21) is the first of the Navy's latest class of attack submarines. Draper has developed the fault-tolerant ship control computer hardware and redundancy management software for the Seawolf class, enabling a high-reliability digital submarine control system, analogous to the digital fly-by-wire flight control systems used in modern aircraft. Mack O'Brien, Draper's Director of Ocean Systems and Special Operations, says "The Seawolf is the first submarine class to go to sea with an integral digital autopilot system. It's significant that Draper was selected to build it because of our ultra-high-reliability design approach." The design features a tightly-synchronized, quad-redundant computer architecture, performance monitoring, and redundancy management software services. Initial sea trials of the SSN-21 Seawolf submarine using the Draper fault-tolerant ship control computer were successfully completed in 1997.

Advanced SEAL Delivery System (ASDS)

ASDS is a manned combat submersible that will allow clandestine insertion and extraction of SEAL (Sea-Air-Land) commandos along hostile shores. Under subcontract to Northrop Grumman, Draper has developed and delivered the first integrated navigation, control, and display system for the ASDS. Building on DSRV and UUV experience, the integrated system is a combination of commercial-off-the-shelf (COTS) equipment, a Draper-designed computer architecture, and Lab-developed navigation, control, and display software. The system will provide the two-man crew—a submarine officer as pilot and a SEAL officer as copilot—with the capability to mate with a submarine and transport a squad of SEAL swimmers and their gear. Initial sea trials are expected to occur in early 1999.

"From the early 1980s through the mid 90s, Draper Lab established the vision and goals for those pursuing military applications of unmanned, undersea vehicles. The DARPA/Draper UUV effort produced significant advancements in undersea propulsion, energy, navigation, and control systems, and was the first such system to exhibit truly long range, high reliability autonomous operations."

– *Charles Stuart,*
Director, Maritime Systems Technology Office, (1991-95), Defense Advanced Research Projects Agency

Photograph:
Today's Unmanned Undersea Vehicles (UUVs), developed for DARPA by Draper, feature Draper's fault-tolerant processing technology and a robust vehicle control architecture.

Information Systems

Bosnia Initiative

Draper's Applied Information and Automation Systems Programs Office focuses on the development and application of information, software, and automation technologies. This represents a significant new business area focused on the development and deployment of information dissemination management systems that will help personnel in command centers communicate rapidly with each other and receive the latest information. One such system, developed under the Bosnia Command and Control Augmentation Initiative, provides access to command, communication, control, computer, and intelligence (C^4I) technology in the European theater.

Photograph: **One component of Draper's information technology activities is the development of C^4I applications.**

Seen here are Thomas Wells, Chien Ma, David Hanson and Kerwin Moy working with some tools in the C^4I Laboratory, including visualization and decision support tools.

Draper has developed a variety of systems that are able to gather sensor data from widely dispersed sources, process it, and distribute the results to geographically dispersed users in real time.

Looking ahead, Draper-developed technology will play a major role in 21st century military and commercial applications. The Laboratory offers a wide range of innovative devices that can locate people and platforms precisely, and can also act as highly sensitive sensors. James Harrison, Principal Director, New Business Development and Strategic Planning at Draper, says, "The ability to pack a tremendous amount of capability into a very small package and to link up these packages through networks is revolutionizing the military picture. Suddenly, you have the ability to know precisely where everything and everyone is, and communicate with them in real time. This represents a tremendous military advantage and has significant commercial implications as well."

Global Positioning System (GPS)

Draper has been developing GPS applications since the mid-1970s, when it worked on satellite-based radio navigation systems and began defining techniques for combining radio and inertial navigation systems for the Air Force.

In the early 1990s, Draper began integrating GPS into the A-10 aircraft for the Sacramento Air Logistics Center. A major goal of this integration was to assess the ability to provide aircraft navigation by using GPS in combination with other sensors to accomplish the mission in the event the onboard inertial navigator fails. The initial task required Draper to develop a 16-state Kalman filter as part of a loosely coupled system that combines the information from several onboard sensors in order to provide the pilot with an optimal navigation solution. This integrated system, demonstrating less than a 12-foot circular error probability (CEP), supported by an automated mission planning system integrated into the A-10 by Draper, was flight tested by the Air Force in 1994.

In a follow-on effort, Draper improved the reliability, maintainability, and supportability of the A-10 weapon systems by integrating a tightly coupled GPS/INS into the A-10 aircraft. One of the first tactical aircraft to receive the embedded GPS/INS technology, the system is currently being tested in flight. Production installations are scheduled to begin in the fall of 1998. In support of both programs, Draper has developed several software simulations to support the testing and integration of the GPS products into the weapon system's avionics suite.

Draper's engineers also recently designed and integrated a 12-channel GPS receiver with a Navy MK 5 guidance system. This experiment demonstrated the acquisition of satellites in a missile environment and the successful generation of guidance system updates by the GPS.

Photograph: **Draper has the ability to design advanced mixed-signal CMOS (complementary metal oxide semiconductor) ASICs (Application-specific Integrated Circuits) that are needed to implement the electronics associated with microelectro-mechanical devices.**

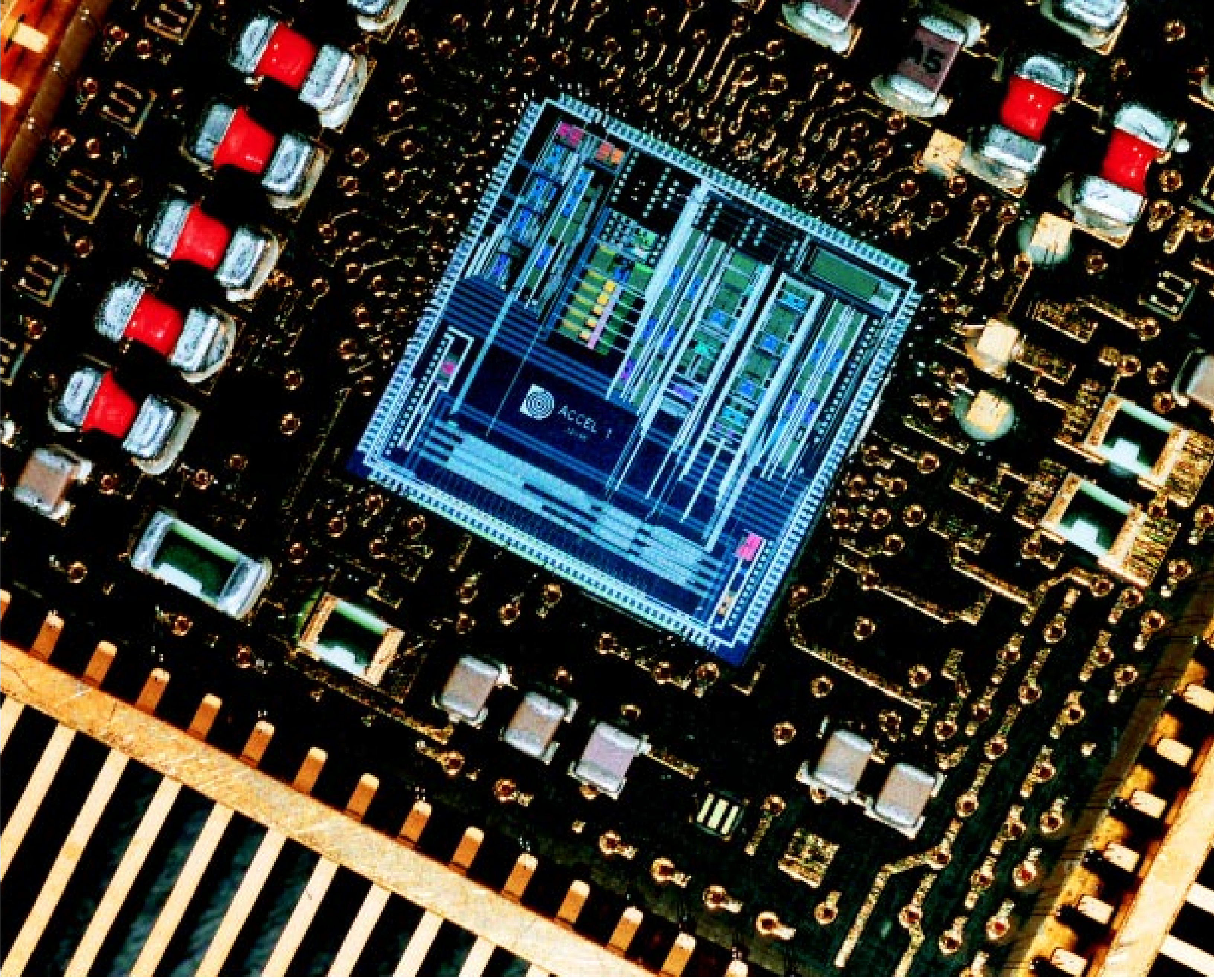
Microelectromechanical Systems (MEMS)

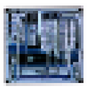
Microelectromechanical systems are one of the most promising new developments at Draper. The Laboratory began developing MEMS technologies in 1984. To date, Draper's MEMS efforts have focused on miniaturized GN&C devices that combine high accuracy, low cost, light weight, and tiny size. They offer the future capability of creating networks of inexpensive, reliable sensors to track people and equipment with great accuracy.

Inertial MEMS

One MEMS device that is being developed within Draper's IR&D program is the Silicon Oscillating Accelerometer (SOA), an open-loop miniature vibrating silicon beam accelerometer that offers extremely high accuracy. Due to the efficiency of batch fabrication, these devices are expected to have low cost and high reliability compared with alternative radiation-hard precision accelerometers. Their potential applications include strategic missile guidance and control. A related, more mature device, the MEMS Pendulous Accelerometer, is a less expensive, closed-loop device designed for applications that do not require the same degree of precision as the SOA. A MEMS Tuning-Fork Gyroscope, the most mature device Draper has developed to date, offers angular rate measuring capability in a tiny, inexpensive package. It contains a miniature tuning fork made of silicon. Its near-term applications include precision-guided munitions, tactical missile guidance, automotive and biomedical applications.

The Laboratory recently demonstrated its micromachined inertial instruments in an 8-cubic-inch IMU for competent munitions, which incorporates Draper's advanced mixed-signal application-specific integrated circuit and multichip module packaging technologies.





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The Lab has achieved significant success in a number of flight tests related to the Extended-Range Guided Munition (ERGM) Demonstration Program, which uses Draper's micromechanical accelerometers and gyros. ERGM is a joint technical effort between Draper and the Naval Surface Warfare Center to develop gun-launched projectiles with improved accuracy and extended range compared with conventional designs. The MEMS devices performed flawlessly during testing. A recent flight test demonstrated the survivability across the flight environment of the entire guidance system, including both the inertial instruments and the GPS system, which worked perfectly during postflight testing.

The 8 cubic inch integrated micromechanical inertial sensor/GPS receiver guidance assembly, developed under the Competent Munitions Advanced Technology Demonstration Program, is shown undergoing laboratory test. A stereolithography model of the guidance, navigation and control assembly is shown in the background.

Noninertial MEMS

A set of noninertial MEMS devices augments the inertial MEMS gyroscopes and accelerometers. They include MEMS chemical/biological sensors that can detect miniature quantities of chemical and biological agents with low false alarms in realistic operational environments. In addition, miniature micromechanical hydrophone arrays make it possible to remotely identify targets in real time from unmanned underwater vehicles or other remote sites. Tiny MEMS microphones only 2 mm wide offer high-fidelity sound pickup in the field. A MEMS nano-g vibration sensor can sense extremely low levels of seismic activity for use in perimeter defense sensing and personnel tracking.

Commercial Applications of MEMS

Draper's ability to apply its GN&C experience to new commercial fields can be seen in the micromechanical gyro that Draper and Boeing North American have developed jointly for use in advanced automotive braking systems. The system operated flawlessly when tested in a vehicle on a rough road last year. Such commercial applications are ideal for MEMS devices because of their ruggedness, small size, and low cost. They will also find applications in consumer electronic devices, such as image stabilization for video cameras, where they offer comparable performance to competing systems, but at a lower cost.

Biomedical Engineering

Draper is involved in several challenging new biomedical engineering programs in its 25th anniversary year. They fall into two main groups: Minimally Invasive Diagnostics and Therapy, and Miniaturized Devices and Implants.

In the area of Minimally Invasive Diagnostics and Therapy, Draper is using structural Magnetic Resonance Imaging (MRI) to enhance images of the brain, allowing physicians to better understand the mechanisms of diseases, such as Alzheimer's and multiple sclerosis, and to provide faster treatment for strokes. Draper is also using its image processing techniques to improve endoscopic procedures for the treatment of Barrett's esophagus, a type of carcinoma, and to help determine if colorectal polyps are cancerous.

Currently, Draper is developing and applying biomedical technologies in partnership with physicians at the Massachusetts Eye and Ear Infirmary (MEEI), Massachusetts General Hospital, and Brigham and Women's Hospital demonstrating that the Lab can be an effective development partner with the medical research community.

The Lab is developing miniature neural stimulators for cochlear implants that are surgically implanted into the inner ear to help restore the hearing of profoundly deaf patients. Draper is also applying its state-of-the-art micromechanical inertial sensing technology to solve inner ear balance problems.

Engineer Ken Houston tests a Draper-designed artificial larynx that more closely approximates normal human voice and speech production than mechanical devices currently in use.

The Laboratory is designing an artificial "voice" to improve on existing mechanical "voiceboxes" used by patients who have had their vocal chords removed.

It is also supporting the development of a retinal implant to restore vision to blind patients suffering from retinitis pigmentosa and age-related macular degeneration. This work is being done in conjunction with MIT and MEEI.

In the near future, Draper will use its MEMS gyros and accelerometers to track surgical instruments inserted into the body in tandem with its image processing techniques to enhance what the physicians see. The Lab will also be developing medical simulations to train surgeons.

The Guidance Technology Center

Draper's Guidance Technology Center (GTC) was created in 1992 to foster, promote, and recognize contributions to the field of GN&C, and to ensure that Draper maintains its international reputation in the field.

The GTC co-sponsors national as well as international symposia in GN&C and coordinates Draper participation in those events. It also promotes the dissemination of knowledge through publications, seminars, and lectures in GN&C, and supports the pursuit of advanced research and development efforts in the field.

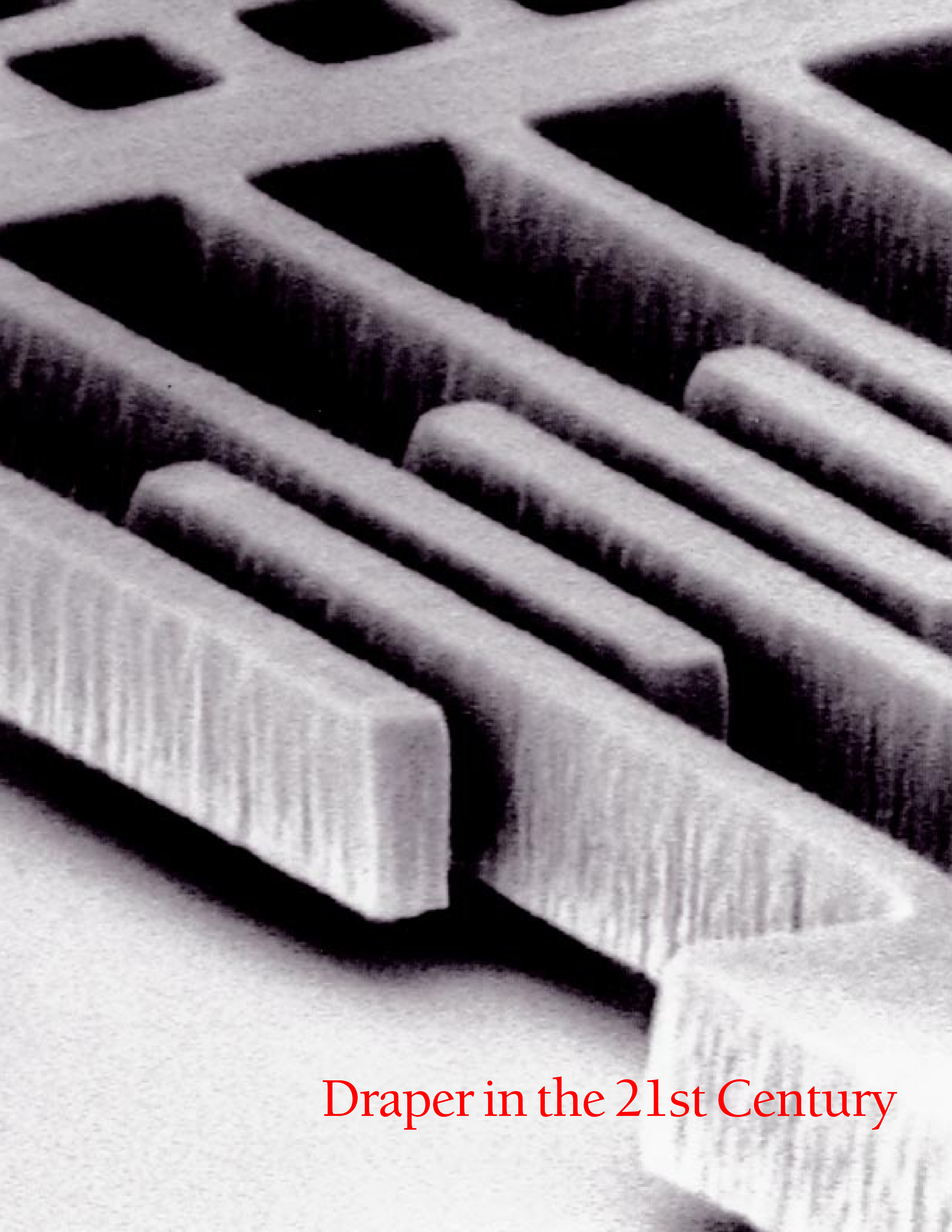
One notable series of symposia has been hosted by Draper since 1994. These symposia, which would have been inconceivable during the Cold War, bring together the Laboratory and its Russian counterparts in GN&C. The 1994 symposium was keynoted by then-Secretary of Defense William Perry. The first conference was precipitated by a visit by a Draper Laboratory team to the former Soviet Union in the summer of 1993 to assess the research underway and to explore possible collaborations. The symposium was well attended by high-ranking officials from both government agencies and private industry. Since then, the Lab has maintained this dialog through joint projects and yearly co-sponsorship of technical symposia. The 1999 symposium will be co-sponsored by NATO, the Scientific Council of the Russian Academy of Sciences, the American Institute of Aeronautics and Astronautics (AIAA), the Institute of Electrical and Electronics Engineering (IEEE), and Draper Laboratory.

Photograph:
Draper's leading edge capabilities in precision micromachining have enabled it to build miniature, low-cost inertial sensors for a broad spectrum of military and commercial applications. In this image of the micromechanical silicon tuning fork gyro, designed for automotive applications, one can see the comb-like fingers with micron-gap spacing.

Anticipating the Future

Draper Chairman Robert J. Hermann sums up Draper's work over the past decade: "We've seen a gradual shift away from traditional guidance technology and toward the challenge of controlling and coordinating major networks of people and equipment. Our products will be increasingly aimed at synchronizing and connecting these worldwide efforts. To help make that happen, Draper has made major, ongoing investments in original research. During fiscal year 1997 alone, we invested $21.5 million in IR&D and CSR programs. Over $8 million was invested in major programs related to strategic missile guidance, microelectromechanical systems, precision strike, and C^4I technology. We stand ready to help our military sponsors as they focus more and more on peacekeeping and major regional conflicts.

"Despite the many changes affecting both Draper and its sponsors in the 1990s, we have remained true to our original charter: to contribute to the knowledge and techniques of applied science and technology in the national interest. It's an important constant for us as we move into the next millennium."



Draper in the 21st Century

Draper

in the 21st Century

Vincent Vitto, who became Draper's President and CEO in 1997 following the retirement of Ralph Jacobson, will lead the Laboratory into the next century. Before coming to Draper, Vitto spent 32 years of increasing responsibility at MIT's Lincoln Laboratory, rising to be the Laboratory's Assistant Director for Surface Surveillance and Communications. He is Vice Chairman of the Naval Studies Board of the National Research Council, and was Chairman of its Space Panel for several years. He is also a member of the Defense Science Board and the Air Force Scientific Advisory Board.

Draper Chairman Robert Hermann calls Vitto "smart, experienced, energetic, dedicated, and very highly thought of among Draper's circle of sponsors. His experiences are totally in sync with a not-for-profit, national-security, technical institution."

Photograph: **This photoelectro-micrograph is a graphic illustration of the compact size of Draper-developed MEMS devices.**

Vision for the Future

Local and Global Issues

"Reflecting on the past 25 years, we see that much has changed since we gained our independence from MIT," said Vitto. "First, the Laboratory's workforce has changed - a large fraction of us have joined Draper only after the divestment from MIT - bringing new aspirations, new ideas, new skills, new experiences to the organization. The Laboratory's senior management also has changed, bringing different management styles and setting new priorities and objectives for the organization. The Laboratory's organizational structure has changed, too, requiring us to learn to work together within new structures, to meet the challenges our sponsors put before us.

"In addition to the workforce and organizational changes, the technology that is so central to what we do has changed, as the age of electromechanical systems has given way to the digital- information age, forcing us to adapt and learn new skills. The world in which we live and work has changed – the Cold War has ended with the collapse of the Soviet Union, removing a significant threat to world peace, and a new era is taking shape with new dangers that are not yet fully understood. During this time, our business has changed, bringing us new challenges and opportunities related to autonomous vehicles, precision guided munitions, information and decision systems. And finally, the business environment has changed, as federal budgets have declined, the defense and aerospace industry has consolidated, and the focus on competitive procurements has increased.

Strong Base of Sponsor Support

"And yet, though much has changed, much remains the same. Most of the sponsors who helped launch the newly independent Draper Laboratory 25 years ago remain loyal sponsors of the Laboratory today. In the interim, we have served as the Navy's design agent for each new generation of strategic guidance systems for the FBM program, and we remain committed to supporting these systems in the fleet. We have played a similar, though less comprehensive, role in the design, development and sustainment of the Air Force's Minuteman and Peacekeeper ICBM guidance systems. We remain strongly committed to helping both the Navy and the Air Force develop the enabling technologies that will be needed in the future and preserve the nation's ability to design, test and evaluate, and deploy a new generation of strategic guidance systems when that time comes. Throughout the past 25 years we have continued to support NASA's manned and unmanned space programs in the areas of guidance, navigation and control and the associated software sciences. We also have continued to support the Navy's DSRVs, periodically refurbishing the integrated controls and displays that make those vehicles safe , reliable and easy to use.

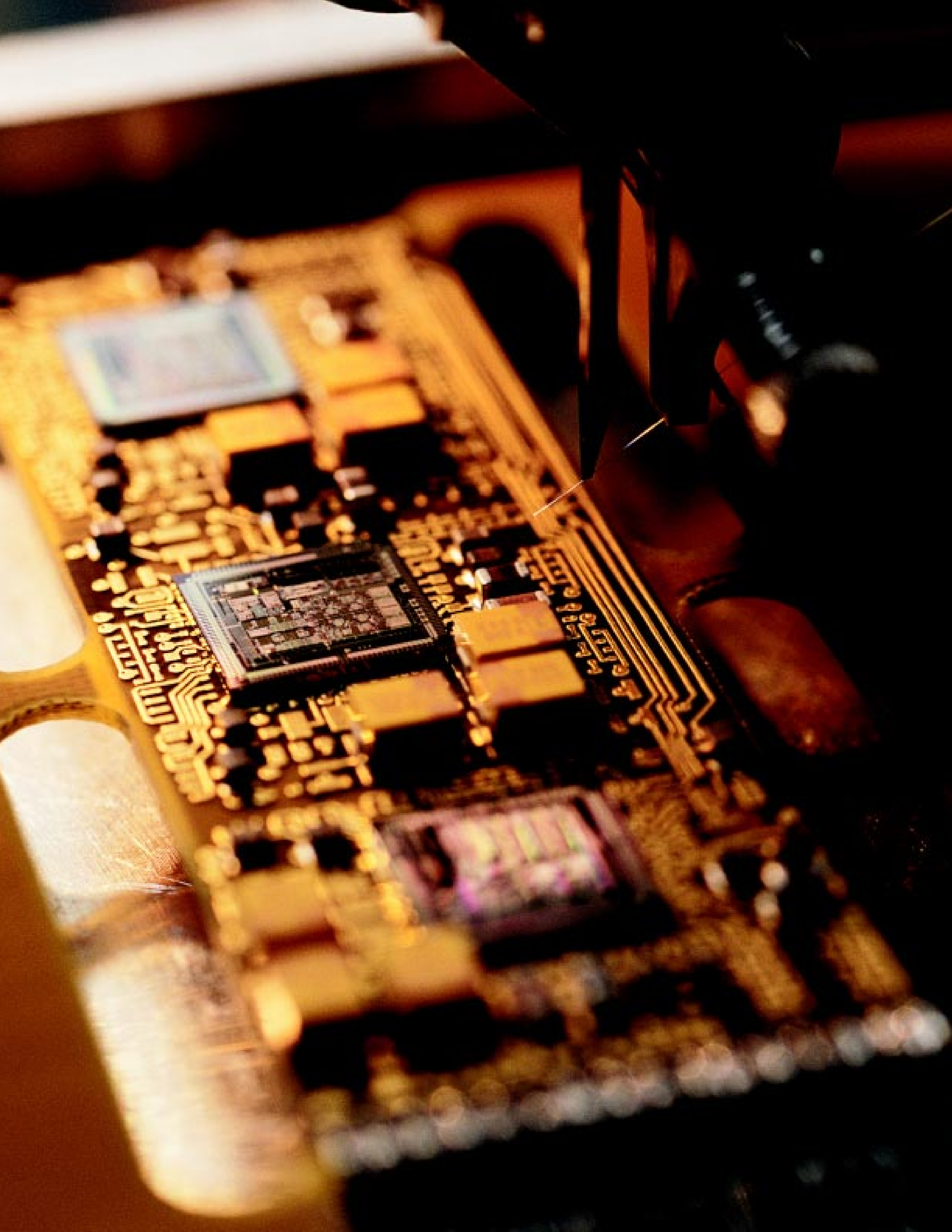
Photograph: **Draper designs and builds microelectronic systems employing various Multi-chip Module (MCM) and Chip-on-Board (COB) technologies.**

Wire-bond, flip-chip, and embedded interconnection technologies, as well as interconnection processes under development support the production of complex, miniaturized systems which are small and rugged.

Real World Applications in the National Interest

"Fundamentally, the Laboratory continues to do today what it has done throughout its history – employ advanced technology to close loops around complex dynamic systems, thereby effecting the highly reliable, precisely controlled behaviors that are needed to fulfill significant national objectives. Although the underlying technology has changed – providing new ways to sense, process and act on information about the system and its environment, and the nature of the control problem has changed - with a shift in emphasis from closing loops around single systems to closing loops around distributed systems of systems, the way in which Draper creates value for its sponsors remains fundamentally the same.

"As we move ahead, we remain committed to preserving the fundamental character of the Laboratory as a working laboratory engaged in leading-edge research and development focused on real-world applications in the national interest. We will continue to be a place where development is as important as research, and concepts are proven through prototyping and demonstrations in realistic operational environments. The Laboratory will continue to pursue the development of first-of-a-kind systems for visionary sponsors, augmenting those revenues with revenues derived from providing high-value-added engineering services to government and commercial customers. To stimulate the growth of our first-of-a-kind systems business, we plan to devote a larger share of our discretionary resources to the conceptualization of novel system solutions to the important problems of our



sponsors and the enabling technologies that are needed to implement those solutions. We will also manage our efforts to secure external funding to integrate and apply these technologies in the context of early feasibility demonstrations.

Program Arenas

"In the area of strategic systems, we are committed to remain a recognized center of excellence in missile and re-entry guidance and control system design. We are also committed to making the discretionary investments that are needed to ensure that Draper's strategic systems technologies play a central role in any new system developments.

Photograph: **Shown in the developent lab, Draper's prototype 8 foot, 300 lb. robotic 'yellow-fin tuna' is up to 10 times more maneuverable than conventional, unmanned devices - an advantage in tight quarters.**

The robotic tuna was developed under Draper's IR&D program.

Seen here are engineer and former Buchsbaum Fellow Jamie Anderson (center), and Draper Fellows Jonah Peskin and Mohan Gurunathan.

"In the space arena, we expect to maintain our traditional roles in NASA's manned space programs, and move, in concert with NASA, to increase our business in unmanned space programs. We also plan to pursue significant new roles in commercial and emerging military space applications.

"In the realm of large-scale decision systems, we plan to build on our successful deployment of the Bosnia C2 Augmentation system to capture major new roles in the design, development and deployment of IDM/DII systems.

"In the biomedical arena, we hope to maintain and expand our collaborations with the major teaching hospitals in the Boston area and their parent academic institutions. Although we have done some work in biomedical engineering in the past, we view this as a new venture for Draper. It brings with it a new set of challenges relating to how we work collaboratively with others to accomplish significant objectives that cannot be achieved by any of the individual collaborators acting on their own.

Innovation for the 21st Century

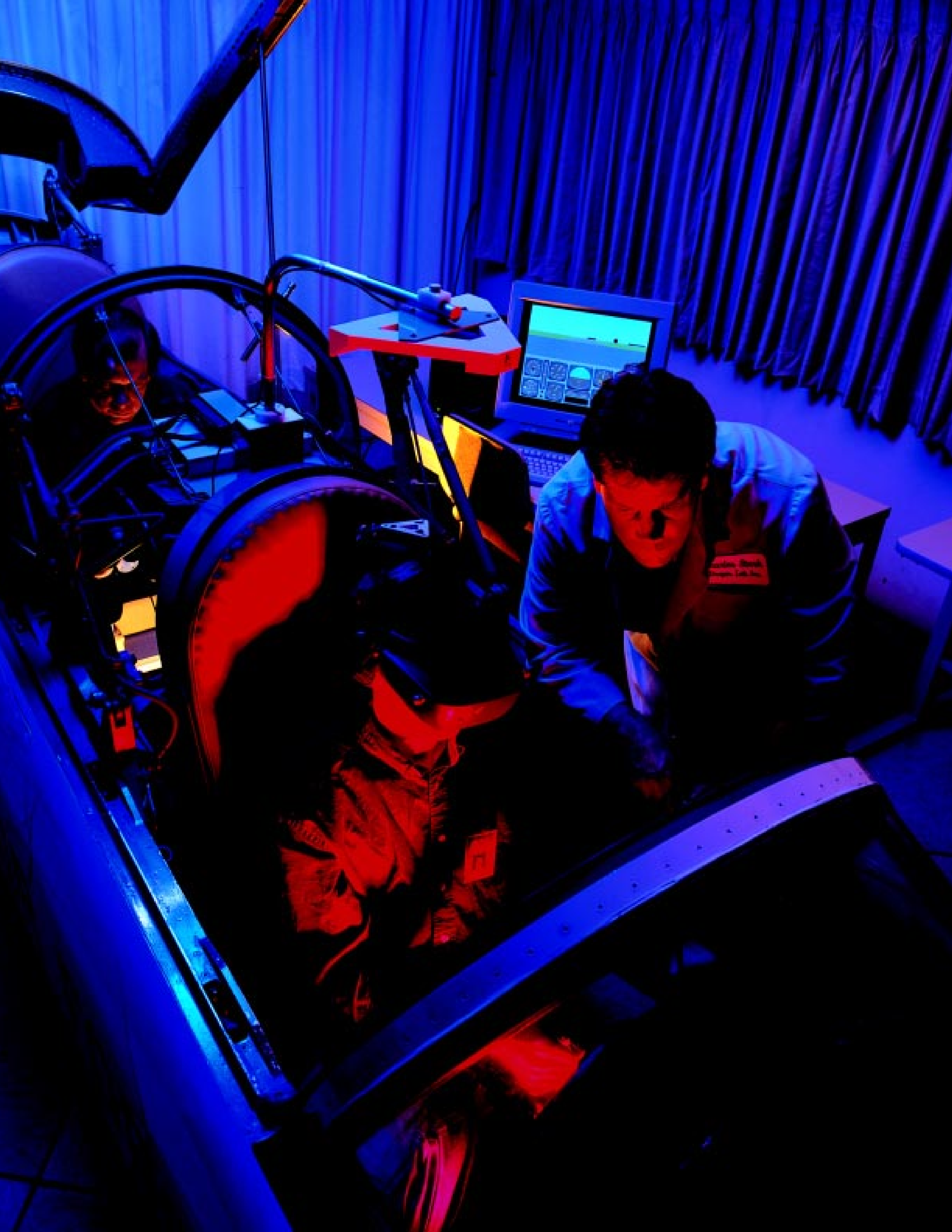
"Perhaps the greatest challenge we face has to do with how we respond to what has been characterized as the current 'revolution in military affairs'. With the end of the Cold War, the nature of the threat facing this nation has changed. The threat we face today no longer takes the form of a single super-power that is capable of launching a massive nuclear, chemical or biological attack on the United States. Rather we face an array of new, and in some ways more insidious, threats from rogue states and stateless terrorists who have access to conventional weapons, as well as weapons of mass destruction, and the ability to deploy them in limited, regional conflicts. This changing threat environment, coupled with the rapid pace of technological change,


VCUUV Meeting Tues
to UNH Wed June
Mechanical

and the ease with which advanced technology can be accessed throughout the world, pose a new set of daunting challenges for this nation in the 21st century.

"To meet those challenges, Draper is currently working closely with its sponsors to design, develop and deploy the innovative new concepts for precision tactical weapons, real-time targeting systems, sensor to weapon command and control systems, autonomous systems, deeply integrated micromechanical INS/GPS systems, and distributed sensors and robotics that will be needed in the battlefield of the future. We will continue to use our discretionary resources to anticipate our sponsors' future needs, to develop novel system concepts and the enabling technologies that are needed to realize those concepts, to add technical breadth and depth to our staff, and to develop the infrastructure that will be needed in the future."

Photograph:
Draper's Rapid Prototyping Center allows engineers to create and evaluate concept models and functional prototypes early in the design process.



Epilog

The Charles Stark Draper Laboratory has had a distinguished history of accomplishment spanning nearly seven decades. On July 1, 1973, as a result of a process set in motion by irresistible social and political forces sweeping the United States, Draper Laboratory was separated from its parent institution, the Massachusetts Institute of Technology.

This was not a welcome event, and indeed, it caused some to predict an early demise for the newly independent institution. The facts have proved them wrong. In this, the 25th year of going it alone, the Laboratory has survived turbulent times, and it can look back to many significant accomplishments and forward to many exciting opportunities. More than anything, this is a tribute to the talents, dedication, and hard work of the men and women of Draper.

This book has been an attempt to capture the nature of the Draper corporate enterprise, to examine what went on during our first quarter century as an independent entity, and to convey the optimism best embodied in President Vitto's vision of the future.

Photograph:
Draper's technical staff is composed of more than 750 scientists, engineers, and technicians.

Seen here are engineers John Danis, Bruce Persson, and Keith Mason conducting a test in the Modeling and Simulation Laboratory, a facility that offers high fidelity, real-time simulations of systems.

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