Milton S. Eisenhower Research and Technology Development Center 50th Anniversary Issue: Guest Editor's Introduction

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> *It is important that we be impractical . . . and that we be intensely practical, as well.*
>
> Milton S. Eisenhower[1]

The Milton S. Eisenhower Research and Technology Development Center (RTDC) traces its origin to a memorandum, dated 1 April 1947, by Lawrence Hafstad, then Director of APL. In marking the Center's 50th anniversary, which is the theme of this special issue of the *Johns Hopkins APL Technical Digest*, there is an irresistible temptation to compare the earlier time with our own.

1947 saw the Laboratory in a state of flux, as the smoke of a worldwide conflict began to clear from the political, economic, and national security landscapes. Demobilization and decreases in defense spending had major impacts on the U.S. economy. Past foes were in the throes of political and economic reconstruction designed to restore them as responsible members of the world community. Past allies embarked on a competitive approach to international policy with the potential to change them into adversaries of the United States. Locally, The Johns Hopkins University, the Laboratory, and the Navy were reconsidering the nature of their previous relationships. Sounds familiar, doesn't it?

Both then and now, APL responded to the changing milieu with substantial reorganization, and in both cases, one element of that reorganization was a commitment to a Center emphasizing research and development. Of course, the previous paragraph's comparison of 50 years ago with today was intentionally drawn to emphasize similarities. Even for rhetorical effect, one shouldn't minimize critical distinctions, like the very real differences between a hot and a cold war. One other difference between 1947 and 1997, of particular relevance to the RTDC, is the perceived value of long-term basic and applied research and exploratory technology development to a technical organization.

In 1947, the role of science and technology in fighting World War II was still freshly seared into the nation's memory. Of the three most critical technological contributions to America's war effort—the atomic bomb, radar, and the variable-time (VT) fuze—APL was principally responsible for the third. In many respects, nothing could have been more natural, for APL or the nation, than to invest heavily in long-term R&D on behalf of national security.

The subsequent dividends of that investment for the nation are well beyond the scope of this introduction, and in keeping with the natural inclination of an R&D organization to look forward, rather than back, only a few highlights of the Research Center's past benefits to APL can be mentioned here (more complete historical accounts can be found in Refs. 2–5). Future benefits are necessarily unknown, but I will briefly address the issue of R&D investment in today's largely short-term economic climate. Of course, I'll say something about the rest of the issue, too.

HISTORY

History can be spelled with either a small h or a big H. The Research Center has some of each; this section outlines our organizational history and notes some scientific high points. As stated previously, the APL Research Center, as it was originally known, was formed in the spring of 1947, with an initially horizontal, academically oriented organization. It was intended to provide long-term focus on fundamental research areas relevant to the Laboratory's mission; it was staffed by senior members of the Laboratory's technical population, as much of the work of the wartime Laboratory was assumed by the Kellex Corporation. The Research Center is therefore the oldest APL organizational unit. The Johns Hopkins University's later commitment, at the urging of the Navy and APL Director R. E. Gibson, to establish the Laboratory as a formal Division marked the end of Kellex's role and left APL with three main organizational entities: the Research Center, the Bumblebee Program, and the residual VT Fuze Program.

As the rapidly evolving Laboratory expanded the scope of its efforts, new organizational units were formed, in some cases as a direct result of activities or personnel in the Research Center. In fact, one measure of the Research Center's role is the large number of Laboratory and University leaders drawn from its "alumni" (see Table 1).

The Research Center has always been a relatively small organization. Its initial, rather stable complement of technical groups has in the more recent past given way to a continuously evolving spectrum of technical groups, in keeping with the changing face of science and technology, as well as APL's changing needs. At some points, the groups have been tightly focused on particular scientific issues (though the group names have typically been fairly generic). Recently, the emphasis has been on the formation of fewer, more broadly based groups capable of supporting diverse applications throughout the Laboratory. Five* individuals have led the Research Center previously (see Table 2).

A singular technical accomplishment, during the administration of Frank T. McClure, had an enormous impact on the current structure of the Laboratory. The invention, within the Research Center, of satellite navigation directly precipitated the formation of APL's Space Department. An article graciously written by Bill Guier and George Weiffenbach, relating this development, is included in this issue. Because of the critical role of navigation in Polaris, the Navy's then infant

*I am intentionally exploiting the ambiguity in Dr. Gibson's title "Chairman, Research Board" to proudly claim him as ours. There is no ambiguity, however, concerning his strong influence in support of the Research Center's formation.

Table 1. Research Center members who assumed leadership roles elsewhere in the University.

Position	Individuals
APL Director	R. E. Gibson, A. Kossiakoff
Deputy, Associate, or Assistant APL Director	A. R. Eaton, R. W. Hart, A. Kossiakoff, F. T. McClure, R. A. Makofski, and A. G. Schulz
Head of other APL Department	W. H. Avery, A. R. Eaton, C. F. Meyer, and G. C. Weiffenbach
Head of Director-level Program	W. H. Avery, J. T. Massey, and A. G. Schulz
JHU Program Chair or Education Center Director	R. A. Farrell, K. Moorjani, T. O. Poehler, R. D. Semmel, and V. G. Sigillito
JHU Vice Provost for Research	T. O. Poehler

Note: This table is based on the compendium of organization charts in J. Goss, *History of Staff Growth and Evolution of the APL Organization*, JHU/APL Report FS-94-170 (1984). Any omissions are unintentional; I would appreciate any corrections.

Table 2. Previous heads of the Research Center.

Head	Tenure
R. E. Gibson (Chairman, Research Board)	1947
F. T. McClure (Chairman)	1948–71
R. W. Hart (Chairman)	1972–82
T. O. Poehler (Director)	1983–89
D. J. Williams (Director)	1990–96

strategic program, APL's Strategic Systems Department (and the Submarine Technology Department, which evolved from it) also have some parentage in the Research Center.

On the research side, the Center has had a number of scientific and organizational highlights as well. Ralph Alpher and Robert Herman played a major (and insufficiently well-known) role in the foundation of the cosmological concept that came to be known as the "Big Bang." James Van Allan, discoverer of the eponymous radiation belts, began his high-altitude research in the Center, after a crucial wartime role in developing and fielding the VT fuze; Professor Van Allan describes his life at APL in this issue. The Research Center's Frank McClure, Al Schulz, and Joe Massey, along with Dr. Gibson (then APL Director) and Richard Johns of the School of Medicine, were instrumental in establishing APL's long and successful history of collaboration with the Johns Hopkins Medical Institutions.

Of course, there are many organizational and scientific contributions made by the Center that are less obvious, less far-reaching, but nevertheless substantial. That is not to say that the Research Center has not undergone constant scrutiny of its mission and role in the organization (Professor Van Allen's article alludes to such scrutiny even in the early 1950s). On at least two occasions, in 1983 and again in 1993, the Laboratory conducted substantive reviews to consider how (or even if) the Research Center could best support the Laboratory and its sponsors. On both occasions, adjustments to the Laboratory's overall management of R&D were effected, including the R&D conducted in the Research Center. Such reassessments are a natural and healthy undertaking for an organization making use of scarce discretionary resources. Since 1993, the Research Center's allocation of Independent Research and Development (IR&D) funds has decreased 29%, while external programs and collaborative work with other Laboratory Departments have increased commensurately; IR&D now accounts for about 20% of the Center's support.

CURRENT ORGANIZATION

The Center's change in funding reflects a more fundamental, renewed emphasis on the Laboratory's mission. This renewed emphasis was endorsed in the Laboratory reorganization of 1 October 1996 by the establishment of the Milton S. Eisenhower Research and Technology Development Center, which comprises the staff and facilities of the Research Center and approximately half the staff and most of the facilities of the Aeronautics Department. In some sense, the merger represents a case of "back to the future," since the first head of the Aeronautics Department was Bill Avery, a plank holder in the 1947 Research Center who led the Center's combustion program at that time.

Our current organization features four groups (Physics, Modeling, and Applications; Advanced Signal and Information Processing; Sensor Science; and Aeronautical Science and Technology) and a Department Office, which includes program development staff emphasizing establishment of new high-technology programs in cooperation with other APL Departments. The merger is reflected in the augmentation of the Advanced Signal and Information Processing Group, creating a substantial cadre of staff in the growing and critical area of information technology, and the establishment of the Aeronautical Science and Technology Group, which brings with it the William H. Avery Advanced Technology Development Laboratory (AATDL)—formerly the Propulsion Research Laboratory. The inheritance brought to the RTDC from the Aeronautics Department is illustrious and includes the invention of the supersonic combustion ramjet.

The RTDC is now an organization with end-to-end capability, from basic research to the fielding of prototype systems. This spectrum, as well as the RTDC's commitment to the Laboratory mission, was displayed in action on 24 January 1997, when an SM2 Block IV-A missile successfully intercepted a tactical ballistic missile in the sky over the test range at White Sands, New Mexico. The elements of the RTDC provided significant support for development of the Navy's tactical ballistic missile defense capability, working with the Laboratory's old Fleet Systems and current Air Defense Systems Departments. Staff in the Aeronautical Science and Technology Group conducted aerothermal tests at the AATDL to enable the use of an infrared seeker protected by an actively cooled sapphire dome. Staff in the Sensor Science Group used fundamental materials science diagnostics to enhance the survivability of the dome. The target used in the flight test, whose telemetry confirmed the successful intercept, was designed by staff in the Aeronautical Science and Technology Group and fabricated at the AATDL. Additional, fundamental ellipsometric diagnostics to support seeker development are being performed by the

Physics, Modeling, and Applications Group. We look forward to many more such full-spectrum contributions to the Laboratory.

THE CASE FOR R&D INVESTMENT

It wasn't until 1979 that the Center was named in honor of Milton S. Eisenhower. It is impossible to briefly summarize the late Dr. Eisenhower's career or influence on the country without slighting him through incompleteness.[6] He held significant diplomatic and administrative posts in the U.S. government, serving as an advisor to seven U.S. presidents. He led three major universities, serving as president of Johns Hopkins on two separate occasions. He was at home in industry, serving as a director for 13 major companies. He had a deep and subtle understanding of the economic and political interactions of the public and private sectors. (He is alleged to have coined the term "military industrial complex" made famous by his brother while president of the United States.)

That understanding could well serve the country and University now, as continued investment in long-term science and technology development has been called into question by Congress,[7] by industry,[8] and by the media.[9] At a time when major industrial and government research establishments (such as Bell Laboratories, IBM Watson Research Center, and Federally Funded Research and Development Centers such as Lincoln Laboratories) have undergone significant reductions, APL renewed its commitment to its R&D unit, broadening our charter to explicitly include technology development.

How can such a move be justified? The overall subject of return on R&D investment, especially at a national scale, is obviously beyond the scope of this introduction. There is no point in rehashing Vannevar Bush's *Endless Frontier* or trotting out this subject's many old warhorses from transistors to Tang. It is not my intention to debate basic vs. applied research, public vs. private funding, or academic vs. industrial conduct of R&D. Rather, I want to state a few facts in support of R&D investment at APL, considering the Laboratory functionally as a problem-solving organization focused primarily on operational (system) needs of the U.S. government.

Within that context, the issues can really be stated in two questions: (1) What should the level of R&D investment be? and (2) How should the R&D be managed? I will address both of these questions in turn.

Investment Level

First, it is worth noting that APL's customer focus on the U.S. government significantly constrains the possible answers to the question of investment level. Unlike a private industrial company, APL's R&D investments are subject to negotiation and monitoring by the government (and, typically, not the same part of the government from which our sponsorship derives), independent of the benefits they produce. However, even given that difference, the experience of industry serves as a guide.

One relatively recent school of thought, as supported by the changes in the telecommunications industry and its R&D base, seems to suggest that corporate R&D investment is not very important. For example, some have noted that MCI became a successful communications company (with help from the government), without the massive research investment made by its competitor, AT&T. In fact, MCI made direct use of the research paid for by AT&T. This supports the view that research results are just another commodity that can be bought, rather than performed in-house (I will have more to say about this later). I think the situation is less clear-cut, both specifically and generally. First, AT&T made a business decision not to protect its intellectual property in semiconductor technology to preserve (temporarily, as it turned out) its monopoly in telecommunications. Had they made the opposite decision, who knows what might have happened? Second, MCI's success does not equate to AT&T's failure. AT&T's continued investment in R&D contributed greatly to its ability to survive the end of its monopoly and remain a large and successful corporation, capable of product development in addition to providing services.

More generally, economic studies suggest that in-house R&D is crucial to a high-technology company's success. In a 1980 study[10] of 16 major American petrochemical companies, Edwin Mansfield of the University of Pennsylvania showed that the more a company invested in research (specifically, "basic science"), the greater its productivity became. A more recent, much broader study[11] of 911 American companies showed that those companies performing basic research consistently outperformed those neglecting it, and in direct proportion to their level of investment.

Note also that the benefits of R&D investment do not accrue only to the investors (or their direct competitors). Another study by Mansfield[12] showed that the average annual investment return on an invention was substantial for the investor, but was *twice as high* (in terms of cheaper and better products) for the customer. Thus, government restriction on our R&D investment can be against the government's interest.

R&D Management

By R&D "management" I mean not the actual direction of projects and programs (according to the late Richard Kershner, former head of the APL Space Department, the less of that there is, the better[13]), but to the process of staffing and apportioning a corporation's R&D investment. There is a spectrum of possibilities, with the extremes represented by the insular, "ivory tower" corporate research center and the pro rata distribution of the R&D investment throughout an organization. APL falls in the middle of that spectrum, and a good case can be made for that compromise.

First, an excellent case can be made against the ivory tower. Frederic Jevons, one of the first scholars addressing this question, studied the origins of 84 technical innovations having significant economic impact in the United Kingdom. He found[14] that although scientific discoveries occasionally lead to new technology, this is rare, with most technological development taking place in the *R&D departments of industry*. Mansfield similarly found[15] that 90% of economically relevant new technology arises from the industrial development of pre-existing technology—not from academic science. This situation is summarized by the old saying, apparently true,[16] that "the steam engine did a lot more for physics than physics ever did for the steam engine." Thus, a corporate research department that clones academia is unlikely to benefit the parent organization, especially in the short to medium term, because such a department will not appreciate the problems that the company's customers need solved. (It should be noted, however, that the infrequent exceptions of commercially important academic research can have tremendous impact; these exceptions apparently account for the phenomenal 28% annualized return on investment quoted[17] for academic science. Of course, that return is distributed throughout the economy, not captured by the innovating institution.)

However, the pro rata distribution of R&D investment throughout an organization can be equally hazardous. One reason is that although the units of an organization most directly focused on outside customers are well versed in the problems that need to be solved, they may not have access to the full range of science and technology available either within or outside the organization. According to Kealy,[18] corporate R&D departments are the most cost-effective way for companies to capture other people's research and distribute it broadly within an organization. For example, a 1992 study[19] by Japanese economists Hiroyuki Odagari and Naoki Murakimi showed that Japan's 10 largest drug companies each averaged a 19% rate of return on their own R&D investments, and an additional 33% rate of return on the investments of the other companies. The extraction of value from the research literature is enhanced by the specially trained staff in a corporate R&D center. A key to making this approach successful, however, is that the R&D department work closely with the operating units of the company (and that the operating units work closely with each other). IBM's Peter Hauge says, "direct interaction of research scientists and engineers with customers and the details and constraints of their problems provides a unique opportunity for broadening the scope and enhancing the value of research by bringing it from the realm of theory into the realm of practical operation."[20] This need for interaction and communication across internal boundaries also emphasizes the importance of other APL institutions such as the biannual R&D Symposium, and indeed the *Technical Digest*.

Another advantage of corporate R&D centers is the interdisciplinary nature of economically important technology today. The opportunities for hybridization among the corporate-aware staff of a customer-focused R&D center offer great potential gains to the parent company. According to the CEO of Glaxo Wellcome, Richard Sykes, "old divides between science and technology and between academic and industrial science are disappearing . . . . Success in science and technology now lies in our ability to create networks between public and private research sectors."[21]

Thus, APL has a well-balanced approach to its corporate R&D investment. APL invests in R&D within each of its sponsored Departments, but also supports a Center to foster the networks demanded by Sykes—an organization to make connections between disciplines, between Departments of the Laboratory, between Divisions of the University, and between the Laboratory and the external science, engineering, and sponsor communities. The balance between near- and long-term research and technology development, the balance between disciplines, the balance between organizational units, the balance between Eisenhower's impractical and practical with which I invoked this Introduction, will never be static. The staff members of the RTDC intend that it remain a key factor for the Laboratory in dynamically striking that balance.

THE ARTICLES

This special issue of the *Technical Digest* is intended to illustrate the range of capabilities within the RTDC and to present examples of its role in making connections of value to the Laboratory. Thus, it is no accident that most of the articles have coauthors who are not staff members within the RTDC.

Although this is a large issue, much isn't reflected here. Many RTDC activities have been described in recent issues of the *Technical Digest*; others are not yet ripe for description. I do need to mention one final category of omission in particular. Unfortunately, the exciting activities of RTDC staff originating in the Aeronautics Department are underrepresented here. This anniversary issue has been planned for some time, with articles due in July 1996. Since the Laboratory reorganization establishing the RTDC was not announced to the staff until last September, it was impractical to include more articles reflecting their efforts. As I have learned more about these activities during the planning for and implementation of the October 1996 reorganization, I have been especially disappointed by that impracticality. I have obtained the assurance of the Editor-in-Chief that this underrepresentation may be redressed in future “Research and Development Update” issues.

The articles begin with the historical (and historic) highlights mentioned earlier. James Van Allen’s article speaks directly to the balance between research and application, at both a personal and organizational level. Today’s fortunate researcher is almost never in the position of having to do tests and experiments in combat! Bill Guier and George Weiffenbach’s article on perhaps the single biggest Laboratory contribution of the Research Center beautifully illustrates the benefits accruing to an organization that can opportunistically fuse awareness of Laboratory problems, interdisciplinary backgrounds and perspectives, and a flexible approach to the prosecution of an unplanned problem. Their article also serves as a fitting tribute to the vision and talents of Frank McClure, who directed this Center longer than any of its other leaders, nearly 25 years.

A section on research opens with an article by Don Williams, currently Chief Scientist of the RTDC, and my predecessor as its Director. The exciting results from Jupiter’s magnetosphere constitute the fruits of *extremely* long-term research—in this case, almost 20 years.

Jim Franson and Bryan Jacobs discuss a novel approach to a new research area with tremendous long-term potential: quantum computing. Their current capabilities are the fruit of APL’s balanced approach to R&D investment, resulting from contributions of all of the components of APL’s IR&D Program [Departmental, Thrust Area, and R(TD)C] over nearly a decade.

With my collaborators Edward Ott and Tamás Tél, I next summarize a multiyear effort to assess the feasibility of modeling continuum systems with low-dimensional dynamics.

A multidisciplinary and interdepartmental team led by Denis Donohue describes an exciting advance in the capability to predict electromagnetic scattering from rough surfaces. The Research Center has a long history in this field, but this recent development brings APL’s capabilities in addressing practical problems into the world class. Novel extensions of the method of moments, achieved by applying techniques developed in the fields of computational fluid dynamics and signal processing, have allowed this research team to address much larger scale problems, involving much rougher surfaces, with less computer power than ever before.

In the area of material science, Dennis Wickenden and collaborators from NASA discuss the development of novel materials with the potential to enable new classes of photosensitive sensors. By alloying specially chosen materials, the semiconductor bandgap can be tuned to select short wavelengths of interest in a variety of applications.

Finally, Bill Christens-Barry and Alan Partin describe collaborative biomedical work applying optical and signal processing techniques to the study and clinical evaluation of prostate cancer.

A section on technology development opens with a history of ramjet and scramjet propulsion development for Navy missiles. The article by Paul Waltrup et al. highlights the crucial role APL has played in this field, including the invention of the supersonic combustion ramjet.

Fernando Pineda and an interdepartmental and interdivisional team of collaborators discuss the interlocking codevelopment of novel analog signal processing hardware and algorithms to exploit that hardware’s unique capabilities. Incidentally, this article illustrates how the pursuit of a solution to a particular problem can have multiple payoffs; the correlation algorithm developed for purposes of acoustic transient classification appears to be much more general, even extending to images and high-dimensional feature spaces.

Two articles follow in the area of information science. Marty Hall and Paul McNamee describe a technique to vastly increase the efficiency of software without increasing coding difficulty. The effort is part of a Small Business Technology Transfer Program, one of APL’s few avenues for direct partnering with industry. Next, Ralph Semmel et al. discuss the use of artificial intelligence techniques to increase the efficiency of, ease the use of, and foster better designs for complex information systems. One of Semmel’s coauthors and collaborators, Robert Winkler, is also our sponsor at the Army Research Laboratory (ARL). This interorganizational effort reflects a growing trend for direct sponsor involvement in the Laboratory’s technical efforts.

The next article describes an effort that the Space Department described to NASA as “exemplifying how the RTDC’s long-term focus can translate into enabling technology for APL Departments.” The article by Wickenden et al. discusses a team effort within the Sensor Science Group to miniaturize a particular class of sensor, in this case a magnetometer (the group has sensor miniaturization, in general, as one of its main goals). The team has developed several alternative approaches, which are now the basis for a joint program with the Space Department to field a space-qualified sensor smaller and more sensitive than any currently available. One of the sensor concepts, the “xylophone” magnetometer, stems from team member Ben Givens’ interest in theater organs—now that’s interdisciplinary!

Denis Donohue and Jim Kuttler next discuss the development of an approach to modeling radar propagation over rough terrain. This constitutes a direct application to a problem of considerable importance to the Air Defense Systems Department.

Finally, Henry Kues, with collaborators representing the federal and a municipal government, discusses an application of APL-developed expertise in the public health policy arena. This unusual opportunity to exercise the University's public service mission also highlights the complicated role of science in public policy today.

The next section of this special issue features a set of collaborative programs in which the RTDC plays a major role. These articles also illustrate how the RTDC can serve as a bridge for APL to nontraditional sponsor communities.

First, John Murphy, Dan Dubbel, and Dick Benson outline one of APL's most unusual national security programs: the Securities Technology Institute. This program, directed at counterfeit deterrence, shows how APL's capabilities and experience can be leveraged into new roles of service to the country, as well as new opportunities for sponsorship.

Wayne Bryden, Dick Benson, and Harvey Ko, along with Defense Advanced Research Projects Agency sponsor Mildred Donlon, then discuss a collaborative program between the RTDC, the Submarine Technology Department, the Johns Hopkins Medical Institutions, and the University of Maryland Baltimore County. This program nucleated around technology developed over a period of years, with funding from both R(TD)C and Thrust Area IR&D programs.

Dick Benson and JHU Materials Science Department Chair Jim Wagner discuss another program with an innovative collaborative arrangement, this time both within the University and with ARL: the JHU/ARL Microelectronics Research Collaborative Program. In this program, which Wagner and Benson administer, researchers in a number of APL and JHU Departments team with ARL researchers on joint projects, using each other's facilities and sharing postdoctoral fellows and students. ARL researcher Doran Smith has been on site in the RTDC for nearly a year; other ARL scientists are expected to join us in 1997.

A large interdepartmental team next discusses APL's attempt, on a heroic time scale, to address a public safety issue for the Washington Metropolitan Area Transit Authority, applying technology to ensure the safety of visually impaired travelers in the Metro system. The successful demonstration of a prototype system at the L'Enfant Plaza Metro station only a few months after the project began is a tribute to the team approach taken to the problem.

A final program-oriented article by Gary Sullins, Paul Waltrup, and Dick Garritson explains the novel APL–government–industry alliances set up to make the facilities of the AATDL available to industry, while avoiding any appearance of conflict of interest that could jeopardize APL's trusted agent status with the government.

This special issue would not be complete without some mention of the RTDC's role in the University's educational programs. Of course, many RTDC staff teach in the G.W.C. Whiting School of Engineering, and a number hold other joint appointments in various academic divisions. Recently, however, the RTDC has been instrumental in establishing a new part-time master's degree program that responds to a critical educational need for people trained in the exploding area of information technology. Ralph Semmel, chair of the new program (as well as chair of the computer science program) describes with Associate Dean Roger Westgate the need for, and focus of, the Whiting School's new program in information science and technology.

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