Defining Innovations

Ralph D. Semmel

APL's 75th anniversary provides us with a great opportunity to reflect on our history and recognize the remarkable impact we have had on the world. There are indeed many achievements to celebrate—too many, in fact, for a short article. The people who make up our past and our present have been responsible for thousands of critical contributions to our nation's most critical challenges, and these include a smaller number of truly defining innovations—game-changing developments that profoundly advanced science, engineering, and national security capabilities. This article celebrates these innovations, the culture that has enabled them, and the possibilities that lie ahead of us.

We should first recognize that our past, current, and future achievements are made possible by a community. It is a community that builds on our deep partnerships with the government, which draws on our capabilities every day. It includes industry, with whom we work closely to get systems fielded. And there are our deep connections to academia, including our parent institution Johns Hopkins University. We also are grateful to the state of Maryland and Howard County, where most of APL is located and where so many of us reside and work. We thrive within the fabric of this community, we are strong because of it, and we are thankful for all that it has enabled us to do.

Throughout our history, APL staff members have been involved in the creation of technologies, systems, and capabilities that have transformed our world. In fact, our desire to have game-changing impact is an APL core value that has driven us since the first director, Merle Tuve, sketched out the Lab's first organizational chart with pen and paper.

That drive for impact is guided by our core purpose of making critical contributions to critical challenges. Moreover, it is inherent today in our strategic goal to create defining innovations that ensure our nation's preeminence, and it permeates our pioneering spirit and culture of experimentation. It is clear that our purpose and spirit were present from the start. As Tuve was known to say, "Our moral responsibility goes all the way to the final battle use of this unit; its failure there is our failure regardless of who is technically responsible for the cause for the failure. It is our job to achieve the end result."

BEGINNINGS: PROXIMITY FUZE

Like many celebrated technology organizations, our story starts in a garage, in our case a used car garage in Silver Spring, Maryland, in 1942. We were focused on a critical challenge that had defied solution: how to defend our forces more effectively against devastating enemy aircraft. The technical hurdles to intercepting fast and highly maneuverable aircraft were immense, and while many ideas had been proposed, no one had been able to develop a viable solution. Many critical contributions were needed, not least among them a proximity fuze that was capable of withstanding 20,000 times the force of gravity and centrifugal forces stemming from 475 rotations per second, so that a round could be detonated at the optimal time to inflict maximum damage. The challenge has been compared to firing a light bulb from a cannon and expecting it to remain in one piece.

A prototype based on a promising approach using radio frequency technology had been created by the Carnegie Institution's Section T (named for Tuve). When the work needed to move from the Carnegie Institution to be completed, Tuve, a Johns Hopkins graduate, recommended that Hopkins take over. The university agreed, and APL was formally established on March 10, 1942.

Thanks to the work begun by Section T and the incredible set of APL contributions that followed, by the close of the war in August 1945, more than 22 million proximity fuzes had been produced. In fact, fully a third of the nation's electronics industry was at the time engaged in fuze work.

The proximity fuze is emblematic of the game-changing impact we seek to have, and it was our first defining innovation. By *defining innovation*, we are referring to a dramatic advance that completely changes the way we live, work, and operate. It is an innovation that creates an inflection point in history and propels humanity forward so that returning to the way we lived beforehand is unthinkable.

Including the proximity fuze, APL today claims nine defining innovations that have changed the world in profound ways and set the stage for future defining innovations.

A sailor aboard USS *Boston* (CAG 1) stands by the missile-loading hatch as a Terrier launcher slews into the sun to point its missiles skyward. (U.S. Navy.)

The proximity fuze was lauded as one of the three most significant technological advances of World War II, along with the atomic bomb and radar.

SURFACE-TO-AIR MISSILES

As we know all too well, the threats to our nation and the world did not stop with the end of World War II. In particular, the threat from fast aircraft and missiles was increasing, and it posed another critical challenge for APL: how to enable stable supersonic flight for the first generation of missiles needed to defend against the growing threat from the air.

There are a few variations on the story of how Al Eaton solved the challenges of supersonic flight, resulting in the major breakthrough for the Navy's surface-to-air missiles, and all of them involved drinks at a bar and drawings on cocktail napkins. Now, most drawings on cocktail napkins are not usually particularly profound (despite how impressive they may seem to us by the end of the evening), but the scribbling on these napkins turned into a revolutionary theory of supersonic aerodynamics that enabled the missiles needed to protect our forces.

Al and his team came to their insights when during early flight tests, they observed that a supersonic missile rolled in the opposite direction of one in subsonic flight. After rigorous analysis confirmed this observation, APL persuaded the Navy to adopt tail control for surface-to-air missiles, which significantly improved stability and speed of response over the entire supersonic regime.[1]

The expertise that came together in that bar after significant experimentation and analysis was applied to a critical challenge for the nation, and, like all of our defining innovations, it had a profound effect. In fact, it would steer more than 70 years of the Navy's guided missile programs, including the work APL does with many of the Navy's missiles today, such as Standard Missile and Harpoon.

TRANSIT

Building on the strength of our relationship with the Navy established through the proximity fuze and guided missile programs, as well as our reputation for trusted service and world-class expertise (two more core values of the Lab), APL was able to tackle another critical challenge: how to accurately determine the location of ships and submarines at sea.

Explaining the Lab's keys to success in building the proximity fuze, Tuve said, "Tell . . . the people of the community what the need is, invite them to contribute in the best way they can, and let them help each other meet that need."[2] With the Transit innovation, APL did just that. Two young researchers, George Weiffenbach and Bill Guier, established that they could follow the Doppler shift of the first Sputnik satellite as it passed overhead. By knowing where they were on the ground as a starting point, they could determine the location of the satellite.

When they shared their idea with the Lab's head of research, Frank McClure—who happened to be working on the Polaris strategic submarine program—the magic of collaboration resulted in a new defining innovation that solved a major Navy dilemma and was the precursor of the modern GPS system. McClure quickly realized that if we instead knew where satellites were as a starting point, we could determine where we were on the ground or the ocean.

McClure's insight to invert Weiffenbach and Guier's solution achieved something truly game-changing. Satellite navigation was born and the rest is history, with the modern implementation being GPS.

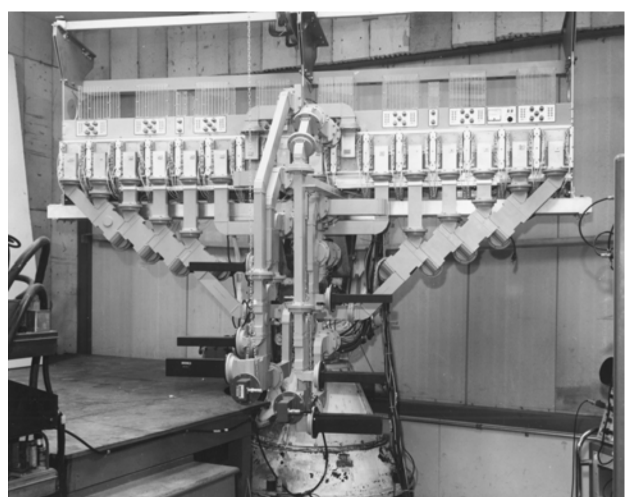
The Lab designed, built, tested, and operated several satellites for the Transit navigation system. The system greatly improved the ability of U.S. submarines around the world to accurately determine their positions. In 1967, APL released use of the Transit system to private industry, and the system became the reference system for numerous critical measurements. It continued to serve into the 2000s.

AMFAR

With many critical contributions and a number of defining innovations under our belt, when it came to tackling the next critical challenge in naval warfare, the Navy knew it could trust us to help. The challenge was a big one: how to engage low, fast anti-ship missiles in the face of intense electronic jamming, while simultaneously guiding multiple missiles launched in defense.

Analysis suggested that phased-array radar, which would not have to mechanically point at each target, could provide the near-instantaneous scanning, tracking, and closed-loop guidance required to defend against simultaneous aircraft and missile raids. The team that would develop what came to be known as the Advanced Multi-Function Array Radar (AMFAR) worked toward that solution by leveraging emerging electronics technologies and a new way of thinking about radar and ship integration. The result was a dramatic advancement in naval warfare that not only better protected ships at sea but also enabled American control of the seas.

The AMFAR prototype led to the development of the SPY-1 radar system on Aegis ships, which still sails with the Fleet today.[3] The SPY-1 has even been upgraded for ballistic missile defense of our European allies on land.



This view of the AMFAR prototype with panels removed shows the interior microwave and electronics elements of the system. Instead of a large, rotating dish, AMFAR used electronics to send out radar beams at any angle in microseconds.

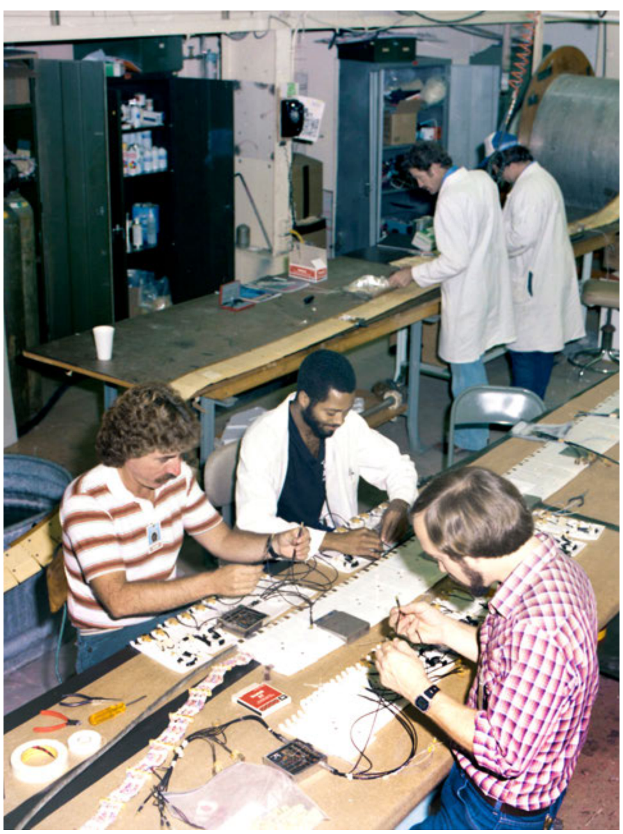
Among its many effects, AMFAR's legacy was evident once again in 2008 when a repurposed Aegis cruiser, with a modified combat system and carrying modified Standard Missiles, along with a multi-organizational team that included a number of APL experts, successfully intercepted an errant satellite as part of the storied Burnt Frost mission. With only a limited number of weeks from when the challenge was identified to when the satellite was due to impact Earth, the APL contingent was able to draw on its wealth of analytical knowledge and technical experience with radar and missile technology, and its deep relationships with the Aegis community, to contribute to an important mission for the nation and the world.

TOWED SONAR ARRAYS

Our highly collaborative environment, another of our core values, was needed to crack the code on towed sonar arrays in the 1980s. The challenge can be stated simply: detect increasingly quiet submarines at long ranges. Unfortunately, the solution was not so simple.

Successfully detecting submarines at sea entailed solving numerous scientific and engineering problems and developing towed arrays of sensors that could be deployed reliably to detect and localize undersea acoustic signals from great distances. Expertise from many disciplines—ocean physics, undersea warfare, analysis, test and evaluation, and systems engineering, to name just some—was necessary to unlock the potential of the technology for the nation's security in the face of an increasingly capable threat.

It was an amazing feat that APL continues to refine and build on in the Submarine (SSBN) Security Technology Program, a program we still lead for the Navy today.



APL staff members assembling and testing towed arrays.

SATRACK

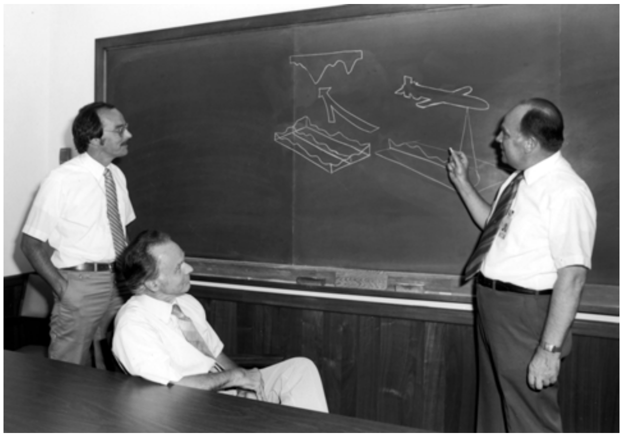
Our next defining innovation came in part because we had solidified our core value and reputation for trusted service to our nation.

Like the preceding challenges, it was a hard one: predict submarine-launched ballistic missile accuracy with high, measurable confidence and do it while reducing the number of test flights required. Failure in the strategic deterrence realm is not an option. Overestimating performance could put deterrence at risk. Underestimating performance could result in inefficient war plans and cause the nation to maintain a larger-than-necessary nuclear arsenal. The Navy trusted APL to find the solution.

To tackle the challenge, the SATRACK team created instrumentation that collected data from both the operating missile and ground stations, and developed hardware, software, and analytics to model and evaluate errors.[4] This work was game-changing for the Navy and is now being leveraged by the Air Force to assess intercontinental ballistic missile accuracy as well.

The trusted service that was so essential for SATRACK continues to underpin our work today, especially as we support critical new initiatives with, for example, the nation's special operations forces and the intelligence community, and it will underpin our work long into the future.

APL's SATRACK facility in 2002. The facility uses satellite-based test and evaluation data to validate and monitor guidance error modeling for the Trident missile.



An illustration showing the basic operation of the TERCOM system, developed for the Tomahawk cruise missile. TERCOM was the key to achieving the accuracy critically needed for the Tomahawk.

CEC being operated aboard USS *Cape St. George*. APL conceived and provided technical leadership with our collaborating partners in industry and warfare centers on behalf of the sponsor PEO IWS to develop CEC. CEC networks multiple radars to provide fire-control-quality composite tracking of aircraft and missiles.

TOMAHAWK

A defining innovation that demonstrates the importance of our core value of unquestionable integrity can be found in the story of APL's contributions to Tomahawk. The challenge we took on was vital: determining the correct location of the Tomahawk missile through terrain contour matching.

In this case, the challenge was already being addressed by others. So why did the government turn to APL? Because one of our engineers, Bill Spohn, had the integrity and the courage to stand up to the development team and tell them they were wrong about the failure probability of the original terrain contour matching.

Telling the sponsor that their new technology is likely to have a 1 in 2 failure rate, rather than the 1 in 250,000 rate the development team predicted, could not have been welcome news, but it was the right thing to do, and Spohn did it.[5] He was proved so dramatically correct in the tests that followed that APL quickly became deeply enmeshed in the overall development of the system. Ultimately, our team developed a mathematically sound approach that was simpler and dramatically improved the system's performance, and, as a result, the Lab later played a key role in the Tactical Tomahawk upgrade.

COOPERATIVE ENGAGEMENT CAPABILITY

Sometimes the needs of the nation have driven our innovations, and sometimes the state of technology has precipitated an innovation that provides an inflection point in the nation's capabilities. The latter was the case with the Cooperative Engagement Capability (CEC). As the state of computing and networking improved, we focused on a critical challenge that, if solved, would have a profound impact on the Navy: combining remote data from dispersed units to create accurate composite tracks of advanced threats that no single unit could create and maintain.

Despite great obstacles, the CEC team invented and prototyped a high-performance computing system and a robust high-speed network that enabled real-time tracking at each ship by using all of the contacts of all of the radars in the battle force. Without this capability, our forces today would be at much greater risk and would be far less effective in defending themselves.

In a sense, CEC dissipates the fog of battle. It has also led to numerous other critical contributions that expand situational awareness and warfighting capabilities for the Navy, such as Naval Integrated Fire Control – Counter Air, which provides a CEC-like capability to engage over-the-horizon targets.

CEC, like so many of our defining innovations, was the result of collaboration among scientists and engineers from across the Laboratory and from external organizations. In fact, the *Technical Digest* article that explained the capability was anonymously written and dedicated to the more than 200 people who made CEC possible.[6]

LOW-COST PLANETARY EXPLORATION

In the case of our most recent defining innovation, before Tom Krimigis and his team worked with NASA to create the Discovery Program, space science missions were generally incredibly expensive and complex. Thus, when the team proposed the Near Earth Asteroid Rendezvous (NEAR) mission, the first of NASA's Discovery Program missions, no one thought it would be possible to build a spacecraft so inexpensively and so quickly. But when we returned $3.6 million to NASA, not only

This high-resolution, color-enhanced image of Pluto was captured by the New Horizons spacecraft, which was designed, built, and operated by APL for NASA. It made the historic flyby of Pluto on July 14, 2015. (NASA/APL/SwRI.)

did APL remove all doubt, we charted a new path for the nation in space exploration. Landing the NEAR spacecraft on the asteroid Eros at the end of the mission, which had not been part of the original plan, and continuing to return science data for a period of time while on the surface of Eros was just an extra benefit to the international planetary science community.

We followed the NEAR mission with the remarkable journey of MESSENGER, which has redefined our understanding of the planet Mercury. And then there was our most recent accomplishment: the flyby of Pluto by the New Horizons spacecraft. APL had to overcome a major challenge on July 4, 2015, when the New Horizons spacecraft went into safe mode. Alice Bowman and her mission operations team performed brilliantly and were able to quickly recover the spacecraft, despite the 9-hour speed-of-light round-trip it took to communicate with the spacecraft.[7] Ten days later the spacecraft took the iconic, breathtaking photo of the planet that showed the world that Pluto has a heart.

The transformation to low-cost space exploration, led by APL, was indeed a defining innovation. Today we are focused on new critical challenges in space, such as how to mitigate the risks that solar flares pose to the well-being of our planet and society. In 2018, we will be launching Parker Solar Probe, which will get closer to our Sun than any previous spacecraft and will hopefully shed light (so to speak!) on incredibly perplexing questions, such as why the Sun's outer atmosphere, or corona, is a few million degrees Celsius while the Sun's surface is only 6000 degrees Celsius.

NEW INITIATIVES

From the proximity fuze to low-cost space exploration, we have, together with our partners in government, academia, and industry, been a catalyst for game-changing impact as we tackled and solved some of the nation's hardest problems. We continue to do so today in numerous ways.

To respond to the threat of terrorism and to protect our forces, we have been creating transformative technologies, such as real-time foliage-penetrating lidar capabilities, rapidly fielded cost-effective persistent surveillance systems, and electronic warfare adaptations for counterterrorism applications. We are also improving soldier protection through our biomechanics and injury mitigation efforts. And we are protecting the homeland through our counter-proliferation work with the Department of Homeland Security.

The emergence and rapid evolution of cyber operations have led us to develop deep analytical tools and stunning visualization capabilities that benefit programs across the Laboratory and enhance cyber capabilities for the nation. The creation of the Live data, Integration, Validation, and Experimentation (LIVE) Lab, where staff members create and experiment with these tools and visualizations daily, has changed the way we and our sponsors monitor and respond to cyber events. Moreover, our efforts have improved the nation's awareness of the threats we face in cyberspace as well as the ways to combat them.

With robotics and autonomous systems, we are building on our storied history, which started in the 1960s with the mobile automatons Ferdinand and the Johns Hopkins Beast, to create intelligent systems technologies that have the potential to transform the military and society.

And working with our colleagues at Johns Hopkins Medicine, we are making deep contributions to restore capacity to critically injured service members, reduce preventable harm, and dramatically improve health around

A congressional tour with Senator Ben Cardin of the unique capabilities of APL's LIVE Lab, a facility that helps researchers develop solutions to continually evolving cyber threats.

the world. The great potential for our technologies to do good for the world in this arena is exciting to all of us.

Finally, in addition to this long list of things we have done and are doing, there is an even longer list that cannot be revealed. In fact, much of what we do at APL does not get exposed to the public, but the results of our classified work are every bit as game-changing and eye-watering as those that can be openly discussed.

I am confident that the breakthroughs we are making in these and other areas will one day lead to additional defining innovations that we will celebrate at our centennial.

LOOKING FORWARD AS A TEAM

For each of our critical contributions and defining innovations, there is one constant: the incredible people who make APL what it is and have made our achievements possible. The scientists and engineers are often named in these stories, but just as important to our achievements are those who serve in critical enabling roles. Whether hiring new staff, managing our finances and business operations, maintaining our applications and networks, providing legal services, ensuring the security of our campus, or constructing and maintaining buildings, our administrative professionals and support staff are an integral part of our team. They make things run, and we could not succeed without them.

I conclude by observing that we are as driven today as we have ever been to making critical contributions to critical challenges and to creating defining innovations that have game-changing impact. While I am excited to celebrate our 75th anniversary, I am even more excited about what we will do to transform the world in the future.

Let us continue to be bold, do great things, and make the world a better place!

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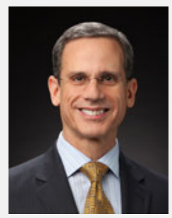

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