Tomorrow's Warfighter Capability: Guest Editor's Introduction

Timothy J. Collins

This issue of The Johns Hopkins APL Technical Digest *highlights some of the Precision Engagement Business Area's recent activities in the science and technology domain. These activities serve to advance the state of the art and offer evidence that emerging technologies are useful and applicable in the national security environment. The purpose of this issue is twofold:* (i) *to reorient readers to the salutary effects of science and technology achievement in the realm of precision engagement and* (ii) *to expose the breadth and depth of the current efforts in the Precision Engagement Business Area as it continues to make significant and meaningful contributions to delivering offensive combat capabilities. With its institutional heritage of 70 years, APL recognizes the contributions of our nation's scientists and engineers to America's rise in global power. Not unlike in our past, today's science and technology endeavors will provide the underpinnings of America's warfighting capability for tomorrow.*

INTRODUCTION

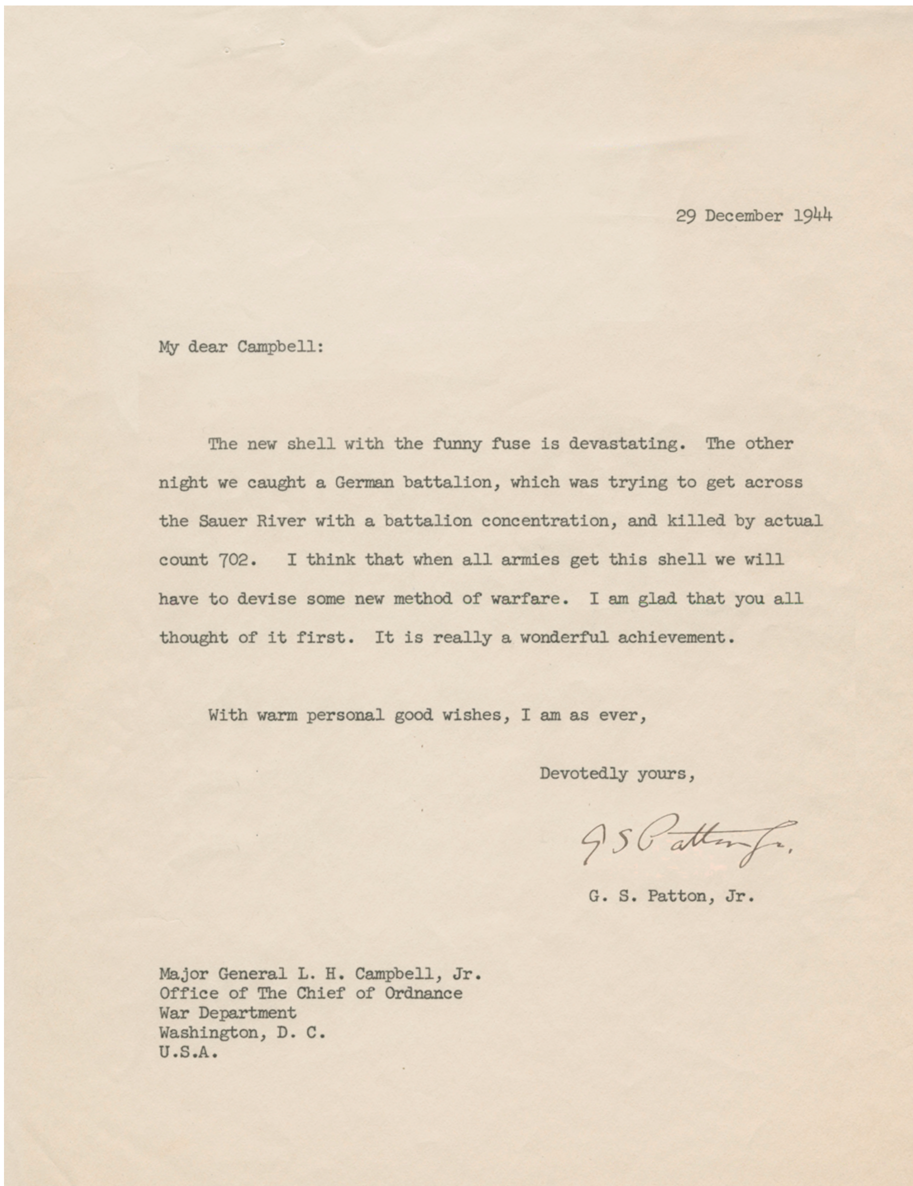
> "One machine can do the work of fifty ordinary men. No machine can do the work of one extraordinary man."
>
> —Elbert Hubbard[1]

We know from our understanding of history that we owe a debt of gratitude to both the Greeks and the Romans for their significant contributions to Western civilization. The Romans were the engineers and the Greeks were the philosophers. However, neither group seems to have had a disposition for technology. In fact, the Roman Emperor Vespasian is said to have had a proscription on technological innovation for fear of the resulting unemployment, and we know of Aristotle's quip that to be engaged in mechanical arts was "illiberal and irksome."[2] Nevertheless, man's interest in the natural world and his desire to control it has always been a force that has driven him to action. The Catholic Church's creation of the medieval institutions that are the archetype of today's colleges and universities is tangible evidence of this motivation.

The American higher-education system was established for the purpose of protecting, transmitting, and generating knowledge. Early on, institutions within U.S. higher education were narrowly focused with a single curriculum for all students in their training as ministers and doctors. It wasn't until Thomas Jefferson founded the University of Virginia in 1819 that we find an opening for introducing advanced education to a greater segment of the citizenry. President Lincoln's signature on the Morrill Act of 1862, which had been vetoed by President Buchanan, established land-grant colleges and signified an expansion of the American effort to improve the quality of agricultural industries through—arguably—the first attempt to organize research within U.S. higher education. Finally, the establishment of The Johns Hopkins University (JHU) in 1876 as our nation's first research university was a significant milestone and a commitment to the contributions university life in this country would make toward the common good. In his installation address, Hopkins President Gilman foreshadowed the path forward, "What are we aiming at? The encouragement of research . . . and the advancement of individual scholars, who by their excellence will advance the sciences they pursue, and the society where they dwell."[3] Since those beginnings, we have seen an assiduous effort to generate new knowledge that has opened horizons; we have conducted research that has literally changed the world; and we have increased opportunities for greatness for both individuals and the nation. This is the story of science and technology and the profound impact it has had on the nation.

The advancement of science and technology throughout the 20th century changed man's environment in countless ways (for an in-depth review, see Refs. 4 and 6). In fact, nearly every aspect of our lives today is touched by the earliest of efforts within the research community. Many of the developments have taken decades to fully understand, for it is rare that a truly groundbreaking technology is immediately impactful. Some our own achievements during the past 70 years of technical contributions, oriented toward national security and space, suggest a tendency to overestimate the contributions in the near term and underestimate their significance in the long term.

APL's initial foray into the national security domain on behalf of the U.S. Army was commended by General George S. Patton, Jr. Then serving as the Commander of 3rd Army following the Battle of the Bulge, he wrote, "The new shell with the funny fuse is devastating. . . . I



29 December 1944

My dear Campbell:

The new shell with the funny fuse is devastating. The other night we caught a German battalion, which was trying to get across the Sauer River with a battalion concentration, and killed by actual count 702. I think that when all armies get this shell we will have to devise some new method of warfare. I am glad that you all thought of it first. It is really a wonderful achievement.

With warm personal good wishes, I am as ever,

Devotedly yours,

G S Patton Jr.

G. S. Patton, Jr.

Major General L. H. Campbell, Jr.
Office of The Chief of Ordnance
War Department
Washington, D. C.
U.S.A.

Figure 1. Letter from Lieutenant General Patton, Commander of 3rd Army, Battle of the Bulge. On loan to APL.

think that when all the armies get this shell we will have to devise some new method of warfare. I am glad that you all thought of it first."[5] From those humble beginnings, APL has since made significant contributions in a wide range of research areas including conceiving and developing transit satellites for ground positioning systems, developing parallel processing technology, building the first all-plastic rechargeable battery (which earned the "Best of What's New" award from *Popular Science* magazine), landing a satellite (NEAR) on an asteroid (Eros), developing a system to identify changes in digital video, and leading the team that developed the first fully integrated prosthetic arm that can be controlled neurally.[6] The story of APL's efforts can be found in the lives and activities of both government and public users. JHU President Gilman would be satisfied that APL has remained true to that initial direction he set for the institution.

Today the primary sponsor set for APL is an eclectic group that includes decision makers and policy implementers, men and women on the front lines and in research laboratories back home, and research professionals who work both in and for the government in countless capacities. Without exception, many of APL's sponsors are focused on the implications on national security of man's discoveries about the natural world. Some worry about what it all means today, while others reflect on what it might imply for tomorrow. APL provides a national treasure in its role, with thought leaders, futurists, former practitioners, scientists, engineers, and pragmatists working daily to assist sponsors in meeting the demands of retaining world-class capabilities that secure vital interests. It is axiomatic that APL's heritage speaks to its ability to add to the body of knowledge in a given domain as well as to translate that human understanding in new and unique ways to give the nation advantages others can only seek to emulate. It is at this very intersection—what we learn as the science today and how it might well become the technology of tomorrow—that we find concordant future contributions in both relevance and importance for America.

I welcome you to this issue of the *Johns Hopkins APL Technical Digest*. It reaffirms the benefits of science and technology and manifests the extent of the scientific and technological achievements in APL's Precision Engagement Business Area. The fiscal climate of any governmental effort is forever fickle; yet, the urgency for continued focus on future needs is invariant. APL's involvement today in research, teaching, and public service makes it a unique organization. Perhaps that is why APL staff so enjoy their association within this historic institution. This issue will provide an overview of the research efforts that will underpin the history of the 21st century. Everywhere you look you can see the realization of yesterday's science and technology accomplishments that help us to appreciate the impact we all can have on the future. If you accept Hubbard's thoughts,[1] you will agree on the enduring importance APL must place on science and technology to remain faithful to a sponsor community it has been serving for 70 years. The 19th-century philosopher Arthur Schopenhauer once stated, "Talent hits a target that no one else can hit; genius hits a target no one else can see." As you reflect on the technical achievements described in this issue, what do you see?

THE ARTICLES

The Precision Engagement Business Area seeks to make contributions within the domain of national security—specifically to providing offensive combat power for conventional theater warfare. APL's challenge, unlike the challenges for any single government sponsor, is to provide the warfighter with capabilities that impact all phases of the fight: locating, characterizing, and tracking targets of interest; employing the appropriate weapon or effect that satisfies the warfighting requirement; and controlling the execution of the entire engagement. This framework is commonly referred to as the "kill chain"—finding, fixing, and finishing targets of interest. APL's science and technology efforts are underway, with both internal and sponsored funding, and span the entire kill chain.

We begin by considering the process by which we use these weapons of war: command and control (C2). Since our earliest days, we have been involved with not only the application of specific technologies designed to achieve a precise effect but also the development of the associated concepts and enablers that allow the designated commander to exercise authority and direction to accomplish the assigned mission. In short, C2 is the glueware that connects what we believe the target to be with what is the appropriate action to achieve the effect a warfighter desires. The contributions APL has made in the C2 domain range from capturing text and voice messaging during operations for playback capability, employing a host of capabilities to operate combat weapons systems, and ongoing work in collaboration and decision making in the C2 environment. Some of the research in this domain revolves around communications systems, but understanding how the battle commander functions in this environment is also an exciting research domain with a significant number of particularly difficult challenges that are in need of solutions. The common denominator—and game changer—in all of APL's work is the effectiveness of the decision maker. Ockerman et al. offer for your reflection an overview of APL's most recent efforts to better understand, appreciate, and leverage the cognitive aspects of C2. In addition, they bring to life the application of their work in a case-study framework highlighting eight key characteristics that appear to make a difference. Their research further identifies four major hurdles to leveraging human performance in the dynamic and chaotic experience of warfighting. The intent of C2, of course, is to wisely use the resources provided on the basis of the best-known information. Is it possible, however, to consider ways to optimize the decision making before allowing the negative effects of fatigue to influence the choices?

Sensor management is an exemplar of such a challenge for a commander. The choice of which sensor is desired always lies in tension with the reality of which sensor is available. Game theory, as our children have shown us, is a mathematical approach to the analysis challenge of understanding how the value of our choices depends on the choices of others. Using sensor management as the C2 function, is it possible to consider mathematically a set of friendly choices that have taken into account the various possibilities for adversary reaction and then to provide the warfighter an optimized recommendation? Peter Chin's article lays out the results of APL's research, with insights from Kalman filtering techniques and game theory, suggesting that such a set of choices is possible. In addition, he describes a software architecture that may be extendable to better perform predictive analysis on defensive strategies. Combined, the articles by Ockerman et al. and Chin expose a research world that is ripe for altering the way we think about employing the weapons of war.

For any C2 activity, understanding the physics of the engagement is crucial, especially in the aviation domain. For more than 100 years, manned aviation systems have continued to evolve. Israel introduced the world to unmanned air systems for military applications connected to the kill chain in the 1982 Bekaa Valley fight in Lebanon.[7] Today, 44 countries are known to be actively pursuing development of these systems. This explosion of unmanned systems has become a reality because of the systems' low cost and demonstrated abilities. Some people predict that the world market for unmanned air vehicles will grow to $80 billion through the coming decade (the current worldwide level of spending is $5 billion per year).[8] APL's Precision Engagement Business Area is actively involved in developing concepts and technologies that will influence this emerging domain of warfare.

If one cannot develop the control systems necessary for these vehicles to operate in the prescribed environments, then one does not have a useful military capability. McGrath et al. describe their work trying to better understand the challenge of unmanned air system (UAS) platforms performing missions in environments with complex terrain and highly variable aerodynamics. Given the increasing need for the warfighter to operate UASs in complex terrain (e.g., urban, canyons, mountains), along with the increasing number and variety of operational areas, missions, and UAS platforms, there is a strong need for a high-fidelity, physics-based modeling and simulation framework that addresses these huge parameters. The UAS mission planning and simulation tool McGrath et al. have developed provides the kind of synthetic environment required to perform environment–vehicle interaction studies and analyses to help reduce the risk of mission failure associated with UAS operation in complex terrain.

Once we have determined how to successfully control the vehicle, we can turn our attention to the capability and operational concepts that leverage the benefits of these systems. Jeff Barton discusses the fundamentals of small, unmanned air systems in flight. Because of advances in sensor, processing, and battery technologies over the past decade, the UASs have become both smaller and more affordable. In particular, readily available low-weight, low-power, low-cost sensors based on micro-electro-mechanical system (MEMS) technology have facilitated the development of UAS autopilots for use by the military and civilians as well as for academic research and recreation.

Over the past decade, warfare has moved into urban areas. The tragedy in New York City on September 11, 2001, shattered Americans' understanding of the nature of war. Prior to the end of the Cold War with the collapse of the Soviet Union, we knew exactly where most targets were located but lacked the ability for all-weather, around-the-clock targeting. Today, we have the precision necessary to attack at our time of choosing; however, we can no longer find the targets. Often, they hide in dense urban areas and reveal themselves only when they find it useful. Thus, using these small, unmanned capabilities in cities and under adverse weather conditions is a requirement for APL's sponsors. Funk et al. describe research involving the use of small unmanned aerial systems across the kill chain, including the weaponization of the vehicles. During a live exercise on the Nevada Test Ranges, the team's research climaxed with a successful effort to provide convoy protection that included the use of unmanned systems operating in a hunter–killer cooperative engagement. This particular internal research effort serves as a pathfinder activity.

The need to stretch our thinking in the domain of autonomous operations reaches to all corners of APL. Most think about autonomy in terms of multiple entities of the same type—for instance, four unmanned ground vehicles rather than one unmanned ground vehicle. However, APL is interested in multiple types of systems operating autonomously. The critical challenge is to develop operations across vehicle platforms rather than to simply add like vehicles to the engagement. Several APL business areas have been collaborating to bring the capabilities of autonomous systems to bear on a focused problem. David Scheidt describes the visionary project Organic Persistent Intelligence, Surveillance, and Reconnaissance (OPISR). Using a novel combination of distributed image processing with information management and control algorithms, the research team has been able to demonstrate real-time coordination between multiple autonomous unmanned vehicles (air, land, and sea), unattended ground sensors, and tactical edge users. This coordination is across the entire kill chain. This is a game changer.

David Kiick provides the final article in this issue. The future for naval forces is no less dependent than air forces on autonomous operations. Our surface Navy seeks reduced manning and increased combat capability, and the littoral combat ship, employing a mission package concept, will leverage the capabilities of unmanned vehicles. This article describes the application of mission-level autonomy as it is applied to surface Navy missions. Mine countermeasures, searching and tracking of ships, and engagements with small boats are only a few areas that will benefit from work in this domain.

CONCLUSION

The exemplars offered in this issue are but a few of the diverse technologies being investigated and developed in the Precision Engagement Business Area. Spanning the kill chain, the business area's task is to bring together the best of American ingenuity and engineering talent. This business area has 24 staff members holding 10 U.S. patents for their work in national security—testimony to the innovative intellectual power they bring to bear on the nation's challenges. We hope this issue will stimulate your thinking as well as remind you of the potential effects of science and technology efforts. Future issues will focus on the process of identifying and characterizing targets and target sets that initiate the kill chain as well as look into the future for the weapons employment aspects of the kill chain. I am reminded of Tom Hanks (playing Jim Lovell) in the movie *Apollo 13*: "For now we live in a world where man has walked on the moon. It's not a miracle; we just decided to go!" On behalf of a grateful nation, my sincere thanks to the authors for their thoughts and continuing research efforts. Enjoy!

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