Integrated Air and Missile Defense: Guest Editor's Introduction

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ABSTRACT

It has been nearly 18 years since the publication of the three Johns Hopkins APL Technical Digest *issues dedicated to air defense. Since that time, many global events have shaped our national defense strategy and military capabilities. Just after the release of the second air defense issue, the 9/11 attacks occurred, followed by the global war on terror. The cost of this war, along with the financial crisis in 2008, strained the national defense budget. Even after recent budget increases, we still face many challenges. China's economic rise has enabled its military buildup. North Korea has increased its development of nuclear weapons and long-range ballistic missiles. Instability in the Middle East, and the procurement of advanced weapons by our adversaries, presents significant concerns and challenges to our nation and allies. To meet these many new challenges, the Air and Missile Defense Sector of the Johns Hopkins University Applied Physics Laboratory (APL) has focused its efforts on the integration of air defense and missile defense as well as of defense resources across the battle force. This issue highlights the challenges our nation faces in air and missile defense and APL's contributions to shape future solutions.*

INTRODUCTION

Air and missile threats have rapidly advanced over the last two decades. These threats come in many forms and degrees of technological sophistication, creating an expansive set that significantly challenges our defense resources. In addition to the more conventional cruise and ballistic missiles, new emerging threats include asymmetric low-cost swarms of unmanned air vehicles, large raids of ballistic missiles with longer range, and hypersonic missiles that threaten our military forces, allied countries, and the homeland. These challenges are further complicated by adversary use of anti-access/area denial (A2/AD) techniques to disrupt freedom of navigation for the United States and the international community.[1] Anti-access deters US military movement into an area of operation through the use of attack aircraft, warships, and missiles designed to strike key military assets. Area denial involves more defensive means such as air and sea defense systems to deny freedom of US action in areas under an adversary nation's control.

In addition, the proliferation of advanced electronics technologies has created an array of adversary electronic warfare capabilities that can deny our sensor, communication, and navigation functions. Both China and Russia have been explicitly developing A2/AD capabilities to deter US operations in regions of interest. The developed A2/AD techniques include advanced anti-ship cruise missiles, sophisticated electronic attack, and ballistic missile variants capable of striking from long range and with precision. Advanced fighter aircraft and an intricate network of air defense systems can deny use of US airpower and cruise missiles.

The US response to these emerging air, missile, and electronic warfare threats is a renewed emphasis on technological leadership to realize superiority in resilient information exchange and exploitation, assured space capabilities, joint force and multi-domain (ground, air, sea, space) operations with a decentralized infrastructure, missile defense, and autonomous systems. The most recent *National Defense Strategy*[2] articulates these objectives, and they are supported by the 2019 *Missile Defense Review*[3] and the US Navy strategy documented in *A Design for Maintaining Maritime Superiority*.[4] In the face of many new highly capable weapons being developed by our adversaries, coupled with the advent of information warfare in the cyber and electromagnetic spectral domains, it is essential that US military capabilities not only maintain the lead but actively advance our air and missile defense advantages in concert with the rapid pace of technological change. An overarching imperative has been and continues to be a more integrated and flexible battle force.

This issue of the *Johns Hopkins APL Technical Digest* presents an overview of recent developments in air and missile defense, with a particular focus on the integration of multiple sensors together with command and control to simultaneously conduct both air and missile defense missions while at the same time improving system performance for the individual missions. This coordination of widely dispersed sensing and weapon assets allows the defense system to more effectively engage a large variety of threats while more efficiently using assets. A critical element in achieving these capabilities is the introduction of new technologies that enable advanced computational resources, complex algorithms, flexible sensing, secure communications, and new human–machine interfaces. Some of these technology applications are described in this issue.

As we look to the future, we expect that the trend to integrate and coordinate military assets will continue with greater use of the space domain and joint forces. New technologies for air and missile defense are now being explored, including multispectral and multifunctional sensor apertures, applications of artificial intelligence, and lower-cost-per-kill lethality mechanisms such as high-energy laser and high-power microwave. A key challenge will be the coordinated integration of new technologies with both the traditional kinetic weapon systems and the electronic warfare systems that include jammers and decoys.

THE ARTICLES

At the start of this issue, Conrad Grant, who led APL's Air and Missile Defense Sector from 2005 through August of 2018, and Matthew Montoya, who spent nearly 20 years in the sector in various leadership roles, provide a perspective on capability needs for air and missile defense in the 21st century. This article includes a short look back into the 20th century and describes how APL has laid the foundation and is now paving the way for transformational 21st-century warfighting.

Subsequent articles describe selected examples of APL contributions to integrated air and missile defense (IAMD). In "Overview of Platforms and Combat Systems," Jerry Bath describes the functions and challenges of combat systems with a focus on Navy IAMD and the many technology advances being incorporated. These include Aegis destroyers and cruisers with their long-range, multifunction phased-array radars; their inventory of many different anti-air warfare weapons, ballistic missile defense, and electronic warfare weapons; and their complex control processes for processing sensor data, making engagement decisions, and controlling those weapons.

The next set of articles discuss specific combat system functions. Sensor resource management is a difficult optimization problem given the complexity of the warfighting environment and the vast number and variety of tasks involved. The article "Integrated Air and Missile Defense Resource Management" by Smouse, Liu, and Sylvester focuses on radar resources, which are most fundamentally the radio-frequency (RF) energy and time segments used to detect, track, and discriminate targets with a phased-array radar. In a dense threat environment, it is essential that radar resources be scheduled so that all threats can be properly engaged within the limits of radar and weapon capabilities.

Another optimization problem for the combat system is design of the target track filters that develop and maintain estimates of threat positions and velocities. A key challenge is the design of a filter response that accurately tracks threat dynamic behavior while sufficiently smoothing the track state estimates to support accurate trajectory predictions. Advancements in computing capability have enabled the implementation of sophisticated track filtering algorithms to better balance these objectives, as Hays and Fatemi discuss in "Combat System Filter Engineering."

Determining which of the various weapons to employ against the threats and when to employ them is yet another optimization function of the combat system. The Combat Information Center (CIC) is the tactical command center for most US Navy ships where engagement decisions are made and implemented. Leveraging the advancements in visualization and gaming will allow for a more effective combat information center that is better integrated with the warfighter. The article "Building the Combat Information Center of the Future" by Reggia and Jessee addresses the warfighting complexities that shipboard operators will face when dealing with multiple missions and future integrated defense systems. APL engineers are collaborating with warfighters to examine potential CIC technology advancements. Their goal is first to identify the most important needs and then to apply human systems engineering and integration principles to develop new concepts for human–machine interactions.

Integral to air and missile defense are the sensors and communication systems that provide the combat and weapon systems with the data necessary to develop threat information, such as estimates of the kinematics and identity of threat objects. In the article "Sensors and Communication Systems," Huffaker et al. present emerging technologies in both the RF and electro-optics/infrared (EO/IR) spectra. Technology advances in radar receivers and exciters, signal processing, and digital beamforming that have contributed to the current state of the art of digital phased arrays are described. The article highlights the development of the AN/SPY-6 radar. Two current areas of focus in EO/IR are free-space optical (FSO) communications and microwave photonics. Research and experimentation in these areas are discussed. Included in the article are descriptions of the environmental models needed to characterize signal propagation effects with the associated measurement and compensation techniques.

CONCLUSION

APL has a deep history in air and missile defense tracing back to the founding of the Laboratory and the development of the VT fuze during World War II. Since then, new threat capabilities have continually forced advancements in our defense systems. In particular, the Aegis Weapon System, for which APL has made key contributions in naval anti-air warfare and ballistic missile defense, has served as the means to integrate these disparate missions and incorporate data from distant sensor sources. We now face new significant threats with A2/AD environments, hypersonic missiles, and large raids of attackers that may vary from sophisticated missiles to asymmetric drones. To counter these evolving challenges, APL is aggressively pursuing new technical solutions to build on the accomplishments of the US Navy and Missile Defense Agency.

REFERENCES

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[2]J. Mattis, *Summary of the 2018 National Defense Strategy of the United States of America: Sharpening the American Military's Competitive Edge*, US Department of Defense, Washington, DC, 2018.

[3]*2019 Missile Defense Review*, US Department of Defense, Washington, DC, 2019.

[4]*A Design for Maintaining Maritime Superiority*, Version 2.0, US Department of the Navy, Washington, DC, Dec. 2018.

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