Concept Design and Realization Branch—Part I: Guest Editors' Introduction

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ABSTRACT

The Concept Design and Realization Branch within APL's Research and Exploratory Development Department provides an array of engineering, design, and fabrication capabilities that broadly support the Laboratory's mission and sponsored work. It has been more than 20 years since these areas have been reviewed in this publication, and during that time, the Lab's ability to develop and build complex systems has advanced significantly. Computing power has exponentially advanced the enabling modeling, analyses, machine programming, and novel manufacturing methods—many of which were unimaginable 20 years ago. Electronics, sensing, artificial intelligence, and other technologies have merged and are increasingly embedded to create powerful automated tools. Today, the branch continues to serve the Lab with hardware design, mechanical and electrical fabrication, systems integration, and breakthrough manufacturing science that will benefit the programs and missions of the future. This issue, the first of two, describes examples of the wide-ranging work of the branch, highlighting how it directly contributes to APL's position as a unique resource to the nation.

INTRODUCTION

The Concept Design and Realization (CDR) Branch of APL's Research and Exploratory Development Department (REDD) is an enabling partner for projects throughout the Lab. For decades, the CDR Branch has offered essential capabilities—from modeling and analysis of multiscale systems to fabrication of one-of-a-kind prototypes and spacecraft—contributing to APL's success and trusted sponsor relationships. Its more than 200 staff members, including uniquely skilled machine operators and electronics technicians and multidisciplinary engineers and scientists, are embedded within projects across the Lab to develop innovative solutions to extraordinary challenges, fabricate and integrate complex systems, and lead pioneering research in manufacturing science.

This issue, the first of two issues dedicated to the work of this branch, illustrates the tremendous breadth and depth of these staff members' contributions. High-level capabilities of the branch can be grouped into three areas: (1) electrical and mechanical design, engineering, and analysis; (2) electronics fabrication; and (3) mechanical fabrication. The 37,300-square-foot electrical fabrication facility in Building 13 on the Lab's main campus encompasses printed wiring board fabrication, electronics assembly, and microelectronics fabrication. The mechanical fabrication facility in Building 15 on the main campus consists of 40,600 square feet and includes subtractive, additive, and hybrid manufacturing as well as engineered materials (composites, polymer molding, etc.). The design, engineering, and analysis teams are collocated in Building 201 on the South Campus with many of REDD's other technical and research-focused staff members and labs.

THE ARTICLES

The issue opens with "History of the Design and Realization Capabilities at APL," a discussion by Charles and Ramsburg of the long history of this branch, one that in fact is rooted in the earliest days of the Lab and its prototyping and demonstration of its first defining innovation, the VT fuze. While the fuze was novel in its design and ultimately game-changing in its impact on World War II, it was APL's ability to field fully working prototypes of the device that initially showed its effectiveness and convinced national and military leaders to invest in it on a large scale. Since then, the growth of APL's capabilities for prototyping have paralleled the growth of the Lab and the rapidly transforming technological landscape, enabling APL to continue generating countless system developments that have positively impacted the warfighter, the nation's security, and the world's understanding of our universe.

The collection of capabilities, facilities, equipment, and talent within the branch is quite unique among national laboratories and APL's peers, and the tight integration of these manufacturing technologies with the Lab's systems engineering–focused technical sectors is one of APL's greatest strengths. Collectively, they create a distinctive competence in developing products from initial ideas to field-ready systems and hardware. Several articles in this issue discuss these diverse end-to-end product development capabilities.

In "APL's Contributions to Stratospheric Ballooning for Space Science," Alvarez et al. explore the Lab's nearly 30 years of experience in the unique field of developing and deploying high-altitude balloons for scientific discovery. Working in close partnership with APL's Space Exploration Sector (SES), staff members from disciplines throughout the CDR Branch have been instrumental in engineering, fabricating, integrating, and operating these spectacular balloons from some of the most remote regions of the world, including Antarctica and the Arctic Circle region. Their contributions include systems for unprecedented pointing accuracy and stability that have enabled missions that would otherwise be impossible. In addition, they have engineered systems for avionics, power, software, command and control, ground support, systems engineering, integration, and testing. Working in the field, APL staff members integrate systems from other scientific partners, troubleshoot, and operate the balloons. These accomplishments have supported innovative space science missions in heliophysics, astrophysics, and planetary science at a fraction of the cost of traditional space missions.

Presley, Parker, and Brandt, in "From Design to Reality: Additive Manufacturing for Spaceflight," share the story of how seemingly impossible technical requirements were ultimately achieved by applying additive manufacturing to produce the Jovian Energetic Electrons (JoEE) instrument for the European Space Agency's JUpiter ICy moons Explorer, or JUICE. This instrument is an innovative electron particle spectrometer that uses additively manufactured collimators to map the processes responsible for making Jupiter the solar system's largest particle accelerator. When traditional manufacturing methods failed to produce a reliable and consistent result, the multidisciplinary team of mission engineers, manufacturing engineers, machinists, and inspectors brainstormed to achieve features and tolerances thought to be outside the reach of the current additive manufacturing state of the art, and a result that challenged the current thinking about the possibilities of the technology.

Activities in the discipline of manufacturing science permeate the branch, and APL breakthroughs in this area are increasingly enabling solutions to challenges at extraordinary small scales and in real-time monitoring of critical build processes.

In "Nanofabrication at APL: Novel Techniques to Deliver Innovative Devices," Currano et al. discuss a variety of advanced nanofabrication techniques being used to pattern nanoscale features on semiconductor and optical material substrates at scales so small they cannot be observed even with conventional optical microscopes. Applying these techniques on a wide variety of nontraditional substrate and film materials, including optical, phase-change, and superconducting materials, enables novel optical and electronic devices.

As previously discussed, additive manufacturing is having a disruptive effect on manufacturing, although it is not without major limitations and challenges that must be addressed to ultimately realize its full potential, especially in critical applications. Among those challenges is the need to detect, understand, and mitigate the defects that occur, as parts produced by this technology effectively involve the formation of new materials. In "Fusion of Novel Sensing Methods and Machine Learning to Solve Critical Challenges in Laser Additive Manufacturing," Storck et al. look at how in situ monitoring of additively manufactured builds using machine learning algorithms enables the detection of flaws in parts in real time, as they are being fabricated. Such qualitative data are critical in predicting how parts will perform in their intended use and provide a basis for the eventual development of live defect healing as parts are fabricated. In particular, this article highlights the powerful intersection of materials science, physics, machine learning, and advanced manufacturing.

Guided by its role as a university-affiliated research center, APL focuses on rapidly developing, prototyping, and demonstrating novel complex systems, and the CDR Branch collaborates with experts across the Lab to support this mission. In "Rapid Prototype Development and Demonstration of a Frequency-Multiplexed Phased-Array Antenna System," Gumas et al. discuss such a project that successfully evolved from an idea to a live airborne system demonstration in less than a year. This team developed a new type of digital beamforming phased-array antenna system that provides greater performance and functionality all while reducing size, weight, and power (SWaP) and overall complexity. In particular, this case study illustrates the breadth of technical skill sets that APL is able to apply to challenges. This multidisciplinary team—including experts in radio frequency (RF) system modeling and validation, RF hardware design prototyping and characterization, firmware development, electronics and mechanical prototyping, system integration, functional verification, and range and flight testing—enabled the agile, rapid, and cost-effective development and demonstration of this novel capability.

Modern engineering and systems development also rely heavily on computational modeling and analysis with the ability to rapidly iterate physical form, materials and composition, system inputs, and the interaction of components or constituents in nearly limitless combinations. Three articles in this issue detail such tools with thought-provoking examples of how each is used to assess and visualize the inherently complex relationships between system design and performance.

"Computational Engineering and Design Tools for Additive Manufacturing" by Carter et al. describes how APL employs an immense range of modeling, optimization, and finite element modeling software to unlock the true potential of additive manufacturing. Because additive manufacturing's selective deposition of material and energy enables the ability to produce new and novel geometries, designers and fabricators need new design software and validation methods to take full advantage of this emerging fabrication technology. By combining these additive manufacturing–specific computational engineering design tools with its diverse expertise in areas such as rapid material development, the Lab can fabricate novel components with unprecedented properties for its sponsors' unique missions.

Le et al., in "Atomic-Scale Modeling for Materials and Chemistry," look at how atomic and molecular modeling techniques have developed into a vibrant field of computational science, used to understand and predict materials properties and phenomena. Benefiting from decades of Moore's law growth in computer processing and algorithm and software development, APL researchers are now applying such methods to the most important problems in fields ranging from battery chemistry, drug design, and mechanics of materials to biocompatibility or catalysis. Density functional theory and molecular dynamics methods are discussed in detail, and several use case studies are presented. The authors also offer a glimpse into future advancements in this area, including integration with modeling methods at other scales and with artificial intelligence–enabled frameworks, to meet the next generation of sponsor challenges.

Lastly, Darragh et al. look at the advanced science of numerical prediction in "From Hospitals to Hurricanes: How APL Is Using Computational Fluid Dynamics to Inform the Future of Public Health and Safety." They detail the application of computational fluid dynamics to better understand two timely threats in the public health domain. The first application models and predicts the spread of aerosols in operating rooms in response to the coronavirus disease 2019 (COVID-19). The insight derived from this modeling will inform the design of next-generation operating rooms that enable better control of airborne contaminants. The second application focuses on modeling and evaluating the impacts of hurricanes by integrating numerical weather prediction and damage prediction modeling tools. The insight gained from these simulations allows for the evaluation of health care worker exposure and facilitates a greater understanding of the threat of severe storms as a consequence of climate change.

These and other modeling techniques accelerate development times and lower research costs by mitigating the need to physically build systems or gather data from real observations.

Given that much of this issue was developed during the COVID-19 pandemic, we would be remiss if we did not discuss the impact of this multiyear event on APL—and specifically on the work of the CDR Branch, where a great deal of hardware is produced and remote work opportunities are limited. Zinn et al. discuss this challenging time for the organization in "COVID-19 Impact on Fabrication and Design in APL's Concept Design and Realization Branch." They describe the broad efforts involving numerous functional areas of the Lab to modify work practices, schedules, and locations as well as safety protocols to protect the health and safety of APL staff members while maintaining demanding project schedules for some of the Lab's most critical work. In fact, the Double Asteroid Redirection Test (DART), one of the Lab's greatest recent successes, was largely built and executed during the pandemic, a true testament to staff members' mission focus and commitment to both sponsors and their teams. This article also highlights one positive consequence of the pandemic: despite the tremendously challenging and difficult time for the Lab and the entire nation, many of the highly effective tools for remote collaboration and communication adopted during the pandemic continue to be used today to the benefit of this expanding organization.

CONCLUSION

Throughout this issue are accounts and examples of how the work of REDD's CDR Branch benefits APL, its sponsors, and the nation. The advanced tools and facilities are a key contributor, but it is the tremendous and diverse team that ultimately makes these achievements possible. These staff members will continue to build on APL's rich history of fabricating and integrating complex systems and leading ground-breaking research in manufacturing science.

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