Prototyping

Increasing the Pace of Innovation

Capt. Richard Hencke, USN

> **Directing R&D money in order to build at least a few prototypes of systems the Pentagon knows it can't afford to buy in big quantities ... moves us forward technically. It keeps our industrial base healthy from a design perspective and it keeps our design teams together.**
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> **—Frank Kendall, Under Secretary of Defense for Acquisition, Technology and Logistics**
> **(American Institute for Aeronautics and Astronautics, Jan. 18, 2014)**

Prototyping has long been recognized as an effective tool for reducing technical risk throughout the development of complex weapons systems. A growing number of leaders in government and industry advocate that it can do so much more. Supporting their claims are recent studies suggesting prototyping can increase the pace and reduce the cost of developing complex systems, enable organizational cultural change, aid acquisition reform, advance the technical skills of the industrial base, and even deter rival nation-states from pursuing paths that threaten our national interests.

Prototyping's role in the capability development process appears to be changing, expanding from focused design tool to potentially paradigm-changing methodology. What once was just another trusted tool in the designer's toolbox has now blossomed into a collection of developmental and experimental activities that are maximizing the value of developing and working with intermediate forms (models or demonstrators).

A Risk Reduction Tool

For the last several decades, prototyping in the Department of Defense (DoD) has mostly been associated with the technical maturation of complex weapon systems. Increased interest in technical maturation prototyping followed the failures of many high-profile weapon system programs during the Cold War. The U.S. weapons development strategy at the time relied upon technical superiority to counter the Soviet Union's numerical advantage. The resulting pressure on the acquisition system to maintain a technological advantage encouraged heavy reliance on

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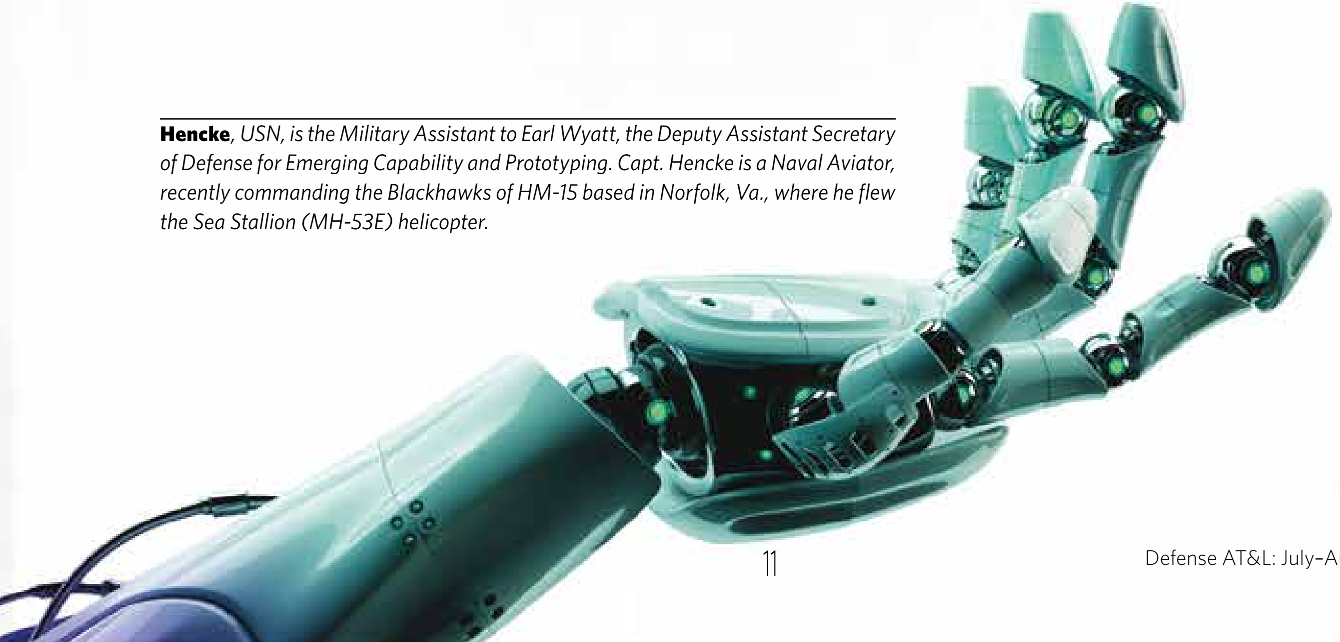


> **"Gentlemen, we have run out of money; now we have to think."**
>
> **—Winston Churchill**

nascent and untested technologies. Acquisition programs suffered lengthy delays as they struggled to mature cutting-edge technologies. Of those programs that eventually fielded, many would falter under battlefield conditions. The 1986 Packard Commission report, a widely cited blue ribbon commission appointed by President Reagan, strongly advocated for "building and testing prototype systems and subsystems before proceeding with full-scale development."

An Expanding Role

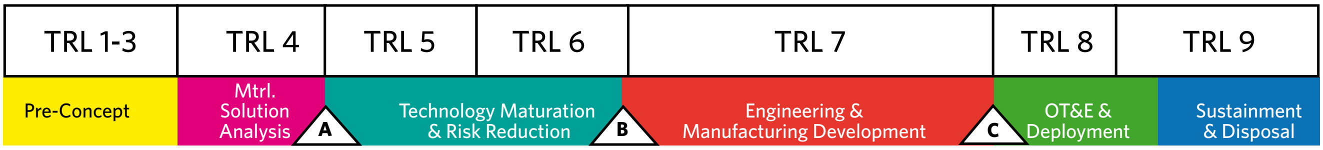
An early hint of the expanded uses of prototyping came in 1947 when Chuck Yeager broke the sound barrier in the Bell X-1 prototype. The feat ignited popular interest and advocacy for big budget prototyping efforts that showcased significant U.S. technical achievements. The X-plane and space programs not only provided the deep understanding of how to operate in the air and space domain (knowledge the United States would leverage for decades), they helped create a virtuous circle of technology development, inspiring a generation to become the future scientists and engineers that would lead the next wave of technical discovery.

John Young, as Under Secretary of Defense for Acquisition, Technology and Logistics (USD [AT&L]) in 2007, advocated yet another role for prototyping, that of a mechanism to enhance competition. He directed major acquisition programs to develop competing designs early in the development process. DoD's competitive prototyping program, according to a 2009 RAND Corp. study, has met with mixed results. The RAND study suggested other factors such as requirements creep, budget instability and technical maturity may be more significant factors to cost growth.

Today's tightening fiscal constraints and the globalization of a diverse and expanding array of threats (that include long-range missiles, sophisticated air defense systems, and chemical weapons) have combined to form a one-two punch that has left the DoD's acquisition system staggering. The acquisition system can no longer afford the variety of systems necessary to sustain a technical advantage across such a large threat landscape. Even without resource constraints, it is unclear if current acquisition processes can adapt products quickly enough to address rapidly evolving threats. Many well-resourced weapons programs show their age and impending obsolescence before the first production run.

There is some cause for optimism. Historically, periods of constrained resources have been marked by extraordinary creativity and innovation. Declining budgets and restrictive arms treaties following World War I coincided with the innovative development of naval air power. Despite or, as Churchill would have said, because of declining budgets, this period was marked by bursts of creativity and experimentation that steadily advanced the state of naval air power throughout the 1920s, eventually resulting in the carrier-based air power systems and concepts that proved so pivotal to Allied success in World War II.

Figure 1. Prototyping Instruments



Developmental Prototypes

- Demonstrate feasibility of an integrated capability.
- Provide evidence of overcoming specific technical risk barriers.
- Develop sufficiently detailed cost data to enable cost-capability trades.

Operational Prototypes

- Demonstrate military utility of integrated capability solutions.
- Demonstrate robust fabrication processes.
- Demonstrate performance in specific operational environments.
- Define form, fit, function and "ilities"—e.g., supportabiity.
- Enable business case analyses.

Figure 2. Prototyping Methodology

To sustain the technical advantage against our adversaries, we must again create an environment in which creative thinking is allowed to flourish and a risk-accepting culture encourages experimentation of new and unconventional ideas. In this environment, higher risk and more innovative prototypes are avidly pursued and honestly assessed, unlocking new insights that can lead to potentially game-changing solutions.

And with new rapid prototyping techniques compressing development cycle times, iterating to better solutions has never been faster. Paul MacCready, the designer responsible for winning the Kremer prize for human-powered flight, argued that the success of his aircraft, the Gossamer Condor, should not be attributed to inspired design but to an inspired design process. He manufactured the Condor to be quickly reconfigured after each cycle of build and test. Competing designers labored over their designs for a year or more, only to witness failure that would require another year of development before another test. The Gossamer Condor could be reconfigured so quickly that testing five designs in a single day was common.

Capability development cycles, traditionally measured in years and decades, will need to be measured in months if they are to outpace our adversaries. Rapid prototyping technologies and techniques are well-positioned to support the need for reduced development cycle times. A well-outfitted rapid prototyping lab contains all that is needed to produce new products in days to weeks. Computer Aided Design and Manufacturing software linked to Computer Numerically Controlled (CNC) machines quickly mill, cut and build up material components. Combined with Field Programmable Gate Array integrated circuits, these tools allow prototyping labs to quickly build up and rapidly modify complicated new prototypes.

The Naval Air System Command's (NAVAIR) Aircraft Prototype Systems Division (APSD) exemplifies the new breed of rapid prototyping labs. Outfitted with design tools and CNC machines, APSD responded to a request for updated flare dispenser pods for several helicopter models. In the case of the AH-1W, APSD completed all the design work and fabrication of the first prototype in-house, in just three weeks. APSD then leveraged NAVAIR's instrumentation and test facilities at Patuxent River and China Lake to flight-test their new prototypes. The results were highly refined designs that offered the program managers significant acquisition alternatives including "build-to-print" solicitations. Because the design work was completed at NAVAIR, smaller fabrication shops, which lacked the specialized design expertise, could compete for the production work.

A Refocus: From Rapid Fielding to Emerging Capability and Prototyping

Recognizing the benefits of prototyping, the current Under Secretary of Defense for Acquisition, Technology and Logistics directed the Assistant Secretary of Defense for Research and Engineering's (ASD[R&E]) Rapid Fielding office to expand its focus beyond developing fieldable prototypes to meet the immediate needs of warfighters at war, including developing less technically mature prototypes that can quickly explore new ideas. To support the change, the office recently changed its name from Rapid Fielding to Emerging Capability and Prototyping (EC&P).

ASD(R&E)'s EC&P office is uniquely suited to take on this expanded role. Skill sets developed under the pressures of war adapt well to the more strategic mission of developing agile, flexible weapon systems. The office cultivated a large and diverse network that includes warfighters in the combatant commands and in the field, academia and traditional and nontraditional solution providers. Their network is a well-spring of innovation they can now exploit for a wider range of prototyping activities.

The EC&P office's existing capability development methodology also supports their new role. The office mined their networks for solutions that fit a tiered set of criteria. The team first looked for existing solutions they could repurpose to meet the warfighter's need. Their second choice was to identify systems that could be quickly modified or be combined with other systems to take on a role perhaps never imagined by the original designers. Only after they exhausted their networks of extant systems and solutions did they consider development of a new system from whole cloth. EC&P's "repurpose, modify and combine" methodology is an early progenitor of the modular, plug-and-play architectures we will need in our future weapon systems. As persistent threats evolve and new threats appear, future weapons systems must have greater flexibility and agility—flexible enough to cover a wide range of missions and agile enough to quickly adapt to fast evolving threats. Creating agile and flexible systems will require open architectures and modular-minded designs. Prototyping plays an important role by testing and demonstrating open architectures, acting as a champion for true plug-and-play versatility.

Housing a prototyping shop inside ASD(R&E) has other benefits as well. ASD(R&E) maintains strong connections across the military, government and commercial labs. ASD(R&E)'s cognizance of military Service core missions and paradigms will ensure they do not duplicate Service efforts or impinge upon Service equities while still taking advantage of the best practices from each Service to satisfy joint and cross-cutting needs. Being ensconced in ASD(R&E) will also facilitate a strong connection to the Joint Staff, whose connection to all the combatant commands can help the new prototyping office identify hard warfighter problems that are both persistent and pervasive across the range of military operations for geographic and functional combatant commands.

Throughout Capability Development

To better manage prototyping activities, the new emerging capability and prototyping office is separating prototyping activities into two categories. Operational prototyping activities will closely replicate previous rapid fielding activities performed by the office. Operational prototypes can be expected to operate in the field for short periods and will incorporate form, fit and function into their design. Several of the system support considerations will also be assessed to help determine what aspects of the prototype will need to be matured for a follow-on program of record.

The second category, developmental prototyping, affords an opportunity to explore the operational and technical value of less mature weapon systems. Form, fit, function and life-cycle affordability are still considered in developmental prototyping but the focus is more on the prototype's ability to achieve useful military effects. Developmental prototyping allows for exploration of high-risk, potentially game-changing designs. Developmental prototyping can advance our technical understanding without necessarily transitioning to a program of record. Instead, tested and assessed developmental prototypes can be "put on the shelf," where they can just as easily be pulled off should the threat environment warrant further development. This put-on-the-shelf strategy will maximize scarce resources by allowing the development of a broad spectrum of threat mitigating technologies without incurring the cost of a major development program with a full production run.

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Prototyping activities are encroaching further and further to the left of the capability development timeline. Operational prototyping, a mainstay for risk reduction in systems nearing maturation, has been joined by developmental prototyping activities that explore less developed areas of the technical realm. The next step to the left is where problem definition and concept development reside. This step in the capability development process is so crucial because decisions made here drive most of the cost and resource requirements. Conceptual prototypes (e.g., mock-ups of systems, early prototypes and computer simulations) physically or visually represent early ideas and concepts, helping decision makers better understand the problem and reach agreement on an approach to solving it.

ASD(R&E) is considering steps to bring the prototyping culture into this conceptual realm. A construct is under consideration that will connect elements of the warfighting community with technologists and scientists through the use of live and virtual collaboration venues. These collaborations are intended to inform both the technology and requirements development communities. The initiative is still in its early development, but these new warfighter/technologist collaborations hold promise as a means of addressing some of the DoD's most challenging problems. By bringing together capability development stakeholders early to decompose and reframe our most challenging problems, these collaborations have the potential to identify new solutions using novel approaches.

Yes, Prototyping Can Do All That

The correct response to claims posed by the prototyping advocates is, "Yes, prototyping can do all that and more." When properly directed and executed, prototyping can support a broad range of capability development activities and strategic initiatives. A diverse prototyping portfolio of conceptual, developmental and operational prototyping activities can explore a wide swath of uncharted technical and conceptual territory, informing the development of new capabilities, stimulating design teams and maturing promising technologies that can ignite support at home while signaling to potential adversaries that fielded variants could be just around the corner.

Perhaps most important, a concerted focus on prototyping activities directed toward developing those critical enablers to innovation—open architectures, modular and reusable designs, and the early application of a rapid, iterative development cycle methodology—can help the DoD build the portfolio of agile and flexible systems it needs to outpace any adversary.

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