CSBA
Center for Strategic and Budgetary Assessments

LIVING WITHIN ONE'S MEANS: REVISITING DEFENSE ACQUISITION AND AFFORDABILITY

A CASE STUDY OF THE ARMY'S FUTURE VERTICAL LIFT PROGRAM

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ABOUT THE CENTER FOR STRATEGIC AND BUDGETARY ASSESSMENTS (CSBA)

The Center for Strategic and Budgetary Assessments is an independent, nonpartisan policy research institute established to promote innovative thinking and debate about national security strategy and investment options. CSBA's analysis focuses on key questions related to existing and emerging threats to U.S. national security, and its goal is to enable policymakers to make informed decisions on matters of strategy, security policy, and resource allocation.

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On March 24-25th, 2021, CSBA, in partnership with Army Futures Command (AFC), hosted a workshop to discuss challenges, approaches, and opportunities related to the Future Vertical Lift (FVL) programs. The workshop convened representatives from the FVL Cross-Functional Team (CFT), Program Executive Office (PEO) Aviation, other Army organizations, Office of Management and Budget (OMB), Congressional Research Service (CRS), other U.S. Services, the F-35 Joint Program Office (JPO), think tanks, private industry, and defense consultancies. The authors would like to express their appreciation to the workshop participants for their valuable insights, debate, and critique. The workshop was conducted under the Chatham House Rule.

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The views expressed here do not necessarily represent those of the Department of the Army, the FVL CFT, the Department of Defense, or the U.S. government.

Cover Graphic: Cover design by James Mersol. Helicopter photographs are courtesy of the U.S. Army, Bell Textron, and Sikorsky-Boeing. Background: Jessie Eastland "Anatomy of a Sunset," June 6, 2015, Creative Commons Attribution-ShareAlike 3.0.

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Executive Summary

Future Vertical Lift (FVL) is a force structure recapitalization effort to design and procure a family of rotary-wing platforms capable of operations in future highly contested environments. The Army's FVL is the leading edge of an effort that has identified the need for a rotary-wing Family of Systems (FoS) that can deliver five capability sets for joint use across the Services. Because of budgetary limitations and force modernization priorities, only two of the five capability sets are currently being pursued. The Center for Strategic and Budgetary Assessments (CSBA) prepared this study to introduce several strategies and considerations about FVL's affordability and contextualize the platform's development with previous rotary-wing platform programs.

The two capability sets for FVL are manifested in the Army's Future Attack Reconnaissance Aircraft (FARA) and the Future Long-Range Assault Aircraft (FLRAA), which will be the first new Army helicopters in more than a generation, as the Army has not fielded a new, clean-sheet design helicopter since the mid-1980s when the Apache was introduced. FVL is a major re-envisioning of the capabilities and platforms for the attack, reconnaissance, air assault, and medical evacuation (MEDEVAC) missions for ground combat in response to the return of Great Power competition and future operations in highly contested environments. FARA and FLRAA are not one-for-one replacements for the current Apache and Black Hawk helicopters. Rather, they are envisioned to be adaptable suites of capabilities centered on the scout and long-range air assault missions, able to both organically conduct these missions and enhance capabilities of other elements of the Army, Joint, and coalition forces. FARA and FLRAA are intended to penetrate, disintegrate, and exploit advanced enemy Integrated Air Defense Systems (IADS), enabling higher flow and survivability of follow-on legacy forces. If realized, this will be the most significant re-envisioning of the role for helicopters since the AirLand Battle operational concept in the last decade of the Cold War.

Pressures from modernization efforts across the Army and all of the Services, along with the budget environment for defense in the 2020s, along with eroding capability advantage against peer adversaries, are converging and promise to be challenging for the nascent FVL program. In June 2020, the GAO reported that cost changes to the DoD's 2019 portfolio of 85 major defense acquisition programs saw a 53.9% increase in their total estimated acquisition cost (in FY20$) since their first full program estimates. As such, the Army FVL has adopted affordability as one of its essential tenants and is using Modular Open Systems Architecture (MOSA) to develop FVL designs that enhance long-term affordability while pacing upgrades as needed to respond to advancing threats.

Affordability challenges to defense programs have recurred frequently over the past few decades, as leap-ahead technology programs did not fully succeed and Congress deferred procurement of new platforms and extended the lifespan of older systems past their usual limits. Previous changes to defense acquisition processes in an attempt to enhance affordability instead largely resulted in vendor-locked closed ecosystems with proprietary architectures.

Primary analytical and assessment tools of cost by analogy and historically derived parametric-based cost methods will need to be supplemented with insights from digital tools, although the respective weights of these different approaches are still unclear and will need to be revisited over time. Overall, the common rule of thumb cost assumption, which has almost become an axiomatic mantra for the defense acquisition community—that O&S costs make up approximately 70% of all program costs—may not apply to the FVL. For the U.S. rotary-wing programs historically, O&S has varied from 55% to 85% of program life cycle costs. Digital engineering and MOSA approaches may shift program cost ratios, where upfront investment may be necessary to realize cost avoidance later in a program life cycle. Therefore, the continued application of this rule of thumb metric may instead create a faulty assumption of increased overall lifecycle costs, despite prudent and targeted early investments.

In recognition of these trends, the Army views the MOSA approach for FVL as a critical enabler to reduce lifecycle costs and increase schedule predictability for the program. While MOSA proponents highlight cost savings, CSBA's assessment of MOSA is that it may be more likely to enhance opportunities to avoid cost growth, which promise significant lifecycle savings. In addition, MOSA approaches may hold costs down while diversifying opportunities for new technologies and subsystem solutions.

The risks of doing nothing must also be considered. If FARA or FLRAA programs are deferred or cut, the Army will incur a significant (on the order of tens of billions of dollars) recapitalization requirement as the Apache and Black Hawk reach the end of their 25-year Economic Useful Life in the 2030s. Operationally, while the Apache, Black Hawk, and Chinook are still being built on hot production lines, their baseline designs were developed 40 to 60 years ago. They will soon reach saturation with regard to space, weight, power, cooling, range, and speed. While advancements in miniaturization have mitigated many challenges for space and weight, advanced avionics, sensors, and effectors all continue to escalate simultaneous demand on platform power and cooling. The rotary-wing platforms in the force today are unlikely to have the growth margins to incorporate technologies and systems required to compete against peer/near-peer adversaries in a future high-end fight. With regard to Industrial Base risk, the acquisition of first FARA and FLRAA then the other

FVL FoS elements can rejuvenate and sustain an influx of human capital talent because of the opportunity from these new designs, creating opportunities for innovation and adoption of advanced manufacturing across the rotary-wing industrial base and supply chain in the United States, as well as key allies and partners.

The consideration of the importance of affordability is not to minimize the significant challenges confronting the FVL. The Army has and must continue to benefit from a thorough, realistic appraisal of the negative lessons learned from the previous Future Combat System (FCS) effort and the RAH-66 Comanche and ARH-70 Arapaho acquisition programs. Since 2009, the Army has been able to thoroughly and methodically de-risk and mature given technologies through Technology Demonstrators. The FVL must continue to avoid operational and program concepts that result in over-intricate system-of-systems interdependencies.

In many ways, affordability begins with simply living within one's means rather than optimistically estimating future cost savings that never materialize. This approach starts with realistic program cost estimates and program strategies. Realism and reducing uncertainty will increase confidence and trust in the program, which promises to foster a virtuous cycle of making progress and delivering. This cycle would contrast with the post-Cold War era of Transformation, where excessive optimism, high uncertainty, and lack of sober assessments led to technical and schedule delays and cost overruns. In turn, these overruns necessitated greater stakeholder scrutiny and inquiries that taxed program office staff at the very time they sought to solve their technical issues. Within this scheme of greater realism, a strategy of clearer and more frequent on-ramps for technology insertion and capability enhancement, along with a consistent demonstration of an open ecosystem approach—regardless of whether it is government-driven or industry prime-driven is a key aspect. Open ecosystems should be incentivized and likewise, closed ecosystems should be disincentivized, based on penalties from the resulting underperformance of those that are slow to adapt and unable to accommodate new technologies and approaches.

By allowing for increased clarity and adaptability, FVL can be one of the first major programs to achieve this virtuous cycle and break the common trend of substantial cost growth in defense acquisition programs. Despite some hopes, digital approaches are unlikely to achieve substantial cost savings. Instead, most importantly, digital approaches in defense acquisition provide a tool set to help reduce uncertainty and iterate and field capabilities more quickly. Instead of envisioning digital approaches as a means to reach new heights of affordability for defense programs, the best result from their use will be to avoid the massive cost growth that has plagued defense acquisition programs in the post-Cold War era. Applying this approach, if the Army can live within well-estimated means, stick to their plan, and pace advancing threats, FVL could become one of the most successful defense acquisition programs of the 21st Century.

CHAPTER 1

Introduction

The Future Vertical Lift (FVL) initiative represents one of the latest attempts by the Department of Defense to replace legacy assets with more capable platforms. Specifically, FVL aims to deliver a family of rotorcraft and associated systems that can operate in highly contested environments. Like any modernization effort, however, FVL raises questions of feasibility and affordability—particularly given the Army's mixed track record when it comes to procuring new vertical lift systems. FVL has tried to address these concerns in a variety of ways, such as using a Modular Open Systems Architecture (MOSA) approach to design and a "Family of Systems" acquisition strategy, which are meant to enhance commonality, increase adaptability, and reduce programmatic risk over the lifecycle of FVL's constituent programs. This chapter introduces these programs, reviews their roles within the broader set of U.S. Army modernization initiatives, and discusses key features of the FVL effort that are intended to avoid previous modernization pitfalls.

FVL and the Army's "31 +4" Modernization

FVL is an Army-led Joint effort to produce an ecosystem of air assault and aviation capabilities, with the nucleus projected to be a family of rotorcraft.[1] This effort represents the most significant update to the attack, reconnaissance, air assault, and medical evacuation (MEDEVAC) missions for ground combat since the Army's AirLand Battle operational concept during the late Cold War.[2] The FVL initiative intends to produce the first entirely

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[1] Although the Army is leading the FVL effort, the Air Force, Navy, Marine Corps, Special Operations Command, and Coast Guard are each participating, and have each been a part of the requirements definition process. Nevertheless, the Army is the lead Service for the FVL, and the two rotorcraft concepts being developed at present are intended mainly to meet Army needs.

[2] The resources provided by the Vertical Flight Society are the most comprehensive non-government information source publicly available on the Future Vertical Lift program. For more documents and material on the future vertical lift program, see "Future Vertical Lift," *Vertical Flight Society*, https://vtol.org/what-we-do/advocacy/future-vertical-lift.

new Army helicopters in more than a generation.[3] Although the Apache attack helicopter, Black Hawk utility helicopter, and Chinook heavy-lift helicopter all remain in production, each was designed decades ago. And although modernization efforts have upgraded their avionics and mission systems, the margins remaining in these designs are quickly reaching their limits in terms of power, cooling, space, and weight.

Proposed FVL rotary-wing platforms will have greater speed, range, endurance, and payload than current Army helicopters – necessary attributes to operate in future high-threat environments. Specifically, Integrated Air Defense Systems (IADS) pose a major threat to rotary-wing aircraft. For example, in recent conflicts between Ukrainian and Russian forces in the Donbas and between Azeri and Armenian forces in Nagorno-Karabakh, there were significant rotary-wing losses during initial clashes before tactics could be modified and countermeasures developed—or before rotary-wing forces were simply withdrawn from high threat areas.[4] The FVL effort intends to develop platforms that can penetrate advanced IADS, destroy them, and then conduct exploitation operations. That, in turn, would enable fleets of legacy rotary-wing assets to mass and maneuver with less risk.

Notably, FVL is but one part of a wider Army plan to modernize for Multi-Domain Operations (MDO) by investing research and development dollars in six key areas. Known as the "Big Six," they are: Future Vertical Lift, Long-Range Precision Fires, Air and Missile Defense, Next Generation of Combat Vehicles, Army Network, and Soldier Lethality. The "Big Six," managed by Army Futures Command, consist of 31 discrete efforts (many are not yet formally programs) intended to achieve the Army's vision of MDO.[5] The Rapid Capabilities & Critical Technologies Office runs four other efforts, including hypersonic weapons and high-energy lasers. Together, this suite of modernization initiatives is known as the "31 + 4".

FVL History

The FVL effort grew out of a 2008 Secretary of Defense directive to examine a Joint approach to future rotorcraft and began one year later with a DoD directive to pursue a Joint rotorcraft recapitalization effort. Over the next four years, the US Army Aviation Center of Excellence (USAACE) studied Joint capability needs. No doubt influenced by the cancellations of the Future Combat System (FCS) effort, RAH-66 Comanche, and ARH-70 ("Arapaho") helicopter acquisitions, FVL program officials have sought to develop the FVL

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[3] With the cancellation of the RAH-66 Comanche and ARH-70 the Army has not fielded a new, clean-sheet design helicopter since the mid-1980s, when the Apache was introduced. The design concept for what would become the Apache was initiated in 1972.

[4] There were also rotary-wing losses in recent conflicts in Syria, Iraq and Afghanistan. However, it is more difficult to draw lessons from them because reasons for those losses varied greatly because of the duration of the conflicts. Adverse weather conditions and accidents were factors in a large portion of rotary-wing losses in those conflicts.

[5] "2019 Army Modernization Strategy: Investing in the Future," *Army Futures Command*, October 17, 2019, https://www.army.mil/e2/c/downloads/567887.pdf

family of systems in a measured, rational way to minimize program risk, avoid unrealistic requirements, and work within the reality of limited budgets.

As part of this strategy, the Services commissioned industry to develop technology demonstrators as part of a Joint Multi-Role Technology Demonstrator (JMR TD) effort. In 2011, the Army Aviation and Missile Research, Development and Engineering Center (AMRDEC) awarded four $4-5 million JMR TD Configuration Trades and Analysis (CTA) contracts to industry. The JMR TD CTA contracts were awarded to AVX Aircraft Company to test a compound coaxial helicopter, Bell Boeing for a more capable tiltrotor, Boeing for edgewise and compound helicopters, and Sikorsky Aircraft for conventional and compound helicopters and also tiltrotors. These studies were completed in late 2012.

The following April, the Joint Requirements Oversite Council (JROC) validated the FVL Family of Systems (FoS) Initial Capabilities Document (ICD). In 2014, staffers from all of the Services reviewed mission-specific Concepts of Operation (CONOPS) for the "FVL-Medium" mission set. In subsequent years, the Joint Staffs reviewed and approved CONOPs for the "Light" and "Heavy" rotorcraft mission sets. The net result of these efforts is the currently envisioned FVL FoS encompassing five capability sets (CS) that include a range of missions.

TABLE 1: MISSION CAPABILITY SETS FOR THE FUTURE ROTARY-WING VARIANTS

<table>
<tr><th>CS #1 (FARA)</th><th>CS #2</th><th>CS #3 (FLRAA)</th><th>CS #4</th><th>CS #5</th></tr>
<tr><td>Light</td><td colspan="3">Medium</td><td>Heavy</td></tr>
<tr><td colspan="5">Common Components: Cockpit—FACE/JCA—Training—Requirements—Reduced overhead—Mission flexibility Sustaining—Maintaining—Repair parts and components—Aerial refuel</td></tr>
<tr><td colspan="5">MISSIONS</td></tr>
<tr><td colspan="2">Reconnaissance</td><td colspan="3"></td></tr>
<tr><td colspan="2">Security</td><td colspan="3"></td></tr>
<tr><td colspan="4">Urban assault</td><td></td></tr>
<tr><td colspan="3">CAS/attack</td><td colspan="2"></td></tr>
<tr><td colspan="2"></td><td colspan="3">Air assault</td></tr>
<tr><td colspan="2"></td><td colspan="3">Amphibious assault</td></tr>
<tr><td colspan="2"></td><td colspan="3">HA/DR</td></tr>
<tr><td colspan="2"></td><td colspan="3">Tactical resupply</td></tr>
<tr><td></td><td colspan="2">SuW/ASW/MCM</td><td colspan="2"></td></tr>
<tr><td colspan="5">DIRECT ACTION</td></tr>
<tr><td colspan="5">MARITIME INTERDICTION OPS</td></tr>
<tr><td colspan="5">MEDEVAC</td></tr>
<tr><td></td><td colspan="4">NEO</td></tr>
<tr><td></td><td colspan="4">CSAR</td></tr>
<tr><td colspan="4"></td><td>MCM</td></tr>
<tr><td colspan="2"></td><td colspan="3">Aerial refuel donor</td></tr>
<tr><td></td><td>Rotary-wing intercept</td><td colspan="3"></td></tr>
<tr><td></td><td>Search and rescue</td><td colspan="3"></td></tr>
<tr><td></td><td>Counterdrug</td><td colspan="3"></td></tr>
</table>

Source: Authors, derived from RAND data

Performance parameters were also developed for the respective Capability Sets / Missions. Because of budgetary limitations and force modernization priorities, only two of the five capability sets are currently being pursued. These are the Future Attack Reconnaissance Aircraft (FARA) (CS #1) and the Future Long-Range Assault Aircraft (FLRAA) (CS #3).[6]

It should be stressed that FARA and FLRAA are not one-for-one replacements for the Apache and Black Hawk: the current principal rotary-wing platforms for air assault missions. In fact, Army legacy helicopters and the FVL FoS will operate concurrently for years to come. Rather, FARA and FLRAA are intended to penetrate and destroy advanced defense systems. Legacy systems are intended to help exploit gaps in adversary defense in follow-one operations. Performance characteristics for legacy helicopter assets are provided for comparison. Note that the FVL FoS have significantly greater desired speeds and ranges than current Army helicopters. Greater speed and range have been identified as key characteristics necessary for successfully operating in future projected high-end adversary environments, particularly in the vast Indo-Pacific region.

TABLE 2: KEY PERFORMANCE PARAMETERS ACROSS CAPABILITY SETS FOR FUTURE ROTARY-WING VARIANTS

	CS #1 (FARA)	**CS #2**	**CS #3 (FLRAA)**	**CS #4**	**CS #5**
	Desired Range of Performance Parameters: Low (Threshold) – High (Objective)				
Speed (knots)	180-250	170-270	270-350	250-300	270-350
Radius (nm)	170-229	300-437	300-450	324-420	750-1,200
Passengers	6	8-10	10-12	24-32	45-54
Internal Payload (lbs.)	1,200-2,000	3,500-5,500		12,000-20,000	24,000-30,000
External Payload (lbs.)	n/a	6,000-8,000		15,000-20,000	30,000+

Source: Authors, derived from RAND data

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[6] CS #1, CS #3, and CS # 4 roughly correspond to the Army's light reconnaissance to medium/heavy air assault and tactical resupply missions, which are currently carried out by the Apache, Black Hawk, and Chinook, respectively. CS #2 and CS #5 roughly correspond to the U.S. Navy and Marine Corps missions currently carried out by the SH-60 Seahawk and CH-53 Sea Stallion, respectively. Note that there is considerable overlap in mission sets and performance parameters across the five Capability Sets. This convergence is understandable in that many of the Services' helicopters stem from the same parent design features. For instance, the Seahawk is a Black Hawk derivative, and the Air Force's MH-53 Pave Low is derived from the CH-53. Only CS #2 and CS #5 are currently envisioned to have some unique missions. CS #2 is the only one to have Rotary-wing Intercept, Search and Rescue and Counterdrug missions. CS #5 is intended to conduct Mine Countermeasures (MCM).

TABLE 3: KEY PERFORMANCE PARAMETERS OF ARMY HELICOPTERS

	OH-58A Kiowa	AH-64A/D Apache7	UH-60M Black Hawk[8]	CH-47F Chinook[9]
Speed (knots)	125	150+	~160	170
Radius (nm)	140	~250	~320	200 (combat) ~1,200 (ferry)
Passengers	6	n/a	12	33-55
Payload (lbs.)	2,000	n/a	9,000	24,000

Source: Author. Note that the recently retired Kiowa is shown for comparison to FARA.

Elements of the FVL Family of Systems

Future Long-Range Assault Aircraft (FLRAA)[10]

The FLRAA program is intended to provide the Army with a fast, long-range squad carrier with the performance parameters listed in CS #3. In the near term, it will augment the capabilities of the Black Hawk, including special operations, MEDEVAC, and tactical assault.[11] Current Army plans call for procurement of the Black Hawk to end in 2035, overlapping with FLRAA, which the Army hopes to procure beginning in 2030.

FLRAA development has benefitted from the JMR TD effort, with multiple companies demonstrating various technologies. The two remaining competitors in the FLRAA competition are Bell and a Sikorsky-Boeing partnership (although other companies are still active in demonstrating specific subcomponents.) In 2020, both companies were awarded Phase 1 contracts to further test their respective JMR TD aircraft. Competitive demonstration and risk reduction efforts on the Sikorsky-Boeing Defiant X and Bell V-280 Valor will help optimize the respective designs and refine the Army's ultimate FLRAA requirements and acquisition approach.

In March 2021, the Army announced Bell and Sikorsky-Boeing were entering the second phase of FLRAA competitive demonstration and risk reduction (CD&RR). Phase II calls for Bell and the Sikorsky-Boeing team to begin the preliminary designs of major FLRAA subsystems and the entire weapons system, in parallel with the programmatic source selection activities, with a downselect to a single team in 2022. The Phase II work also supports

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[7] For more technical details about the AH-64 Apache, see "AH-64 Apache," *Boeing*, https://www.boeing.com/defense/ah-64-apache/#/technical-specifications

[8] For more details about the Black Hawk, see "Black Hawk: Best-in-Class Multi-Mission Performer," *Lockheed Martin*, https://www.lockheedmartin.com/en-us/products/sikorsky-black-hawk-helicopter.html

[9] For more details about the Chinook, see "H-47 Chinook," *Boeing*, https://www.boeing.com/defense/ch-47-chinook/

[10] "Future Vertical Lift," *Vertical Flight Society*, https://vtol.org/what-we-do/advocacy/future-vertical-lift.

[11] Mandy Mayfield, "Army Powering Through with Future Vertical Lift Programs", *National Defense – NDIA's Business & Technology Magazine*, April 2, 2021

preliminary analysis of requirements for Special Operations Command, as well as the medevac mission and exportability features. First Unit Equipped (FUE) is then anticipated for 2030.

FIGURE 1: SIKORSKY-BOEING DEFIANT X

Photo courtesy of Sikorsky-Boeing.

FIGURE 2: BELL V-280 VALOR

Photo courtesy of Bell Textron.

Future Attack Reconnaissance Aircraft (FARA)

FARA is an Army-led initiative to design, develop, and deliver the preeminent attack reconnaissance aircraft for Army Combat Aviation Brigades and the Joint Force. FARA is the Army's response to the lack of critical capability to conduct armed reconnaissance, light attack, and security in operations against peer and near-peer adversaries with improved stand-off and lethality. With the retirement of the Kiowa, the Apache has taken up the Army's scouting role, even though it was optimized for the attack role. FARA is not an Apache replacement, but will be the principal system to assume this scouting role as a solution set to achieve CS#1, allowing Apache to focus on attack missions. The Army plans to end Apache procurement in 2025 and field FARA in 2030.

After an initial phase containing five competing designs, in March 2020, the FARA design concepts offered by Lockheed Martin-Sikorsky and Bell were selected for the next phase of competition. Sikorsky's offering, the Raider X, is a single-engine, compound helicopter with two rigid, coaxial rotors and one pusher propeller. Bell has proposed the Model 360 Invictus as its FARA candidate. In 2021 and into 2022, Bell and Sikorsky will build prototypes for the next stage of the design competition. Flight testing for the prototypes is anticipated in 2023, then leading to downselect.

FIGURE 3: SIKORSKY'S RAIDER X

Photo courtesy of Sikorsky/Lockheed Martin.

FIGURE 4: BELL'S MODEL 360 INVICTUS

Photo courtesy of Bell Textron.

Future Unmanned Aircraft System (FUAS)

The Army is also exploring ways to maximize the effectiveness of future manned platforms by using unmanned systems, including organic systems hosted by FARA and FLRAA or offboard systems that operate alongside them. These supporting capabilities are intended to extend the range or persistence of Intelligence, Surveillance, Reconnaissance, and Targeting (ISRT), enable longer-range precision fires, elicit adversary responses that can be exploited, and contribute to multi-axis attack strategies. For instance, when it comes to the threat posed by advanced IADS, unmanned systems could conduct active or passive Detection, Identification, Location, and Reporting (DILR) across multiple spectrums, including electro-optical, infrared, and radio frequencies. They might also employ electronic warfare or cyber effects. Finally, they could deploy decoys to spoof adversary IADS and make targeting FARA and FLRAA more difficult.[12]

Two programs are underway as part of the FVL Family of Systems to realize this vision: Future Unmanned Aircraft System (FUAS) and Air-Launched Effects (ALE). The Army is currently using the MQ-1C Gray Eagle Unmanned Aircraft System (UAS) as a surrogate for the FUAS, supporting continued experimentation and informing future requirements

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[12] Jared Keller, "The Army Wants a Drone Swarm to Back Up its Next-Generation Helicopters Against Enemy Air Defenses," *Task and Purpose*, August 17, 2020, https://taskandpurpose.com/news/army-drone-swarm-air-launched-effects/

efforts. Multiple types of ALEs—large, medium, and small—are being considered and are under continued development.[13]

FIGURE 5: RQ-7B SHADOW

Photo courtesy of United States Army Alaska (USARAK).

FIGURE 6: MQ-1C GRAY EAGLE UNMANNED AIRCRAFT SYSTEM (UAS) AS A SURROGATE FOR THE FUAS

Photo courtesy of the United States Army Acquisition Center.

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[13] "Air Launched Effects,"*U.S. Army PEO Aviation*, August 21, 2020, https://www.army.mil/article/238407/air_launched_effects_ale

FIGURE 7: AIR-LAUNCHED EFFECTS AIR VEHICLE

Photo courtesy of the U.S. Army Program Executive Office – Aviation.

Modular Open Systems Architecture (MOSA)

An essential part of the FVL effort is the mission systems integration of a wide variety of weapons and effectors across the FVL FoS. The Army intends to accomplish this with a Modular Open System Architecture (MOSA) approach and sees such an approach as the key to delivering capability integrated across the FVL FoS. The Army is also working to harmonize the various MOSA options that have developed and matured over the years, including: Army Common Operating Environment (COE), C5ISR/EW Modular Open Suite of Standards (CMOSS), Future Air-Borne Capability Environment (FACE), Integrated Sensor Architecture (ISA), Sensor Open Systems Architecture (SOSA), and Vehicle Integration for C4ISR/EW Interoperability (VICTORY)[14]. Additional approaches, such as the Army adopting the Universal Armaments Interface (UAI), can also help further these objectives.[15]

The Army envisions MOSA approaches to use shared design standards and common interfaces to support technology insertion for system and component upgrades. This framework includes a standardized cockpit, FACE/JCA software design standards, training, repair parts, and components. Proponents hope that

> MOSA is not only cost-effective but allows for more rapid and proactive platform updates and optimizations, deters vendor lock, and allows for industry-wide advancements. This

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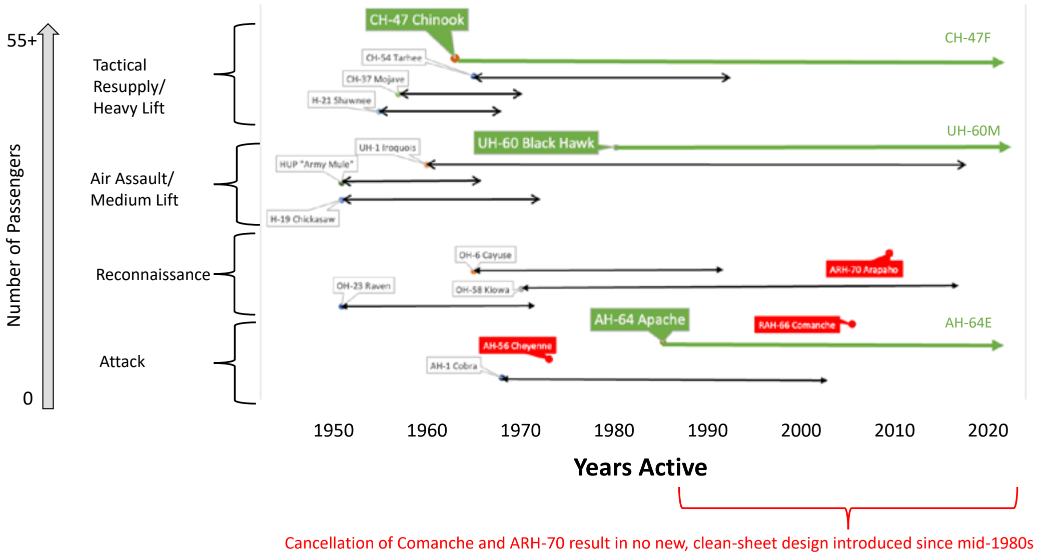
[14] Sydney J. Freedberg, Jr., "Army Seeks Open Architecture for All Air & Ground Systems: Jette", *Breaking Defense*, October 14, 2020, available at https://breakingdefense.com/2020/10/army-seeks-open-architecture-for-all-air-ground-systems-jette/

[15] For example, see Oren Edwards, "Universal Armament Interface," available at https://www.iqpc.com/media/6729/4428.pdf

> effort means a truly best–in–class FVL ecosystem becomes available to the defense community, and it is constantly adapting to an everchanging, connected battlespace.[16]

The Army forecasts that such an approach will reduce overhead, enhance mission flexibility, and reduce sustainment and maintenance costs. In addition, such an approach is intended to preserve opportunities for future competition and improve interoperability throughout the FVL ecosystem across the Army, the joint force, and coalition forces.[17] MOSA approaches will enable some international customers and operators to customize for operational specific needs and local defense industrial base considerations.

FIGURE 8: U.S. ARMY HELICOPTERS, 1950-2020



Cancellation of Comanche and ARH-70 result in no new, clean-sheet design introduced since mid-1980s

Credit: Authors. Canceled acquisition programs are in red, active helicopters are in green, and since-retired helicopters are in black. No new, clean-sheet design has been introduced since the mid-1980s, but there have been significant upgrades to legacy helicopters. The latest model/incremental upgrade is shown for active helicopters in 2020. Helicopter missions are shown as originally intended. Since the retirement of the Kiowa, the Apache has assumed the reconnaissance mission in addition to its original attack mission.

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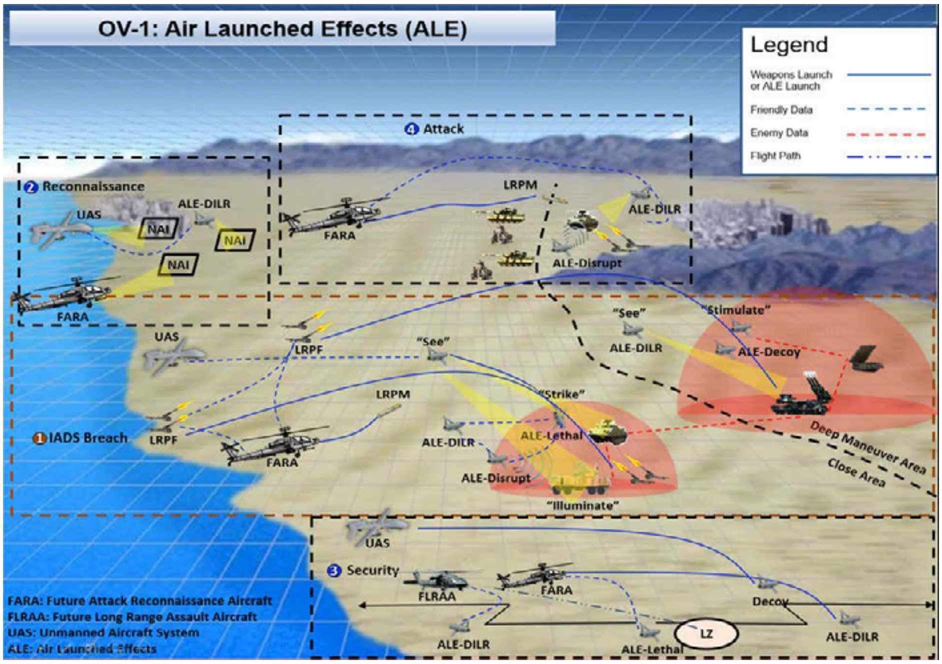
16 Chelsea Barone, "Future-Proofing FVL Efforts with the Power of MOSA", *The Modern Battlespace*, April 16, 2021. https://modernbattlespace.com/2021/04/16/future-proofing-fvl-efforts-power-mosa/#.YM3vTS1hodU

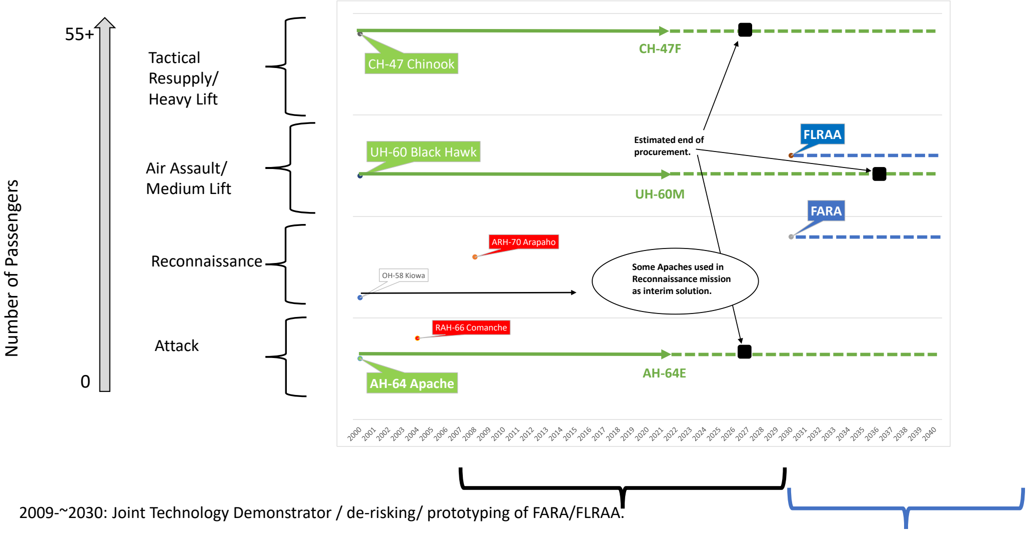
17 Defense Standardization Program, "What is MOSA", *Defense Logistics Agency*, available at https://www.dsp.dla.mil/Programs/MOSA/; Deputy Director for Engineering, Modular Open Systems Approach (MOSA): Reference Frameworks in Defense Acquisition Programs, Office of the Undersecretary for Defense for Research and Engineering, Director of Defense Research and Engineering for Advanced Capabilities, May 2020, available at https://ac.cto.mil/wp-content/uploads/2020/06/MOSA-Ref-Frame-May2020.pdf and"Systems Engineering: Modular Open Systems Approach", AcqNotes, updated June 14, 2021, available at https://acqnotes.com/acqnote/careerfields/modular-open-systems-approach

FIGURE 9: U.S. ARMY FUTURE BATTLEFIELD CONCEPT USING THE FVL FAMILY OF SYSTEMS



Credit: U.S. Army, Image accessed from Joseph Trevithick, "The Army Has Unveiled its Plan for Swarms of Electronic Warfare Enabled Air-Launched Drones," *The Drive*, August 16, 2020, https://www.thedrive.com/the-war-zone/35726/the-army-has-unveiled-its-plan-for-swarms-of-electronic-warfare-enabled-air-launched-drones

FIGURE 10: U.S. ARMY HELICOPTER FORCE STRUCTURE TRANSITION



2009-~2030: Joint Technology Demonstrator / de-risking/ prototyping of FARA/FLRAA.

2030: Projected timeframe when Apache, FARA, Black Hawk & FLRAA begin concurrent active service. Unknown when Apache / Black Hawk will leave service.

Credit: Authors. Latest model / incremental upgrade shown for active helicopters in 2020. Canceled acquisition programs are in red, active helicopters are in green, since-retired helicopters are in black, and projected programs are in blue.

CHAPTER 2

Lessons from the Past

The Army has been procuring and operating helicopters since World War II. Yet, its recent helicopter design and acquisition experience is limited given that two previous post-Cold War attempts – the RAH-66 Comanche and ARH-70 “Arapaho” – ended in cancellation. Nevertheless, its earlier history can be mined for valuable lessons, drawing on both failures (such as the AH-56 Cheyenne attack helicopter) and successes (such as the AH-64 Apache attack helicopter).[18]

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[18] As noted, the Cheyenne was selected because it is the most well documented of the Army’s helicopter acquisition programs. There is much less open-source information regarding the Comanche and Arapaho programs.

TABLE 4: U.S. ARMY HELICOPTERS

	Role	Designation	Name	Approx. Operational Span	Approx. # Built	Manufacturer
LIGHT	Multipurpose light	OH-23	Raven	1950– ~1970s	2000	Hiller
	Light Observation/ Utility	OH-6	Cayuse	1966-~1990s	1420	Hughes
	Observation/scout	OH-58	Kiowa	1969– ~2015	2200	Bell
	Armed reconnaissance	ARH-70	Arapaho	Canceled 2008	4	Bell
ATTACK	Attack	AH-1	Cobra	1967-2001	1116	Bell / Textron
	Attack	AH-56	Cheyenne	Canceled 1972	10	Lockheed
	Reconnaissance and attack	RAH-66	Comanche	Canceled 2004	5	Boeing/ Sikorsky
	Attack	**AH-64**	**Apache**	**1984-in service**	**~1200**	**Hughes**
MEDIUM LIFT	Utility	HUP	"Army Mule"	1949–1964	339	Piasecki
	Utility	H-19	Chickasaw	1950– ~1970s	1102	Sikorsky
	Utility	UH-1	Iroquois	1959–2016	16000	Bell
	Utility	**UH-60**	**Black Hawk**	**1979-in service**	**2700+**	**Sikorsky**
HEAVY LIFT	Cargo	H-21	Shawnee	1954–1967	707	Piasecki
	Assault Transport	CH-37	Mojave	1956–1969	153	Sikorsky
	Heavy-lift cargo	CH-54	Tarhe	1964–1991	105	Sikorsky
	Transport	**CH-47**	**Chinook**	**1962-in service**	**1180**	**Boeing**

Credit: Authors Note: Shading indicates helicopters in active service. The Apache, Black Hawk, and Chinook have hot production lines. Base models shown, although many have received significant upgrades over the decades.

AH-56 Cheyenne[19]

In 1962, the Cheyenne was the Army's first attempt at developing a clean-sheet Attack Helicopter rather than modifying existing Army helicopters or adapting a commercial variation. In 1972, however, it became the first high-profile cancellation for Army helicopter acquisition after a decade of development.

The Cheyenne program was canceled for several reasons. The first reason was a lack of clarity regarding mission needs. Early on, the Army was unsure if it wanted a helicopter with conventional performance or if it should pursue a design that pushed the state of the art. This uncertainty stemmed from an early lack of clarity regarding its mission. At first, the Cheyenne was to perform a basic escort mission. As U.S. involvement in Vietnam escalated, the UH-1 Iroquois (aka "the Huey") was modified to act as a gunship and armed escort and later upgraded as the Cobra gunship. This shift introduced institutional tension between

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[19] This section summarizes findings from "An Abridged History of the Army Attack Helicopter Program," *Office of the Assistant Vice Chief of Staff (Army) Washington DC*, October 29, 1973, https://apps.dtic.mil/sti/pdfs/AD1121533.pdf

proponents of the Iroquois/Cobra as adequate and those who pushed for the Cheyenne. With the development of the TOW missile and the emergence of an anti-armor capability, the Army began to develop new CONOPS. However, the Cheyenne requirements initially based on the escort mission were not modified when the Army's primary mission requirement shifted to an anti-armor mission.

In addition, the Cheyenne program suffered from personnel problems and unclear lines of authority for most of its existence. The original program manager for such a high-profile project was a Lieutenant Colonel, whose program office was located at Army Material Command from 1962-1969. It moved to the hub of Army aviation acquisition, AVSCOM, only in 1969. The program office had trouble attracting qualified acquisition specialists and personnel with appropriate technical qualifications to perform program oversight early on. The number of billets allotted to the program was wholly inadequate, and early on, these few billets could not be fully filled. Later, when the program hit technical roadblocks, DoD added a second management oversight structure that confused lines of authority.

FIGURE 11: AH-56 CHEYENNE

Photo courtesy of William Pretrina.

Perhaps not surprisingly, these personnel conditions contributed to a flawed acquisition strategy and poor program execution. The contractor selected to build the Cheyenne had no prior helicopter experience, leading them to pursue a concurrent testing and production strategy and develop a program schedule based on calendar dates rather than passing desired milestones. As a result, design flaws and technical feasibility problems were not discovered in time.

Finally, DoD stakeholders added requirements late in the development process to make the helicopter appear highly capable, exacerbating all of the previously discussed flaws. Stakeholders saw these added requirements as an effective strategy to differentiate it from the Iroquois/Cobra in order to secure resources. DoD openly acknowledged that it had added the requirements "to show clear need for the aircraft in a sophisticated environment in order to assure funding."[20] However, it did not analyze how these added requirements would affect technical feasibility, development times, or costs. Instead, the cost was based on extremely optimistic assumptions.

AH-64 Apache[21]

One factor that contributed to the cancellation of the Cheyenne in 1972 – namely, North Vietnam's use of armor supported by highly capable air defense systems to conduct offensive operations in South Vietnam—was also the genesis of the Apache. For much of the war, the North Vietnamese had favored Viet Cong guerilla tactics because they were no match in a head-to-head fight against the U.S. military.[22] The shift to conventional operations in 1972 stemmed from greatly reduced U.S. force levels and the decision to turn over most ground operations to the South Vietnamese. Thus, when the South Vietnamese moved into Laos in force in February 1972 (Operation Lam Son 719), they were surprised by the North Vietnamese, who employed conventional weapons and dealt the South Vietnamese serious losses. In response, the United States sought to relieve its allies and was immediately confronted by "mid-intensity conflict" levels of air defense. Army helicopter losses skyrocketed, with rates of 1 out of every 500 sorties. In response, Army helicopter pilots adapted by resorting to extreme low-level flying to hide among the terrain.

The following month, the North Vietnamese Army (NVA) launched the Easter Offensive into South Vietnam. The NVA besieged An Loc for four months. American and Army of the Republic of Vietnam (ARVN) air forces attempting to break the siege faced a complex, multilayered defense. During the siege of An Loc, a tube-launched, optically tracked, wire-guided TOW-missile-equipped COBRA recorded the first tank kill by a helicopter. In response, the Army had to improvise:

> One key to success at An Loc was effective, Joint/Combined aerial fires. Those fires created successive, lethal, layers of defense. Navy, Air Force, and VNAF attack aircraft bombed NVA forces as they massed. These attacks reduced the NVA forces able to enter the city. NVA entering An Loc then suffered from Cobras working with Air Force AC-130 and AC-119K gunships. The situation became so desperate that B-52 strikes were ordered on staging areas very close to An Loc. Skilled, coordinated, direct, aerial fires were vital as NVA forces closed

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[20] Interestingly, sometimes funding is more easily secured by underselling a capability. In the 1920s and early 1930s, the Army Air Corps advertised its bombers as purely for coastal defense, even though they had operational ranges that could take them far out to sea. During that period there was a gentleman's agreement with the Navy that Army bombers would not operate more than 100 miles from the US coast. Beyond that was the realm of carrier aviation. To reduce the risk of funding conflicts, the Army Air Corps intentionally undersold the range capabilities of its bombers.

[21] This section summarizes findings from "An Abridged History of the Army Attack Helicopter Program," *Office of the Assistant Vice Chief of Staff (Army) Washington DC*, October 29, 1973, https://apps.dtic.mil/sti/pdfs/AD1121533.pdf.

[22] This is best exemplified by the Tet Offensive. While a political success for the North Vietnamese, it was a crushing defeat militarily, especially for Viet Cong guerilla forces.

> within 20 meters of friendly troops. These were the kinds of danger-close situations that those who had argued for organic gunship had in mind in squabbling with the Air Force over roles and missions. Chinooks were vital, airlifting in 105mm howitzers that chewed away NVA attackers.[23]

Lam Son 719 and the Easter Offensive of early 1972 caused the U.S. Army to conduct a fundamental reappraisal of their helicopter needs. The two battles reinforced a growing realization in the U.S. military that a decade of operations in Vietnam would not be appropriate preparation for future potential high-end battlefields in Europe against the Soviet Union. By August 1972, the Cheyenne was canceled, and the Army authorized a new Advanced Attack Helicopter (AAH) design after an AAH Task Force formulated new requirements and determined the Cheyenne, King Cobra, and the then-in development Black Hawk design were inadequate.

The new requirements called for an AAH (later Apache) that was smaller and more agile, technologically simpler, and cheaper to buy, maintain and operate. In addition, all future helicopters had to be more survivable. In the future, helicopters would have to operate against tanks supported by highly capable air defenses. They would be needed in large numbers for massed attacks and with the capabilities to be integrated with ground elements and linked to suppressive fire from artillery and tactical aircraft. This prediction would later develop into the 1980s AirLand Battle concept.

FIGURE 12: AH-64 APACHE

Photo courtesy of Tim Felce.

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[23] Williams, A History of Army Aviation, p. 168.

Army Aviation's assessment of the future battlefield gained support during the 1973 Arab-Israeli War when Israeli aircraft faced Soviet-supplied tanks supported by sophisticated air defenses. Combat operations also revealed that the Soviets intended to conduct future operations around the clock. As such, Army helicopters would need night-vision devices and other systems to enable operations at night – a rare scenario in Vietnam. These assessments informed both the Apache and Black Hawk requirements.

Insights

The checkered history of the Cheyenne program highlights the importance of avoiding requirements creep and rosy cost assumptions. For FVL, which will depend on a Family of Systems, avoiding these additions and eschewing over-optimism is especially imperative given the risk to the whole if one part is delayed or runs over budget.

The Army and FVL leadership should also be aware of competing existing assets that are considered adequate or cheaper, albeit less capable, stopgaps. The Cheyenne's acquisition strategy of introducing several new technical capabilities—all while concurrently testing and developing them—presented considerable program risk. The daily, albeit suboptimal, usage of the modified Iroquois gunships and Cobra in Vietnam made it difficult for Cheyenne program managers to continually examine program assumptions and descope planned capabilities when they encountered technical problems.

FARA and FLRAA are being pursued concurrently (not to be confused with concurrency, which is associated with parallel technology and system development efforts- typically leading to unexpected integration challenges) and in conjunction with MOSA and ALE. While FARA and FLRAA are not direct replacements to the Apache and Black Hawk, their capabilities are similar enough that Army leadership will likely be tempted to tout the capability increases that the FVL FoS represent against those baselines. As the premier Army rotorcraft acquisition in a generation, the most competent acquisition professionals and technical oversight staff should be assigned to the FVL, and its physical program office should be geographically and organizationally prominent.

By contrast, the Apache case highlights the conservative tendency to base decisions on recent history and experience and the importance of demonstrated adversary capability improvements in overcoming this bias. It would have been unsurprising if the Army had modeled its force in response to the extensive operations in Vietnam or stuck with the Cheyenne because they had already put ten years into its development. Today, the decades-long operations in Afghanistan and Iraq and the long operational history of the Apache and Black Hawk –not to mention the negative examples of the Comanche and "Arapaho" – could have exerted a similar bias toward doing more of the same. Instead, the Army assumes that future battlefields promise to be completely different from those in the wars fought in response to September 11, 2001. The Army must maintain its focus and clear communications on the relevance of the FVL for the "high-end fight" of the modern multi-domain battlefield against a great power. Yet, it must also constantly revisit these assumptions.

CHAPTER 3

Benchmarking Affordability

Affordability has long been a DoD focus, especially since the 1980s when the modern Defense Acquisition Reform movement began with the Packard Commission and Goldwater-Nichols. But what does it mean to say that a defense acquisition program is affordable?

Defense Acquisition University (DAU) defines affordability as "A determination that the Life Cycle Cost (LCC) of an acquisition program is in consonance with the long-range investment and force structure plans of the DoD or individual DoD components."[24] Also, this definition of affordability is not strategic per se. That is, it is not about the value of the capability as a part of your strategy for achieving your objectives against an adversary. Rather, it is economic. In other words, a program is affordable if its expected cost aligns with long-term plans for spending and organization. If costs exceed plans, then a program becomes unaffordable under this definition.

In theory, DAU's definition makes good sense. In practice, however, defense policymakers use criteria other than the alignment of actual costs with resourcing plans to judge affordability.[25] First, policymakers may deem a program affordable if its costs appear small relative to overall spending, though the relative cost has little to do with cost-plans congruence. Second, policymakers may label a program affordable if its costs compare favorably with similar programs, but again, the comparative cost is not cost-plans congruence. Disagreements arise when a program appears more affordable from one perspective but less affordable from the other, creating a mixed picture that precludes a consensus bottom-line judgment.

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[24] Defense Acquisition University (DAU), "Affordability," accessed June 25, 2021, available at https://www.dau.edu/glossary/Pages/GlossaryContent.aspx?itemid=26814.

[25] Stephen Singer, "The F-35 Joint Strike Fighter, Equipped by Pratt & Whitney Engines, Is the Costliest Weapon System in US Military History. It Now Faces Pushback in Congress," *Hartford Courant*, June 1, 2021, available at https://www.courant.com/business/hc-biz-pratt-whitney-f-35-20210601-syxi7oyoyraijkdt7c6aditl6a-story.html.

Defense policymakers are right to judge affordability in terms of relative cost and comparative cost. Both perspectives represent different ways of gauging opportunity costs, the value of alternative uses for spending.[26] Opportunity costs lie at the heart of affordability. Determining affordability requires comparing an acquisition program to something else, not examining it in isolation.[27] When judging whether a program is affordable, policymakers are really assessing whether it fits in the budget and provides at least as much net capability after making tradeoffs as existing programs.[28] DAU's definition assumes implicitly that DoD's plans incorporate thinking about opportunity costs. Yet organizations charged with evaluating DoD's plans, such as Congress, need the Pentagon to show its work explicitly. They need DoD to demonstrate how assessments of opportunity costs shaped its plans and how those plans, in turn, shaped its acquisition programs.

Relative Cost Perspective

Policymakers frequently use relative cost to assess affordability. Computing relative cost involves determining what portion of an organization's total spending an acquisition program will consume. The Army's overall budget ("topline") and procurement budget work well for the total spending components because they highlight what the Army must relinquish budget-wise to bring FVL to fruition. The Army has not fully determined FVL's program costs or deployment schedule because the program remains in a development stage.[29] FVL costs per year thus remain unknown. Like previous studies, this section uses historical data from previous helicopter programs to fill in the gap.[30]

The relative cost perspective has strengths and weaknesses. In terms of strengths, relative cost usefully frames intraorganizational tradeoffs. Instead, the Army topline portion dedicated to FVL could flow to other priorities such as end strength or readiness. Computing

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[26] Defense acquisition is not the only field that thinks about affordability along these lines. Economists have adopted similar perspectives when studying health care policy, especially after passage of the 2011 Affordable Care Act. They have compared health care costs to household income (relative costs) and examined whether similar families obtain similar health care (comparative cost). The symmetry between health care and acquisition affordability suggests that defense policymakers are asking the right questions. Defense analysts must continue striving for better answers. Janet Weiner and Aaron Glickman, *What Is 'Affordable' Health Care? A Review of Concepts to Guide Policymakers* (Philadelphia, PA: Leonard Davis Institute of Health Economics, University of Pennsylvania, 2018), p. 2, available at https://ldi.upenn.edu/sites/default/files/pdf/Penn%20LDI%20and%20USofC%20Affordability%20Issue%20Brief_Final.pdf.

[27] Gene H. Porter et al., *Affordability of Defense Acquisition Programs* (Alexandria, VA: Institute for Defense Analyses, February 2015), p. 3, available at https://apps.dtic.mil/sti/pdfs/ADA620059.pdf.

[28] Kent D. Wall and Charles J. LaCivita, "On a Quantitative Definition of Affordability," *Military Operations Research* 21, no. 4 (2016), p. 34.

[29] Jeremiah Gertler, *Army Future Vertical Lift (FVL) Program* (Washington, DC: CRS, April 29, 2020), p. 2, available at https://fas.org/sgp/crs/weapons/IF11367.pdf.

[30] Congressional Budget Office (CBO), *The Cost of Replacing Today's Army Aviation Fleet* (Washington, DC: CBO, May 2019), available at https://www.cbo.gov/publication/55180; and Rhys McCormick, Gregory Sanders, and Andrew P. Hunter, *Assessing the Affordability of the Army's Future Vertical Lift Portfolio* (Washington, DC: CSIS, November 2019), available at https://csis-website-prod.s3.amazonaws.com/s3fs-public/publication/191112_McCormick%20et%20al_ArmyFVL_WEB_FINAL.pdf.

relative cost helps crystallize these types of choices. Relative cost also accounts for changing budgetary trends, such as inflation or personnel cost growth. By comparing program cost to total spending on a year-by-year basis, the relative cost reflects how both variables change over time due to the trends. Both the numerator (program cost) and denominator (total spending) used to calculate relative cost will reflect the trends, meaning the resulting comparison will be fairer than if one variable reflected the trends and one did not.[31]

In terms of weaknesses, the relative cost perspective is subject to misinterpretation if policymakers do not exercise caution. Two possible misinterpretations spring to mind. First, a program is not affordable simply because it consumes a smaller topline portion. A smaller portion does not equal more affordable. Instead, a smaller portion implies fewer opportunity costs. Policymakers must still weigh those opportunity costs against the expected gains from the program. Second, the topline portion allocated to previous programs does not necessarily equal the appropriate portion for future programs. As technologies advance and organizations evolve, the topline portions dedicated to specific activities may vary. If previous helicopter programs consumed X percent of the Army topline and FVL consumes X+5 percent of the topline, that does not mean FVL is unaffordable. What matters is whether the Army can fit X+5 percent within its budget, whether it will make the tradeoffs necessary to do so, and whether the resulting Army forces will perform at least as well—but, ideally, significantly better—than existing forces.

Two previous Army helicopter programs, the AH-64A Apache and the UH-60A Black Hawk, provide a useful relative cost benchmark for FVL for three reasons. First, the Army has conceptualized FARA and FLRAA as performing missions roughly comparable to upgraded versions of AH-64 and UH-60, respectively.[32] FARA and FLRAA will thus serve as partial successors (but not one-for-one replacements) to these existing aircraft. Second, the AH-64A and UH-60A represented the first aircraft of their classes, just as FARA and FLRAA will represent the firsts of their classes.[33] A first aircraft often encounters initial development challenges that may not affect upgraded versions later in the class, meaning first aircraft comparisons are closer to "apples to apples." Third, the acquisition of the AH-64A and UH-60A overlapped in time, a condition that will also apply to FARA and FLRAA. Examining the relative cost of simultaneously acquiring the AH-64A and UH-60A simulates the budgetary burden of simultaneously acquiring FARA and FLRAA.

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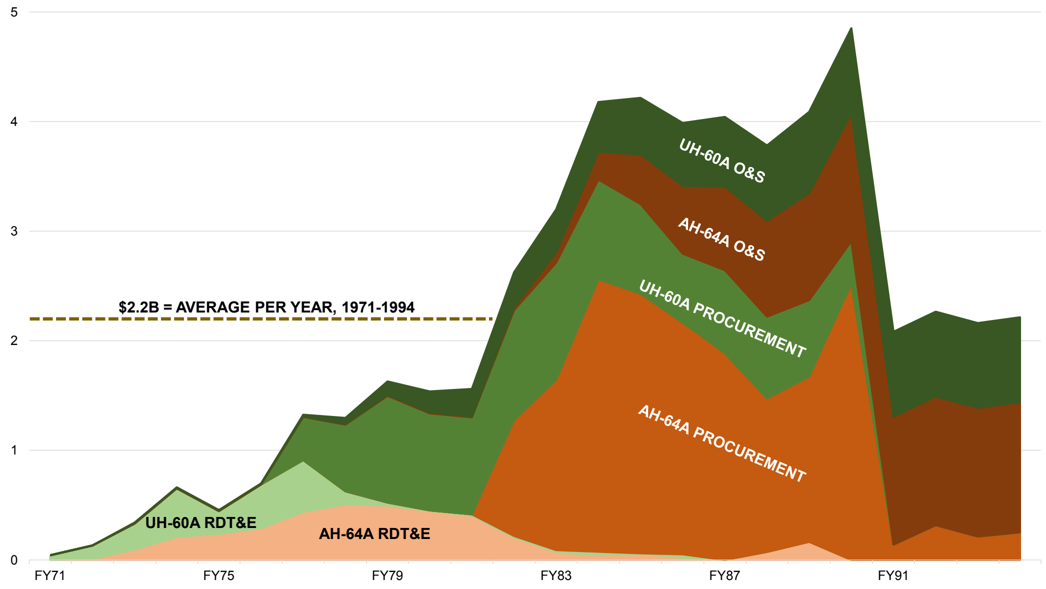
[31] That said, budgetary trends such as inflation do not affect all parts of the defense budget equally. Simple relative cost calculations do not account for these complex heterogenous effects. CBO, Long-Term Implications of the 2021 Future Years Defense Program (Washington, DC: CBO, September 2020), available at https://www.cbo.gov/system/files/2020-09/56526-FYDP.pdf.

[32] Jeremiah Gertler, Army Future Vertical Lift (FVL) Program (Washington, DC: CRS, April 29, 2020), p. 1, available at https://fas.org/sgp/crs/weapons/IF11367.pdf.

[33] On Apache's development history, see Thomas C. Lassman, "Reforming Weapon Systems Acquisition in the Department of Defense: The Case of the U.S. Army's Advanced Attack Helicopter," Journal of Policy History 25, no. 2 (2013), pp. 173–206.

FIGURE 13: AH-64A APACHE AND UH-60A BLACK HAWK FUNDING, FY71 TO FY94 (FY18$)



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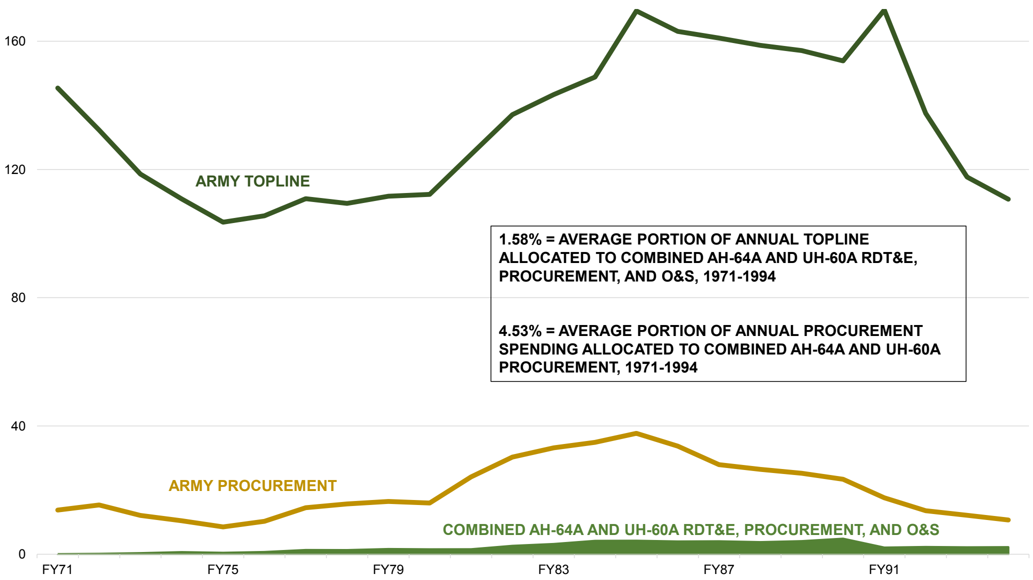
- O&S: DoD, *Selected Acquisition Report: UH-60M Black Hawk Helicopter* (Washington, DC: DoD, December 2019), p. 40, available at https://www.esd.whs.mil/Portals/54/Documents/FOID/Reading%20Room/Selected_Acquisition_Reports/FY_2019_SARS/20-F-0568_DOC_80_UH-60M_Black_Hawk_SAR_Dec_2019_Full.pdf; DoD, *Selected Acquisition Report: AH-64E Apache New Build* (Washington, DC: DoD, December 2019), p. 43, available at https://www.esd.whs.mil/Portals/54/Documents/FOID/Reading%20Room/Selected_Acquisition_Reports/FY_2019_SARS/20-F-0568_DOC_06_AH-64E_New_Build_SAR_Dec_2019_Full.pdf; and John C. Hawkins, "Analysis and Forecasting of Army Operating and Support Cost for Rotary Aircraft," M.A. Thesis, Air Force Institute of Technology, Air University (March 2004), pp. 39, 41, available at https://apps.dtic.mil/dtic/tr/fulltext/u2/a423135.pdf.

Notes: In billions FY18 $ budget authority. Adjusted for inflation using DoD, *National Defense Budget Estimates for FY 2018* (Washington, DC: DoD, revised August 2017), Table 5-6, pp. 62-63, available at https://comptroller.defense.gov/Portals/45/Documents/defbudget/fy2018/FY18_Green_Book.pdf.

- RDT&E: AH-64 RDT&E funding shifted to Longbow development in the late 1980s/early 1990s. Longbow funds do not appear in the dataset.
- Procurement and Inventories: The dataset includes transition quarter procurement between FY76 and FY77 in the FY76 totals. CBO and Janes report different AH-64A annual production rates from FY89 to FY94, but both sources report 218 total aircraft procured during the period. The dataset uses the CBO rate because it mirrors the figures contained in DoD's annual reports from the period. FY73 and FY79 AH-64A quantities represent prototypes and preproduction, respectively. FY73 UH-60A quantity represents development aircraft. Janes reports that a) the Army procured 1,048 total UH-60As (excluding six FY73 development aircraft) and b) UH-60L replaced UH-60A starting in FY90. The dataset thus assumes 47 UH-60As procured in FY90 to reach the 1,048 total. The FY90 UH-60 figure differs from CBO because the dataset only considers the UH-60A, not the UH-60L. The FY90 figure derives from multiplying the assumed FY90 UH-60A quantity (47) by the average UH-60A unit procurement cost from FY77 to FY89 (5.04 million), i.e. 47 x 5.04m = ~237m.
- O&S: The dataset assumes an annual UH-60A O&S cost per aircraft of $734,000 (FY18$), the average of the figures reported in Hawkins (for the UH-60A) and the December 2019 SAR (for the UH-60L). The Hawkins figure includes fuel, ammunition, consumables, repairables (net), intermediate maintenance, and depot maintenance (end item). The SAR figure includes unit operations, maintenance, sustaining support, and indirect support. The dataset assumes an annual AH-64A O&S cost per aircraft of $1,437,000 (FY18 $), the average of the figures reported in Hawkins (for the AH-64A) and the December 2019 SAR (for the AH-64D Longbow). The Hawkins figure includes fuel, ammunition, consumables, repairables (net), intermediate maintenance, and depot maintenance (end item). The SAR figure includes unit operations, maintenance, sustaining support, continuing system improvements, and indirect support.

Figure 13 depicts funding allocated to AH-64A and UH-60A from FY 1971 to FY 1994 across three phases of acquisition: 1) research, development, testing, and evaluation (RDT&E); 2) procurement; and 3) operations and support (O&S). Over the 24-year period, annual funding of all types for both programs averaged $2.2 billion (FY18$). Annual funding remained lower during the early development phase (1971-1978), averaging $600 million per year, and increased to around $3 billion annually in later years (1979-1994). From FY 1971 to FY 1994, the Army purchased 827 AH-64As and 1,054 UH-60As (including development aircraft). AH-64A procurement peaked in FY 1985 with the purchase of 138 aircraft. The Army procured 90 AH-64As per year, on average, from FY 1982 to FY 1990. UH-60A procurement peaked in FY 1982 and FY 1983 with the purchase of 96 aircraft each year. The Army procured 75 UH-60As per year, on average, from FY 1977 to FY 1990.

FIGURE 14: AH-64A APACHE AND UH-60A BLACK HAWK FUNDING RELATIVE TO ARMY TOPLINE AND ARMY PROCUREMENT, FY71 TO FY94 (FY18$)



1.58% = AVERAGE PORTION OF ANNUAL TOPLINE ALLOCATED TO COMBINED AH-64A AND UH-60A RDT&E, PROCUREMENT, AND O&S, 1971-1994

4.53% = AVERAGE PORTION OF ANNUAL PROCUREMENT SPENDING ALLOCATED TO COMBINED AH-64A AND UH-60A PROCUREMENT, 1971-1994

Sources: Aircraft data sources listed in previous figure. Army funding data drawn from DoD, *National Defense Budget Estimates for FY 2018*, Table 6–19, pp. 190–192.

Notes: Aircraft data notes described in previous figure.

Figure 14 compares combined AH-64A and UH-60A funding to the Army topline and Army procurement spending from FY 1971 to FY 1994. Over this period, AH-64A and UH-60A combined funding of all types consumed from 0.03 percent (FY 1971) to 3.2 percent (FY 1990) of the Army topline, averaging 1.6 percent. Meanwhile, procurement funding for the two aircraft together consumed from 0.8 percent (FY 1991) to 12.5 percent (FY 1990) of Army procurement spending, averaging 4.5 percent. Based on the data, FVL's ability to be affordable may be to ensure that combined spending on FARA and FLRAA for RDT&E, procurement, and O&S consumes approximately 1.6 percent of the Army's annual topline, on average. Similarly, FVL will enhance its affordability if combined spending on FARA and FLRAA procurement consumes approximately 4.5 percent of the Army's annual procurement budget, on average.

As noted previously, FVL will not automatically become unaffordable if its relative costs exceed these benchmarks. Nor will it automatically remain affordable if its relative costs fall below these benchmarks. Rather, the benchmarks indicate the opportunity costs that the Army proved willing to incur previously to obtain two new types of helicopters. The Army may prove willing to incur greater or fewer opportunity costs to acquire FARA and FLRAA. Regardless, it must persuade other stakeholders, especially Congress, that its preferred course of action represents the right choice for the future Army.

Comparative Cost Perspective

In addition to relative cost, policymakers also use comparative cost to assess affordability. Comparative cost analyses often come in three different forms, though other forms exist, too. First, the "per unit" form compares the per-unit cost of related platforms over time, generally showing cost in inflation-adjusted dollars. For example, an analyst could study the average unit cost or cost per flight hour of different types of helicopters to assess the extent to which cost grew above inflation. Second, the "composition" form compares the composition of life cycle costs for related programs. Here an analyst might examine whether O&S costs for different helicopters comprised 70 percent of total life cycle costs, a standard ratio used in acquisition planning.[34] Third, the "cost per effect" form compares the cost of delivering a military effect from different platforms.[35] For instance, an analyst might assess the munitions fired, distance traveled, or cargo carried per unit of expenditure for different helicopters.

Like relative cost, the comparative cost perspective has strengths and weaknesses. On the strengths side of the ledger, comparative cost focuses policymaker attention on whether new programs outperform existing programs with respect to both cost and capability. If a new program exceeds the cost of an existing program by a factor of X, then policymakers expect the new program's capability also to exceed the existing program's capability by a factor of X, at minimum. Relatedly, if existing platforms (P) provide a capability (C) that in the aggregate yields P*C, and new platforms cost more, then policymakers may prefer buying only the number of new platforms required to deliver P*C, meaning new platforms will not replace existing platforms one-for-one.

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[34] Gary Jones et al., "Investigation into the Ratio of Operating and Support Costs to Life-Cycle Costs for DoD Weapon Systems," Defense Acquisition Research Journal 21, no. 1 (January 2014), pp. 442–464.

[35] David A. Deptula and Douglas A. Birkey, Resolving America's Defense Strategy-Resource Mismatch: The Case for Cost-Per-Effect Analysis, Mitchell Institute Policy Paper, Vol. 23 (Arlington, VA: Mitchell Institute for Aerospace Studies, July 2020), available at https://a2dd917a-65ab-41f1-ab11-5f1897e16299.usrfiles.com/ugd/a2dd91_9eb547d3420d47bc932c95f7e949d024.pdf.

On the weaknesses side of the ledger, the comparative cost perspective can perpetuate status quo thinking among acquisition planners. Although the past is the most reliable guide to the future, not every successful new program will exhibit the same cost and capability trends as successful existing programs.[36] Judging affordability based on comparative cost can lead policymakers into an incrementalism mindset in which new programs exist solely to replace existing programs. This mindset leaves little room for the U.S. military to adopt innovative force structures and capabilities that change the status quo. The status quo reflects the accumulated wisdom and aggregated effects of decades of experience, both good and bad, so policymakers should not discard it lightly. Still, policymakers should strive to remain open-minded enough to entertain new programs that break the mold of the standard forms of comparative cost analysis.

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[36] An oft-cited example of acquisition success that did not adhere to the usual process was the mine-resistant ambush-protected vehicle (MRAP). Jessie Riposo, Megan McKernan, and Chelsea Kaihoi, *Prolonged Cycle Times and Schedule Growth in Defense Acquisition: A Literature Review* (Santa Monica, CA: RAND Corporation, 2014), pp. 63–69, available at https://www.rand.org/pubs/research_reports/RR455.html.

CHAPTER 4

Revisiting the Conventional Wisdom about Defense Acquisition

As U.S. force structure ages, moreover, affordability becomes even more difficult to achieve. Across the joint force, the Services mainly field platforms that were designed in the second half of the Cold War. For example, the bulk of the Army's rotary-wing force today, the Chinook, Apache, and Black Hawk, was conceived before the 1980s. Similarly, the heart of the Navy's surface fleet (*Nimitz*-class aircraft carriers, *Ticonderoga*-class cruisers, *Arleigh Burke*-class destroyers, and *Wasp*-class amphibious assault ships) and much of the Air Force's front line inventory (F-15, F-16, A-10, B-1, B-2, and the venerable B-52) have mid-to late-Cold War design pedigrees. Much of the Services' logistical and support platforms and infrastructure also stem from that era.

The present force composition is the product of decades of acquisition strategies seeking, in the name of affordability, to strike a balance between existing force levels and emerging capabilities. Since the end of the Cold War, DoD has attempted to field new systems with generational lead-ahead capabilities, such as the F-22, F-35, Littoral Combat Ship, DDG-1000, and the Future Combat System, while continuously upgrading and improving legacy platforms that form the core of the defense force.[37] The results have been mixed, especially regarding affordability. As such, affordability becomes more imperative with each passing year because more legacy assets must be replaced if threat-pacing capabilities are to be maintained. Meanwhile, potential adversaries have been steadily improving their

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[37] It is noted that the F-22 and FCS design efforts predate the end of the Cold War and that there are many earlier examples in DoD history of introducing, piecemeal, cutting-edge capabilities. Indeed, most defense force structures throughout history have been a balance of the legacy "good enough," relatively-affordable assets and more expensive, "revolutionary" weapon systems. The point is that post-Cold War budgets are an especially significant driving factor in American defense force structure policy.

capabilities relative to the United States, adding to budgetary and readiness pressures. Recognizing this fundamental tension between advanced capabilities and affordability, in the 2010s, the Department of Defense initiated its most recent comprehensive effort to reform its processes and improve the affordability of the systems it acquires. Under the backdrop of these Department-wide efforts, the Army began pursuing the FVL Family of Systems.

The Quest For Both Technological Superiority and Affordability

During historical periods of large defense budgets and clear threat assessments, the United States has been able to field many advanced capabilities. However, defense acquisition programs have been less successful in periods of competing modernization priorities, compressed budget resources, and unclear threat perceptions. For many decades the DoD has attempted to institute reforms to achieve its affordability goals. The most recent comprehensive Department-wide initiative was Better Buying Power (BBP)[38] which stemmed from the recognition that the technological superiority enjoyed by the United States for the last 30 to 40 years was by no means assured. Potential adversaries are actively attempting to erode that superiority. The source of much of the recent dominance are capabilities that began their development in the 1970s and 1980s. These include:

- precision munitions
- wide-area surveillance systems
- networked forces
- stealth technology
- a relatively small number of high-value assets in space, land, and sea

As noted previously, much of the last 40 years of defense acquisition can be characterized as maintaining and upgrading military systems designed during the latter half of the Cold War. Although the core systems have been incrementally improved, they are reaching the limits of their design margins while continuously trying to keep pace with new and future threats. These so-called SWAP-C (Space, weight, power, and cooling) margins also have shifted from a historical norm of space and weight being the key limits to instead power and cooling now being the key limits. This shift is primarily due to a combination of advancements in miniaturization and advanced digital capabilities for avionics, software, sensors, and payloads. Adversaries have studied American successes, especially since the First Gulf War, and have developed systems that challenge existing capabilities. BBP was predicated on the

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[38] Frank Kendall, "Better Buying Power 3.0, White Paper", Office of the Under Secretary of Defense Acquisition, Technology and Logistics, September 19, 2014.

assumption that we can and must replicate acquisition practices from the 1970s and 1980s that produced an array of systems that resulted in decades of dominance.

Better Buying Power Framework

The BBP initiative had three major iterations. Advancing from BBP 1.0 through 3.0 Better Buying Power was based on the principle that continuous improvement is the best approach to improving the performance of the defense acquisition enterprise and the resulting systems fielded.[39] The emphasis of BBP 1.0 to 2.0 was specifically on establishing and implementing "best practices." These included: helping acquisition professionals think critically and make better decisions as they confront the myriad, complex situations encountered in defense acquisition; cultivating cost consciousness as a critical element of the acquisition culture; supporting professionalism and providing better tools to help the acquisition professionals in DoD make sound decisions; and focusing on "core" initiatives including items such as affordability constraints, should-cost management, use of data to inform policy, strong incentives to industry, and the use of competition.

BBP 3.0 then shifted the emphasis toward achieving dominant capabilities through innovation and technical excellence. The growing concern that the United States' technological superiority over potential adversaries is being threatened today in a way that has not been seen for decades has been a powerful catalyst throughout DoD and spur on efforts to press forward with institutional reform.

BBP 3.0 Fundamentals

BBP 3.0 was devised on two core sets of fundamentals: Costs and Productivity. Combined, these two elements provide the basis for sustained dominance of the resulting fielded military systems and capabilities. The fundamental assumptions and principles of BBP 3.0 were[40]:

Costs

Program Costs: Set cost caps. Require the Services—before the program's start—to see if a program can be afforded in future budgets, especially concerning production and sustainment. Enforce the caps.

Control Life Cycle Costs: Require the Services and program managers (PMs) to gain an intimate understanding of where costs accrue for a given program and to set goals for reducing

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[39] "Better Buying Power (BBP)," *AcqNotes*, updated July 23, 2021, https://acqnotes.com/acqnote/tools/better-buying-power-2

[40] "Better Buying Power (BBP)," *AcqNotes*, updated July 23, 2021, https://acqnotes.com/acqnote/tools/better-buying-power-2

costs ("should cost" goals) in specific program areas. As of 2014, most endeavors in DoD were being managed to "should cost" goals.

Collaboration and Adaptation: Build stronger partnerships between acquisition, requirements, and the Intelligence Community (IC). A predicate of BBP is that our adversaries have been observing the elements of our dominance for decades and have developed successful counters to our strengths. The IC has the most insight into adversary capabilities. Therefore, a BBP initiative is to bring the IC into the requirements generation and acquisition process from the outset and on a continuing basis. Adversaries are continually adapting to our capabilities, so we must develop our systems to foster continual adaptation.

Rational, Long-range Research and Development: For too long, research and development (R&D) has not been coordinated across the entire DoD portfolio in a rational manner, let alone with a vision for fundamental decades-long change. The last time such a coordinated perspective was developed and executed was in the 1970s. Unsurprisingly, it was this prior effort that bore the fruit that was the source of our post-First Gulf War overmatch. To stay relevant, DoD must pursue R&D holistically and for the long-term, again.

Productivity

Profit: The incentive for profit must be aligned with performance, resulting in greater profits to those companies that perform better and less to those that do not. At all levels of the supply chain for a defense program, the profit incentive can actually be used as a means to ultimately control costs, especially by leveraging short-term emphasis to incentivize up-front efforts in the program that result in downstream capabilities and achieving long-term cost reductions. Therefore, DoD's effort should recognize and accept profit maximization as a strong incentive to shape through contracting approaches. One example of this is performance-based logistics (PBL), where better performance is rewarded with higher profits while also setting the new normal for performance.

Tech Sector: DoD recognizes that the commercial sector frequently adapts technology much more rapidly than the military. It also acknowledges some cultural barriers and timeframe misalignments that have often kept the Tech sector from fully contributing to and partnering with the defense community. However, in addition to recent efforts to address these barriers, DoD can also renew efforts to recognize and incentivize more results from its own DoD laboratories and technologists, which essentially comprise a competing tech sector. Ultimately, technology generation is not the real issue. Designing acquisition programs with frequent on-ramps to incorporate the mountains of technologies available both in the commercial and defense industries, as well as the DoD labs remains the paramount challenge.

Incentivize Innovation in Industry and Government: Technology demonstrators, prototyping, and experimentation are key to reducing technical risk and increasing understanding to minimize the potential for technical overreach before starting a new acquisition program. Designing technology insertion and refresh explicitly into program planning at frequent intervals is important to allow mature technology insertion, deferral of immature capabilities until they are ready (the now or never fallacy), and incentives for competition by a steady stream of upgrade opportunities. If done as an open ecosystem approach, Modular Open Systems Architecture actually provides the means to stimulate innovation and allow for maturity.

Historically, the Department was able to work closely with industry in the earliest stages of the product life cycle, but this has declined. One way DoD can revitalize this interaction is by asking industry for feedback and recommendations on early-stage draft requirements. Another is to fund competitive concept definition studies (e.g., early design trade studies and operations research) to inform decisions about requirements and as inputs to a formal Analysis of Alternatives conducted after the Material Development Decision. The perceived barriers between industry and government can be overcome, and doing so will lead to better-informed government decisions and more innovative products.

Improve the Professionalism of the Total Acquisition Workforce: The post-Cold War period has adversely impacted the defense acquisition workforce. While there have been many upgrades to the Chinook, Apache, and Black Hawk (and the since-retired Kiowa), the overall trend in the Army Aviation acquisition world has an increasing workforce cadre of limited experience. This dearth of experience is not insurmountable but will require a measured, realistic approach to developing the cadre of professionals who will oversee the execution of FVL. People with professional qualifications and wide-ranging experiences must be prioritized to staff key leadership positions for all acquisition specialties. The engineering field and the competencies necessary to understand and manage R&D programs need to be bolstered to ensure sufficient understanding of the technical implications of options and decisions. There is no quick fix. A nationwide effort is also important to expand the Science, Technology, Engineering, and Math (STEM) talent pool for the defense acquisition workforce[41]. These professionals must also be adept at conducting business in a nearly all-digital environment, requiring training for large swaths who may not have had previous exposure to these approaches.

Application to FVL

How do these broader acquisition and affordability principles apply to FVL? Several themes emerge concerning affordability and feasibility when examining FVL.

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[41] A model for this nation-wide effort was the National Defense Education Act during the Eisenhower Administration. Recently, some have called for a similar effort. For example, see https://thehill.com/blogs/congress-blog/technology/552248-now-is-the-time-for-a-new-national-defense-education-act

Program Concept

One of the most significant difficulties facing the FVL effort is rooted in its overall approach. While five capability sets (CS) are envisioned (as discussed in Chapter 1, Table 1), only FARA (CS#1) and FLRAA (CS#3) are currently the focus of Army efforts. CS#5 is still uncertain, in some part due to the necessity of finalizing the sling loads from other key Army systems it would transport, such as Next-Generation Combat Vehicle (NGCV) systems and Long-Range Precision Fires (LRPF). As noted, FARA and FLRAA are not one-for-one replacements for the Apache and Black Hawk, respectively. Rather, the FVL approach entails considering the FVL from the standpoint of a capability ecosystem concept, where the combination and interrelationship of the constituent elements create a flexible force package. At various times, this ecosystem approach has been referred to as "family of systems" or "system of systems." This conception is not new. The Army's Future Combat Systems (FCS) transformational efforts during the 2000s combined multiple interrelated ecosystems. FCS was ultimately unsuccessful. The ecosystem approach entails many risks and requires different considerations for program management application and deconfliction than are often considered in traditional approaches for defense acquisition. These considerations are essential to maintain and ensure the proper interrelationships across the various individual programs.

This more complex and holistic formulation for managing an FoS requires:

1. an understanding of the total capability set required;
2. clarity in the nominal delineation across various constituent elements (primary and secondary); and
3. finally, the ability to clearly communicate the formulation and interdependencies to stakeholders, program managers, and the workforce, especially in an unclassified manner.

The reinforcing elements of the Air Assault force package should be clearly identified and sequenced to allow for the steady progression of the FVL ecosystem capability as a whole, rather than managed in parallel as two separate rotary-wing platforms. Consistency of this formulation should also result in steadily maintaining projections of the required numbers for each of the constituent ecosystem elements and resulting costs. The Army should accomplish these tasks while consistently showing how the desired increased mission capabilities of FARA and FLRAA are differentiated from the current systems in the force structure that will still be in active service concurrently with FVL.

An example of program technical risks, which are exacerbated by a Family of Systems approach, was highlighted as this report was being finalized. In August 2021,[42] the FARA

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[42] Steve Trimble, "Physics-Busting Requirements Challenge U.S. Army FARA Program", *Aviation Week*, August 3, 2021 https://aviationweek.com/defense-space/aircraft-propulsion/physics-busting-requirements-challenge-us-army-fara-program

program manager noted that all of the desired capabilities of the FARA could not be met—a typical discovery as additional engineering and analysis accompany further maturation of a program. The maximum takeoff weight requirement affects engine size, power, and the diameter of the disc rotor, which in turn limit potential speed and endurance at a given range. This report does not focus on the specific technical design aspects of the FVL effort. While not only the FARA and FLRAA are being designed and procured as a Family of Systems, they are intended to operate in conjunction with each other. If some requirements as presently formulated cannot be met for the FARA, it may ultimately affect the FLRAA's requirements. This dynamic has happened in the past. The since-retired Kiowa, with a primary mission to scout targets for the Apache, was slower than the Apache, which limited the full combat potential of both helicopters operating together.

Program Schedule

There are two significant and competing considerations related to the program schedule. On one front, there may be pressure exerted from some constituencies and stakeholders to speed up the program schedule because of accelerated threat projection timelines or the actual fielding of threats. This situation may result in pressure to resort to a development timeline based on concurrence (of development and production), which has routinely proven detrimental to defense acquisition programs.[43]

On another front, topline Department of Defense (DoD) and/or Army budgetary limitations may result in pressure to defer at least one of the ecosystem components, resulting in compounding complexity and capability gaps. The FVL ecosystem of programs, and the Army overall, may struggle to achieve sufficient recognition and prioritization, given the convergence of U.S. defense and overall federal government spending priorities during the 2020s.

Program Cost

Cost remains the most visible and important element of either keeping defense acquisition programs on track or becoming derailed. The Army should have the ability to account for previous and ongoing FVL de-risking efforts. For example, through modeling and simulation (M&S), extensive use of technology demonstrators and prototyping, and digital engineering informed cost estimates. Some program execution options, such as either having government-led mission integration or using a third party, independent integrator, may be perceived by some stakeholders as an additional, unnecessary cost to the overall program budget.

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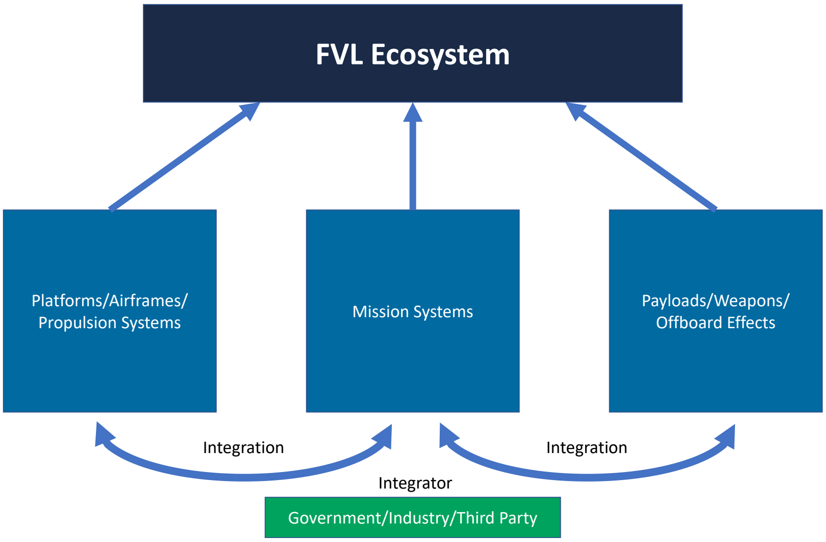
[43] For more information on this type of model, known as "Spiral Development," in the context of the military acquisition process, see Barry Boehm, *Spiral Development: Experience, Principles, and Refinements* (Pittsburgh, PA: Carnegie Mellon Software Engineering Institute, 2000), https://apps.dtic.mil/sti/pdfs/ADA382590.pdf.

With regard to cost estimation, reliance on historical, parametric-based modeling from previous programs may have limited utility for an all-digital designed, produced, and fielded system. Cost by analogy approaches may be problematic in that the delineation and recombination of capabilities across different platforms may limit the utility of the comparison.[44] Both Army cost modeling and other external verification (e.g., OSD CAPE) should carefully consider and explicitly note the inherent assumptions and associated uncertainty used for the cost estimate. If they are not considered or sufficiently noted, they may generate unreliable estimates or be used for inappropriate comparisons of dissimilar ecosystems elements.

Program Execution

Program Pillars: For program execution, one option the Army should consider is distinctly splitting platforms/airframes from mission systems and payloads/weapons/offboard effects. These three groupings could account for the major pillar elements of the FVL ecosystem. The government and eventually industry performers could manage within and across each of these pillars and their full lifecycles. The integrator, whether government, industry, or a third party, could also seek to ensure maximum cross-utilization of components and technologies in these distinct elements. This approach promises to result in cost savings through economies of scale for development, production, and operations and maintenance once the ecosystem is fielded.

FIGURE 15: PRIMARY COMPONENTS OF THE FVL ECOSYSTEM AND INTEGRATION CHALLENGES



Credit: Authors

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[44] For an overview of parametric, analogy, and engineering cost estimation, see Diana I. Angelis and Dan Nussbaum, "Cost Analysis," in Francois Melese, Anke Richter, and Binyam Solomon, eds., *Military Cost-Benefit Analysis: Theory and Practice* (New York: Routledge, 2015), p. 123.

Block Upgrades vs. Incremental Approach: While the program is still in development, and even after production ramps to full-rate production, the FVL programs should avoid using a block upgrade construct. The Block upgrade approach combines a larger grouping of capabilities, rigid timelines, and additional program management overhead. Instead, the ecosystem should execute a periodic and incremental approach. Such an approach will enable continuous modernization of the ecosystem and constituent components while also ensuring technologies are mature and ready for integration. The approach will keep risks to program cost and schedule minimized, further guaranteeing the programs can execute on time and on budget, maintaining credibility. An incremental capability upgrade approach should be on a feasible schedule (e.g., no faster than annual or biennial) to allow for the development efforts, stable resourcing, and sufficient time for replication to training systems (depending on the capability). It may also consider decoupling hardware timelines from software timelines. Software timelines may also be further decoupled, especially in the early phases of production, to account for deficiency correction compared to new capability insertion.

Additional Operational Users and Customers: The FVL programs can leverage other joint partners and allied customers. These additional operators may achieve greater volumes for production and larger operational fleet sizes, both of which would improve program life cycle affordability through economies of scale and enhance negotiation leverage with all tiers of the supply chain.

Industrial Base: A clear assessment of the state of the defense industrial base is also a key requirement. Such an assessment is predicated on the leadership of the FVL programs having a clear understanding of when particular elements of the industrial base are needed to support a specific program milestone or in the overall program timeline. This understanding will inform the leadership of the FVL programs on what steps are necessary to ensure the industrial base is prepared and able to support the programs. A potential risk discussed is the implications from the down select of FARA and FLRAA, especially if there was a single winner for both platforms. Other critical elements to consider may include: how should the U.S. government manage/influence/monitor the supply chain? Can/should the government be the supply chain manager for the program? What does a healthy vs. unhealthy industrial base look like? What are the pros and cons of minimally sufficient vs. ideal (and how to track variations between the extremes)? The health of sub-tier suppliers today and projected relative to program milestone schedule should be clearly understood. The health of the supply chain is especially critical considering the Apache, Black Hawk, Chinook (and H-53K) are all approaching the end of production. With regard to the industrial base, there are no other U.S. rotary-wing platforms on the horizon besides the FARA and FLRAA. The decision made on the FARA and FLRAA will have enormous implications for this portion of the U.S. Defense industrial base.

Prototyping: For prototyping, the Army and vendors should agree on a test flight regime and a design iteration process. Because of the ecosystem elements, especially FUAS and ALE, manned-unmanned teaming for the FVL programs, and even evolutionary upgrades that eventually produce unmanned variants of the ecosystem components could be a priority focus.

Software Strategy: Software development and software sustainment approaches that avoid the additional complexity, overhead, and constraints from traditional approaches used in the defense acquisition community should be implemented. A model being piloted elsewhere in the Department of Defense for software modernization (development + sustainment= modernization) is a key paradigm shift, both for execution and resourcing (via the potential option using "software color of money"[45]). The Army may consider asking Congress for the opportunity to establish and use a "software color of money" for the FVL programs. These would enable integrating and scaling digital efforts to provide new capabilities, sustain existing ones, and ensure that software development and sustainment are clearly delineated. The FVL programs should also have a clear data strategy and clarify as early as possible how data and intellectual property (IP) are shared with the government and across the defense-industrial base. Ownership of and access to IP and software–who shares what, who gets what, and who can access what and when should be well defined, negotiated, and commonly understood. The program office should also avoid using outdated and unhelpful metrics, like source-lines of code (SLOC) to manage software progress and successful completion.

Digital Backbone: The digital backbone of FVL is the invisible foundation for the success of the programs. Who owns the data, which parts, and when? Who manages/curates the data? Who can access the data? This need for data will influence everything across the programs, from target coordinates to engine diagnostics. The program offices should also clearly identify and establish how testing works in the prototype phase. The Army and vendors should work together to set clear expectations for who gathers data and who sets the flight test regime. There should also be clear linkages throughout the design iteration process to determine how a specific prototype represents a particular set of focused design aspects.

Personnel Competencies: The Army should also carefully assess current and future projections for personnel talent in key areas in government and industry. Key considerations include: how talent is measured and tracked, and if investments are required to maintain or build particular skill sets during times of program need. Having sufficient personnel in key competencies will be a critical element to the success of whatever Software and Digital Backbone program strategies are chosen.

Sustainment Focus: The allocation of resources to sustainment issues early in a program is essential. Investing additional funds earlier in the program to support the planning and establishment of repair and sustainment lines that provide the platforms with maintenance support after production of the aircraft can have beneficial results. By moving some financial resources earlier in the program execution, to proactively address the logistics piece of

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[45] Jackson Barnett, "New 'color of money' for DoD software gaining traction, Lord says"," *FedScoop*, 13 August 2020. Available at https://www.fedscoop.com/new-color-money-software-likely-stay/

the program, the FVL team could gradually ameliorate long-term costs associated with the constant upgrades and repairs needed to keep the FVL platform(s) operational. Considering sustainment early in the program lifecycle gives the best possible chance that the platform's relevant operational life will not only increase against a wider range of future threat projections and timelines, enhancing the relevance of the overall platform longer, but also that the costs to maintain that longevity will be maintained at predictable and acceptable levels since the program's sustainment base has been supported.

Other Program Considerations

As an Army-led program, but with joint partners in the U.S. Marine Corps (USMC), U.S. Navy (USN), Special Operations Command (SOCOM), U.S. Air Force (USAF), and U.S. Coast Guard (USCG), FVL has the potential to maximize some of the advantages while minimizing some of the complications, complexity, and slower execution time for a truly joint acquisition program. While potentially perceived as resource-intensive and costly upfront, the FVL ecosystem elements should all be designed with options for export to a global array of allies and partners. This approach can proactively help support future interoperability, force interchangeability, and the resilience of allies and partners.

Despite bureaucratic incentives to avoid and defer considerations for export, the Army should ensure that export considerations are confronted early in the program and the necessary considerations implemented. Export for these systems is not a question of if but rather when and to whom. Currently, over forty different nations have deployed the Black Hawk platform, and many of them will likely want to buy and operate components from the FVL ecosystem. The FVL programs should also consider establishing a consortium of Foreign Military Sales (FMS) customers to pool resources for future capability upgrades, spare parts, and regional maintenance capabilities U.S. forces can use while forward-deployed. These are all examples of external investments and benefits the Army can lead and capitalize on without requiring additional resources.

FMS customers, in particular, may be a potential means to generate resources to leverage and offset future sustainment costs. Many U.S. allies and partners have expressed significant interest in the FVL ecosystem elements and likely will be interested in opportunities to customize some of the mission systems and payloads for any FVL systems they would acquire. The FVL CFT should consider pathways in which the other services, and international customers, can contribute financial assistance, technical knowledge, or other support to help offset or support costs incurred by platform development, production, and sustainment. However, the Army's decision to carry out direct leadership of the program instead of expanding stakeholders will likely avoid additional costly, delays. This decision will also benefit the availability of stock/resupply in large-scale conflicts.

The FVL programs should also maximize leverage from other programs and other investments in the department. These investments should include technology development, as well as best practices and pitfalls to avoid while executing the program. Of particular relevance to the FVL programs are the B-21, F-35, MQ-25, and MV-22, as well as other systems and components from across the Services, Defense Advanced Research Projects Agency (DARPA), and Special Operations Command (SOCOM). These other programs can help to give FVL insight into what works, what does not, and best practices and advice from acquisition community members who have confronted similar challenges to the FVL program. Some investments in and leverage from the civil rotary-wing market and some elements of the emerging Urban Air Mobility (UAM) market may also provide the Army with additional opportunities to leverage technology investments and scale of supply bases for the benefit of the FVL programs.

CHAPTER 5

Acquisition in the Digital Era

Despite the contributions from digital engineering approaches to defense programs for over two decades, DoD is still adopting its acquisition processes and approaches to reflect the accelerating advances and diffusion of digital engineering approaches and capabilities. The critical but uncertain link between MOSA and affordability will continue to be important for FVL. In many ways, affordability begins with simply living within one's means rather than optimistically estimating some cost savings that never materialize. This approach starts with realistic program cost estimates and program strategies. The overarching approach for the Army should be to leverage MOSA and digital engineering to live within their Army TOA. A stable budget and sound program management approaches are key contributors to program success. Concerning the budget for the FVL FoS, the Army must take a hard look at its cost estimates to ensure sober realism and maximal output from the available resources versus anticipating the need to ask for more in the future. By living within their means, FVL could be a model defense program, especially during the 2020s, when there will be many competing defense modernization priorities and budgetary pressures on defense overall.

Further Adapting the Better Buying Power Framework to the Digital Era

The FVL program has been at the forefront of using technology demonstrators (and in the next few years, prototypes) and MOSA approaches to help potentially reduce risk and life cycle costs. To date, the FVL program has de-risked through 14 different technology demonstrators.[46] A decade ago, the Army sponsored trade studies to determine if an avionics reference architecture could be developed. These studies included:

- "Boeing for mission scenarios/interoperable- based communications analysis;
- Honeywell Aerospace, conducting sensor and sensors fusion trade studies

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[46] Frank Colucci, "FVL on Four Fronts," *Vertiflite*, May/June 2021, https://vtol.org/files/dmfile/fvl-vf_mayjune_2021.pdf

- Lockheed Martin for trade studies regarding cockpit human-machine interface (HMI) technologies, capability-based mission equipment packages, weapons vs. targets vs. missions, and battlefield sensing optimization
- Rockwell Collins to study mission systems architectures
- Sikorsky for survivability optimization analysis; and for lethality and survivability systems trades and analysis tools."[47]

The Joint Common Architecture (JCA) studies determined that the JCA could derive from the Future Airborne Capability Environment (FACE). FACE is a reusable software standard co-developed by the government and industry. While FACE shows great promise and has achieved significant gains, integration into military systems requires substantial effort and program attention. Many Services have recently attempted ambitious software-oriented projects. For example, the Air Force's "Digital Air Force" initiative attempted to be an all-encompassing method to gather and share data throughout the Air Force and was met with mixed success.[48] There have also been efforts to develop a Universal Armaments Interface (UAI) in the last few decades. UAI is a U.S. DoD and NATO initiative to develop standardized functional interfaces in aircraft, weapons, and mission planning to support the integration of future weapons independent of aircraft OFP cycles.[49] These efforts show the importance of not just mission systems, but also weapons payloads.

The digital nature of the strategy for FVL program acquisition also increases the number of challenges surrounding of adapting DoD's previous Better Buying Power (BBP) 3.0 framework's applicability to the new platform. BBP presents a series of guidelines for acquisition programs to reduce costs in the long run. FVL benefits from lessons derived from the experience of previous rotary programs but also faces unique challenges on the digital front. The adaptation of BBP 3.0 concepts to FVL will require a combination of both hindsight from these past initiatives and new lessons that can inform how the U.S. military approaches new acquisitions in the future. Based on prior programs' experiences, a critical decision for the FVL will be its approach to intellectual property, not as a static decision, but one that can evolve to meet the program's needs across its lifecycle.

Besides increasing mission flexibility and generating rapid upgrades, MOSA increases the options for industry competition, and together these results can integrate to reduce long-term sustainment costs. These outcomes from MOSA would be in contrast to the current approach, where upgrades in today's platforms most often necessitate the full recertification

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[47] Mike Hirschberg, "JMR Technology Demonstration Update: The Road to Future Vertical Lift," *Vertiflite (JMR Tech Demo Update),* January/February 2016, https://vtol.org/files/dmfile/JMR_Intro-Vertiflite.pdf.

[48] "Donovan Stresses 'Digital Air Force's' Importance and Necessity," *Secretary of the Air Force Public Affairs*, July 9, 2019, https://www.af.mil/News/Article-Display/Article/1899838/donovan-stresses-digital-air-forces-importance-and-necessity/.

[49] For example, see Oren Edwards, "Universal Armament Interface (UAI)," *USAF Aeronautical Systems Center*, https://www.iqpc.com/media/6729/4428.pdf.

of aircraft operational flight programs (software). While MOSA proponents often highlight the potential for cost savings, CSBA's assessment of MOSA is that it may be more likely to enhance opportunities to avoid cost growth, which promise significant lifecycle savings. In addition, MOSA approaches may hold costs down while diversifying opportunities for new technologies and subsystem solutions.

Insights for Program Costs: Living Within the Means

The acquisition community has settled on a rule of thumb that 70% of program life-cycle costs are from O&S. Digital engineering and MOSA approaches may undermine this assumption when it comes to the FVL FoS, however, by creating new opportunities for cost savings over the life of FVL programs. That, in turn, means that continued reliance on this rule of thumb could contribute to exaggerated cost estimates.

Even without the application of digital engineering techniques and open architectures, there is much wider variation in costs across program lifespans than the 70% assumption indicates. Even for U.S. rotary-wing aircraft, O&S has varied historically from 55% to 85% of program life cycle costs. CAPE's own estimate for the rotary-wing program average is 68% for O&S, 4% for RDT&E, and 27% for Procurement.[50] In contrast, for UAVs, the average is 58% for O&S, 12% for RDT&E, and 28% for Procurement. Although UAVs perhaps vary more widely than rotary-wing programs, the era for those programs more closely approaches the digital engineering tools of today. So ultimately, program costs for each of the components in the FVL FoS may be closer to these averages than historical rotary-wing averages, which may lead some to disproportionately increase potential estimates of O&S, although corresponding investments up front (manifested in both RDT&E and Procurement budgets) would actually have a positive effect on reducing O&S downstream in the program lifecycle costs.

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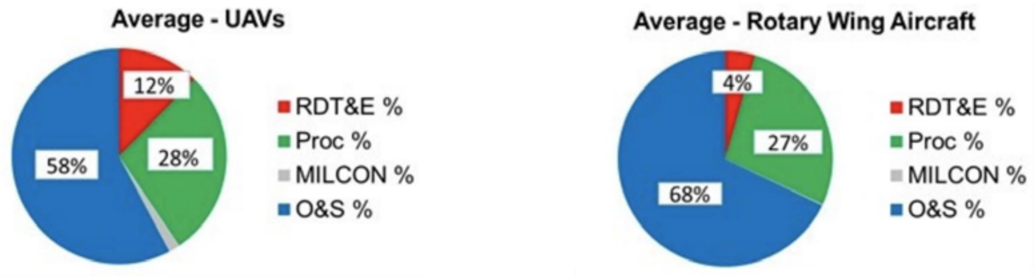
[50] See graphic in "Operating and Support Cost-Estimating Guide," *Office of the Secretary of Defense, Cost Assessment and Program Evaluation*, September 2020, p. 5, https://www.cape.osd.mil/files/OS_Guide_Sept_2020.pdf

FIGURE 16: OSD CAPE'S ESTIMATE OF ROTARY-WING AND UAV PROGRAM AVERAGE LIFECYCLE COST BY BUDGET CATEGORY



Credit: "Operating and Support Cost-Estimating Guide," *Office of the Secretary of Defense, Cost Assessment and Program Evaluation*, September 2020, p. 5, https://www.cape.osd.mil/files/OS_Guide_Sept_2020.pdf

From program, experience, and CAPE's O&S cost Guidebook, typically the two largest contributors to O&S costs are unit-level manpower and spare parts.[51] Investments by the Army upfront will be key to addressing these two main drivers. While not "gold-plating" system components, designing for reliability and maintainability, along with advancements in prognostic health monitoring (PHM) algorithms, should help identify parts that may have high consumable rates and target efforts to mitigate the reasons. Likewise, Army and defense prime efforts to increase the workflow rate of repair depots and flight line maintainers, from digital tech manual updates, cross-training, and other approaches, will be key to reducing cost contributions from unit-level manpower. Additionally, the Army and DoD typically focus on Cost Per Flying Hour (CPFH) as a key O&S metric, but Cost Per Tail Per Year (CPTPY) should be the primary, due to its more comprehensive considerations, with CPFH a secondary metric. This is because CPFH is highly variable and dependent on how many hours an aircraft is flown. CPTPY, in contrast, more accurately reflects total costs to operate and maintain an aircraft.

By operating as an open ecosystem, MOSA will also help avoid costly and time-consuming redesign to accommodate both hardware and software upgrades by making standards and interfaces readily available. Whether driven by threat advancements or capability needs, clear and easy availability of the interfaces and standards for key elements of the architecture will allow both the existing industrial base and potential new entrants to proactively prepare and sufficiently mature their subsystems and components for more rapid integration, testing, and fielding. Digital engineering may also alter production learning curves, challenging historical assumptions and assessment metrics. The Army, industry, and CAPE will have to collaborate to determine new predictions.

The Army should continue to use technology demonstrators and prototypes and emphasize open architectures and digital engineering to avoid technical overreach. To date, this is one of the most significant steps the Army has taken to prevent unaffordability on the

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[51] Ibid.

FVL effort. The Army should also emphasize upgradability/adaptability to avoid operational irrelevance. FVL has done this with its speed and range requirements, power/cooling requirements, and open architecture (MOSA) approach. Finally, it should seek more accurate and complete cost estimates to avoid unnecessary cost growth or perceptions of unusual cost growth. The Army should accomplish this goal by accurately appraising likely lifecyle costs, using digital engineering to narrow the band of uncertainty, and picking more suitable metrics to assess program performance.

Conclusion

Future Vertical Lift is one of many key defense programs that the United States looks to harness for near-peer competition with adversaries like Russia and China. Acquisition programs have failed to move to full-rate production while also missing opportunities to frequently, but measuredly, incorporate new technology and capabilities upgrades. Without these, existing platforms with decreasing relevance to high-end combat have blunted the United States' ability to maintain a competitive pace with these competitors, leading to continued calls for more efficient acquisition processes. While life extension of current platforms has somewhat contributed to extending the U.S. military advantages, this competitive advantage is eroding as systems near the end of their lifespans, the advancement of threat capabilities increase, and new systems must be fielded to fill emerging critical capability gaps.

The challenges and lessons presented in this report are not only relevant for FVL procurement but broadly apply across the U.S. military acquisition enterprise. A refined digital approach to FVL serves as a baseline for how future platforms and capabilities can be designed, planned, and produced. The program itself represents a decisive pivot point by which Washington can either remain entrapped in current acquisition feedback loops or pioneer new innovative strategies to modernize its forces properly.

Historical trends in the U.S. defense-industrial base and the prior experiences of current and canceled rotary platforms demonstrate that the FVL affordability issue is symptomatic of broader systemic challenges in the acquisition process. Going forward, U.S. defense planners will have to carefully re-examine programmatic timelines and sustainment models to determine how and where costs increase significantly. Furthermore, the growing digitalization of U.S. platforms and increased requirements for jointness and multi-mission capabilities will further strain acquisition programs. Current efforts to streamline programs and reduce costs must factor in the effects of digital architectures/engineering, as the shape of defense procurements will continue to change in the medium-to-long term.

LIST OF ACRONYMS

A2/AD	Anti-Access Area Denial
AAH	Advanced Attack Helicopter
AFC	Army Futures Command
AH	Attack Helicopter
ALE	Air-Launched Effects
AMC	Army Material Command
AMRDEC	Army Aviation and Missile Research, Development and Engineering Center
ARH	Armed Reconaissance Helicopter
ARVN	Army of the Republic of Vietnam
BBP	Better Buying Power
CAPE	Cost Assessment & Program Evaluation
CBO	Congressional Budget Office
CD&RR	Competitive Demonstration and Risk Reduction
CDC	Combat Development Command
CFT	Cross-Functional Team
CG	Commanding General
CMOSS	C5ISR/EW Modular Open Suite of Standards
COCOM	Combatant Command
COE	Common Operating Environment
CONOP	Concept of Operations
CPFH	Cost Per Flying Hour
CPTPY	Cost Per Tail Per Year
CRD	Controller of Research and Development
CRS	Congressional Research Service
CS	Capability Sets
CSBA	Center for Strategic and Budgetary Assessments
CTA	Configuration Trades and Analysis
DARPA	Defense Advanced Research Projects Agency
DAU	Defense Acquisition University
DDRE	Director Defense Research and Engineering
DILR	Detection, Identification, Location, and Reporting
DMAG	Deputy's Management Action Group
DoD	Department of Defense
DOT&E	Director, Operational Test and Evaluation
FACE	Future Airborne Capability Environment

FARA	Future Attack Reconaissance Aircraft
FCS	Future Combat Systems
FLRAA	Future Long-Range Assault Aircraft
FMS	Foreign Military Sales
FoS	Family of Systems
FRIP	Full Rate Initial Prodcution
FUAS	Future Unmanned Aircraft System
FUE	First Unit Equipped
FVL	Future Vertical Lift
GDP	Gross Domestic Product
HMI	Human-Machine Interface
IADS	Integrated Air Defense Systems
IC	Intelligence Community
ICD	Initial Capabilities Document
IP	Intellectual Property
ISA	Integrated Sensor Architecture
ISRT	Intelligence, Surveillance, Reconaissance, and Targeting
JCA	Joint Common Architecture
JMR TD	Joint Multi-Role Technology Demonstrator
JPO	Joint Program Office
JROC	Joint Requirements Oversight Council
LCC	Life Cycle Cost
LRIP	Low Rate Initial Production
LRPF	Long-Range Precision Fires
M&S	Modeling and Simulation
MCM	Mine Countermeasures
MCO	Major Combat Operations
MDO	Multi-Domain Operations
MEDEVAC	Medical Evacuation
MOSA	Modular Open Systems Architecture
MVP	Minimum Viable Products
NGCV	Next-Generation Combat Vehicle
NVA	North Vietnamese Army
O&S	Operations and Support
OSD	Office of the Secretary of Defense
PBL	Performance-Based Logistics

PEO	Program Executive Office
PHM	Prognostic Health Monitoring
PM	Program Manager
QMR	Qualitative Material Requirements
QMDO	Qualitative Material Development Objective
RAH	Reconaissance and Attack Helicopter
R&D	Research and Development
SA	Secretary of the Army
SLEP	Service Life Extension
SLOC	Source-Lines of Code
SOAR	Special Operations Aviation Regiment
SOCOM	Special Operations Command
SOSA	Sensor Open Systems Architecture
SPU	Supplemental Power Units
STEM	Science, Technology, Engineering, and Math
SWAP-C	Space, Weight, Power, and Cooling
TOW	Tube-launched, Optically tracked, Wire-guided
TPP	Total Package Procurement
UAI	Universal Armaments Interface
UAM	Urban Air Mobility
UAS	Unmanned Aircraft System
USAACE	US Army Aviation Center of Excellence
USAF	United States Air Force
USCG	United States Coast Guard
USMC	United States Marine Corps
USN	United States Navy
VICTORY	Vehicle Integration for C4ISR/EW Interoperability

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