Research Report

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Department of Defense Considerations for Leveraging Commercially Developed Emerging Technologies

Preliminary Insights from Advanced Air Mobility

Traditionally, the defense sector has been an important source of technological innovation, not just for military capability but also for the broader civilian economy. In recent years, this development pipeline has increasingly flowed in the opposite direction, with commercial markets developing technologies that have derivative military applications.[1] At the same time, recent U.S. national security guidance shows a renewed U.S. commitment to sustain its innovation edge by investing in cutting-edge technologies and, more broadly, U.S. technological leadership and to protect these investments to enable national security objectives (Biden, 2021). In this environment, it has become more imperative for the U.S. Department of Defense (DoD) to work closely with U.S. commercial entities to both promote commercial technology innovation and shape, acquire, field, and sustain commercially developed technology. To effectively perform these activities, DoD will need to identify existing tools and develop new approaches. Ongoing efforts to leverage innovation from a commercially dominated market may provide insights.

One recent example is the emergence of advanced air mobility (AAM) technologies, including those for electric vertical takeoff and landing (eVTOL) aircraft. By the end of 2021, the AAM commercial market had attracted at least $12.8 billion in investment, with several of the industry's highest-valued firms based in the United States (Esqué and Riedel, 2022). Recognizing the potential for military application of this commercially developed technology, the Air Force Research

Laboratory launched the Agility Prime Program within AFWERX in April 2020 to "expand technology transition paths to accelerate emerging dual-use transformative vertical lift markets by leveraging government resources for rapid and affordable fielding" (AFWERX, undated). Agility Prime is intended to help the U.S. Air Force (USAF) (1) advance a commercially developed technology that has potential military applications and (2) navigate a path to transition such a technology to the warfighter.

The Agility Prime team includes a core group of program managers and engineers, supported by the broader AFWERX infrastructure, who leverage government resources for AAM-related efforts through several mechanisms, the most prominent of which is AFWERX's innovative capabilities opening. Through this opening, AAM companies that align with published areas of interest may proceed through three phases of downselection: response to a request for information; an engagement opportunity with the Agility Prime team; and, finally, submission of a written proposal for potential award of an Other Transaction for Prototype agreement.[2] These agreements generally tend to support the test and evaluation of AAM aircraft, while additional Small Business Innovation Research contracts support R&D activities. In addition to these funding mechanisms, Agility Prime leverages USAF test infrastructure, certification authorities, and interagency relationships to create a government-industry partnership that is mutually beneficial. AAM companies benefit from access to the unique aviation infrastructure and expertise of the USAF, while the USAF obtains technical and operational test data, as well as market intelligence to inform future AAM operational concepts and acquisition decisionmaking.

As a part of the Agility Prime effort, the Air Force Research Laboratory asked RAND Project AIR FORCE to provide an assessment of AAM developments, the potential for AAM technologies to support military missions, and the implications of AAM commercial markets for DoD objectives. Our preliminary findings provide a number of useful insights as DoD explores ways to leverage commercially derived technologies. In summary, these finding indicate that, while there are opportunities for AAM capability to contribute to various USAF missions, the potential for DoD to constitute a small market share may challenge its ability to shape the technology for defense-specific capabilities. As it considers whether to acquire AAM platforms and how to do so, given the market's commercial orientation, DoD has many tools at its disposal, aside from its buying power, to support U.S. technological leadership and military adoption of AAM. Furthermore, while DoD has numerous mechanisms to facilitate early R&D activities, experimentation and acquisition mechanisms for emerging technologies are limited and hindered by numerous barriers. These preliminary findings indicate that, regardless of whether the U.S. military ultimately adopts AAM technologies, AAM may provide a useful case study for DoD as it explores ways to leverage commercially derived technologies.

While our ultimate findings and recommendations from this research, presented in Goldfeld et al. (forthcoming), do not recommend large-scale USAF adoption of eVTOL technology at this time, the insights shared from these preliminary findings should still provide value to DoD's efforts to leverage commercially derived technologies.

Abbreviations

AAM	advanced air mobility
DoD	U.S. Department of Defense
eVTOL	electric vertical takeoff and landing
R&D	research and development
USAF	U.S. Air Force

Insights from Ongoing AAM Efforts

Our research has identified a set of considerations that should help to inform DoD decisionmaking when considering involvement in relevant commercially developed emerging technologies. Does the technology have the potential to cost-effectively contribute to operational capability needs? If so, what constraints and opportunities for achieving national security innovation objectives does the technology's commercial market pose? Further, what opportunities are currently available to prepare for future adoption of the technology as a defense capability? Finally, how can the technology be transitioned to the defense sector? In this chapter, we provide related insights for AAM technologies.

U.S. Military Applications of eVTOL Aircraft

State-of-the-art, battery-powered eVTOL aircraft are capable of transporting three to five people or approximately a ton of cargo (~200 cubic feet of space) for approximately 150 miles in one hour. While capable of short-duration vertical flight during takeoff and landing, these aircraft are unable to sustain hovering flight because this results in extreme electrical drain on the battery. Thus, in comparison with traditional reciprocating or turbine-powered helicopters, eVTOL aircraft currently offer inferior capability. However, eVTOL aircraft companies and independent analyses project that, when produced in quantity, these aircraft are likely to be less expensive to acquire and significantly cheaper to operate than traditional helicopters (Morgan Stanley, 2021; Joby Aviation, 2021; Booz Allen Hamilton, 2018; Mihara et al., 2021). These projections suggest commercial prices lower than those for a helicopter and equal to or slightly higher than those for luxury automobile ridesharing.[3] This framing provides for an entirely different set of applications for the USAF and DoD to explore.

As part of our assessment, we have explored such applications through a set of use cases. For example, the USAF could use eVTOL aircraft to ferry people and parts inside test and training ranges, such as the Nevada Test and Training Range, the Eglin Range, or perhaps the Utah Test and Training Range. Currently, each of these relatively large ranges relies on surface transport for this purpose. Range leadership we spoke with stated that the large areas and remote locations of some ranges result in long transport times for individuals commuting from their homes or when traveling across the range itself. They discussed how this creates challenges for, respectively, recruiting and maintaining staff and meeting range time demands. Our preliminary findings indicate that eVTOL aircraft use on these ranges could greatly reduce transport times, which would save time for individuals traveling across ranges and commuting to ranges in remote locations. Range leadership stated that this would allow the ranges to be open longer each day and, potentially, reduce attrition.

As another example, eVTOL aircraft could support the USAF's future concept for agile combat employment, which leverages dispersion of forces into mobile, small, and relatively autonomous force packages reliant on shared resources. This employment method will likely increase mobility requirements and, in turn, the operational demands for such aircraft as the C-17 and C-130. Small fleets of eVTOL aircraft could be used in this concept to conduct operational support airlift missions and release these C-17s and C-130s to perform other missions. These eVTOL fleets could provide crucial movement of people and small parts within an agile combat employment cluster, for example, to return an F-35 radar circuit board to service or to transport a flight surgeon to a forward location in an emergency.

Discussions with operational communities across the USAF, other services, and the combatant commands have revealed a number of other potential use cases for eVTOL aircraft, including personnel recovery, short-range logistics and resupply, and last-mile tactical delivery. However, many of these operational stakeholders stated that eVTOL capabilities did not align with their current capability gaps.[4] Instead, they expressed interest in observing how the technology evolves and matures. AAM developers we spoke with discussed directing their efforts and investment toward new airframes and new lift and propulsion

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systems. While these companies did not discuss intentions to develop new battery systems, AAM performance should soon benefit from battery and electrification investment and development trends more generally.[5] As the available battery technology improves, eVTOL performance attributes such as hover time, range, and payload will increase.

If eVTOL company cost projections hold true, the technologies could have the potential to cost-effectively contribute to various USAF, and more broadly DoD, missions.[6]

Achieving National Security Innovation Objectives in a Global, Commercial AAM Market

Given the potential for military applications for AAM technologies, subsequent questions surrounding the constraints and opportunities that the AAM market presents rise to the forefront. Such constraints and opportunities can inform DoD efforts to meet the national security innovation objectives of (1) ensuring a secure, reliable, and timely supply of suitable AAM platforms to meet military requirements, if and when DoD determines it should buy them, and (2) ensuring "U.S. technological leadership," as detailed in the Interim National Security Strategic Guidance (Biden, 2021).

Our preliminary analysis indicates that the AAM market's heavily commercial orientation will likely be a dominant constraint on DoD effectively pursuing its objectives. Our review of market forecasts and data, as well as numerous stakeholder discussions, indicate that a global, commercial AAM market is very likely to emerge over the next ten years, with DoD likely constituting a very small share of total industry demand once commercial growth accelerates. Estimates of global AAM markets from financial and consulting firms range from a low of $90 billion to a high of $1.5 trillion in cumulative value by 2050.[7] For comparison, the fiscal year 2022 President's Budget includes a total of $25.1 billion in aircraft procurement spending, none of which includes cargo aircraft procurement, and $6.2 billion of which is for helicopters, including the V-22 Osprey (Office of the Under Secretary of Defense [Comptroller]/Chief Financial Officer, 2021).

The commercial orientation of a global AAM market would affect DoD interests in the technology in several ways, particularly as the AAM industrial structure evolves to meet the needs of a large, global customer base. Currently, the United States is home to several of the worlds' leading companies developing AAM technology and operational concepts, and these companies tend to keep manufacturing in house to facilitate product development. However, as the industry matures and moves from test ranges to real-world operations, our preliminary analysis indicates that market forces could shift the geographical locus of AAM production and technological leadership. For instance, the pace of regulatory approval of AAM platforms and operating infrastructure will be an important driver of the location of AAM operational rollout; the economics of scaled production might ultimately favor global supply chains and non-U.S. AAM production hubs.

These potential shifts in the geography of AAM employment and production have implications for DoD interests in AAM technology. First, DoD cannot depend on the continuation of domestic production to ensure secure, reliable, and suitable AAM supply. Additionally, in terms of U.S. technological leadership, because operational and manufacturing experience is an enabler of technological development, AAM technological leadership might follow any market-induced geographical shifts in their use and production.

At the same time, its relatively small market share of the global market could limit the DoD's ability to pursue its AAM objectives through buying power. That is, if the AAM industry does not see DoD as an important customer—given the large,

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global, commercial customer base—traditional mechanisms, such as defense-specific technical and sourcing requirements that favor U.S.-based development and production might have little influence on the market's direction.

Yet as Agility Prime's involvement in the AAM industry demonstrates, DoD has means other than buying power to foster secure and reliable supply and to support U.S. technological leadership. Our analysis of Agility Prime's influence on the AAM industry indicates that many of the most promising opportunities for DoD to pursue are in the early stages of market development, when firms depend primarily on investment for operating funds. Since investment funding is motivated by the potential for future profits, uncertainty over future technological and business success can compromise firms' ability to continue product development. While the volume of DoD spending might be dwarfed by current private investment and future commercial sales, DoD can still pursue its objectives by offering firms in the AAM industry financial and nonfinancial benefits that differ in key ways from investment funding.

For instance, for such emerging technology industries, DoD can blunt the effects of investment volatility on technological progress by awarding funding to firms based on metrics related to successful technology improvement. This differs from investors, who often provide funds based on potential future market success. AAM investors and companies stated that revenue from the USAF, which was tied to technology development activities, has had outsized benefits because it came at times when investors were particularly apprehensive, such as during the early stages of the COVID-19 pandemic. Moreover, it seems USAF investment played a role in attracting investors to the industry. Several AAM companies advertised partnership with the Agility Prime program to potential investors, suggesting that USAF investment enhanced investors' perceptions of the AAM industry and firm credibility. Also, AAM investors explicitly noted to us that USAF investment informed their investment decisionmaking for specific companies.[8]

Stakeholders further stated that USAF partnership has enabled companies to mitigate the consequences of technical uncertainty during the development process. For example, Agility Prime participants have had opportunities to gain operational experience during flight testing that should later enhance operational performance in commercial transportation markets. Testing and operating an eVTOL under conditions that push the platform's limits can also facilitate the development of safety protocols and features that enhance the safety of later platform iterations.

In addition to mitigating the consequences of uncertainty, there are indications that Agility Prime has furthered the development of a diverse and competitive U.S. AAM market by providing specialized resources to industry-wide commercialization efforts. USAF testing infrastructure, pilots, and expertise have directly contributed to the development of technical and regulatory standards, such as federal airworthiness certification requirements. AAM stakeholders also mentioned that these resources accelerated companies' ability to proceed through federal certification by, for instance, providing opportunities for technical refinement and meeting flight-hour requirements. All are critical for successful commercialization. Without USAF participation, these resources would have been challenging to

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assemble at an industry-wide scale at such quality, quantity, and speed.

In summary, a global, commercially oriented market for a new technology may limit DoD's ability to pursue its objectives through its buying power. Nonetheless, our analysis of Agility Prime indicates that DoD has several other carrots to offer industry.

Planning for Military AAM Adoption

Adoption of AAM technologies by U.S. or adversary militaries remains uncertain. If these technologies are adopted by either, the current time frame presents DoD with a window of opportunity to influence technology design and plan for the support infrastructure.

First, our discussions with AAM stakeholders indicate that at least some AAM companies have adopted an early business model that hedges against the risk of slow or limited commercial adoption by focusing on dual-use capabilities. This environment provides an opportunity for DoD to shape AAM technology evolution and maturation to consider defense-specific capability needs. Indeed, one AAM company revealed to us that it had prioritized a defense-specific capability in its design because of the Agility Prime partnership. Given that DoD will likely comprise a very small share of the AAM market, early involvement, such as the Agility Prime effort, may present the best opportunity to influence AAM technology design.

Second, adoption of these technologies will require DoD to develop some infrastructure to support AAM employment, including electric charging infrastructure, pilot training, and related concepts of employment. Agility Prime is supporting such planning efforts, for example, with Air Education and Training Command to develop eVTOL pilot training and has requested that electric infrastructure requirements and considerations be explored as part of our own work. Preliminary findings from our assessment indicate that eVTOL electricity requirements will exceed what is consumed at an average hangar and that an acre of solar panels could charge four to six eVTOL aircraft daily. In developed countries with robust electrical power grids, employing eVTOL aircraft may not require much new electrical infrastructure. However, employment in less-developed countries may require DoD to secure alternative electrical supplies, such as mobile generators and renewable sources in the near term or, possibly nuclear microreactors in the medium to long term. Some of these sources reduce fossil fuel and grid-related dependencies but, similar to stationary energy sources for traditional helicopters and automobiles (i.e., large fuel storage tanks), are vulnerable to attack. These considerations indicate that diversifying energy sources could improve mission resilience more generally but that the mission impact of eVTOL support infrastructure requires further analysis. Early insights and planning, such as these, can enable DoD to deploy resilient AAM capabilities more rapidly.

Pathways to Defense Transition for AAM

The U.S. commercial industry currently outpaces DoD in many areas of technology innovation. To leverage commercial innovation, DoD must have the ability to successfully transition emerging technologies to the defense sector. This includes the mechanisms to perform or support R&D activities, allow operators to experiment with the technology in a relevant environment, and acquire the technology for the warfighter. Our research effort for AAM indicates that, while DoD has numerous mechanisms to facilitate early R&D activities,[9] experimentation and acquisition mechanisms for emerging technologies are limited and obfuscated by numerous barriers.

In terms of acquisition mechanisms, operational community sponsorship acts as the traditional and dominant gateway to transitioning a technology to the warfighter. However, numerous disincentives exist to operational community sponsorship of an emerging capability. Operational stakeholders we spoke to, for instance, discussed that fulfilling both immediate and emerging capability needs falls under the same fixed budget, which often deprioritizes future needs. Further, capability sponsorship documentation preparation is nontrivial and requires specific expertise, which is often in short supply. These disincentives likely contribute to the reluctance we found in the operational community to sponsor an AAM capability unless it clearly aligns with a current operational gap. To overcome such disincentives, an emerging capability, therefore, must show clear, significant, and immediate military value. Experimentation activities could help demonstrate such value. However, under current DoD practices, most military experimentation mechanisms are aligned with sponsored capabilities. This, in turn, creates a chicken-and-egg problem: To access experimentation opportunities, emerging technologies must align with a sponsored capability, but obtaining capability sponsorship is difficult without demonstrating value through experimentation.

While other paths to DoD technology transition exist, they are few, are mostly uncharted, and lack formal mechanisms to facilitate them. These findings indicate a need for DoD to develop new and untraditional means of commercial technology transition to the defense sector. Regardless of whether militaries adopt AAM technologies, the technology and its current status in the commercial and defense sectors present an appropriate test case for DoD technology transition. Indeed, we have been unable to find another technology transition case with the same attributes as AAM—attributes that are more likely to emerge in the future as commercial innovation continues to outpace that of DoD. As part of this AAM test case, barriers could be identified and mitigations or work-arounds could be developed. Untraditional paths and informal mechanisms could be tested.

Such efforts can pave the way for smoother technology transitions, more generally, in the future. As one example, we are exploring the potential of the range support use case to serve the same purpose as experimentation events. While test and training range stakeholders we spoke with saw potential value in AAM, this use case alone may not justify the sponsorship of the operational community. Instead, the USAF could acquire a small quantity of AAM platforms for range use that could provide direct benefit to a range, while also increasing AAM access and experience to the USAF more broadly. As another example of an ongoing AAM-related effort, the Agility Prime program is using ad hoc mechanisms to support the efforts of capability sponsorship for Air Force Futures, a nontraditional sponsor. Air Force Futures is a relatively new office that has the important mission of identifying USAF enterprise-wide capability needs for future force planning, independent of the siloed and near-term-focused functional operational commands. While it has the potential to sponsor a capability requirement, it has yet to exercise this authority and may, therefore, benefit from the lessons of more-experienced organizations. The partnership with Agility Prime has the potential to facilitate the process for future emerging capabilities as well.

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Conclusion

As outlined in the Interim National Security Strategic Guidance (Biden, 2021), DoD has many factors to consider as it makes decisions about investments in the portfolio of emerging technologies, which includes both technologies developed organically to fulfill a specific defense capability and commercially developed technologies with potential defense applications. Investment in the former is often directly tied to warfighter objectives, while that in the latter may also include broader objectives for U.S. technological leadership and national security. The appropriate level of investment across this portfolio, as well as between technologies, is a question the USAF is currently confronting (e.g., Tirpak, 2022). Given a fixed technology development budget, investment in additional technologies equates to fewer resources for other technologies in the portfolio. Each technology investment carries the risk of failure to cost-effectively support operational needs and improve broader national security objectives.

As with any emerging technology that has potential military applications, DoD must weigh the costs of preparing for military AAM adoption against the risk that such adoption is not realized. Investment in AAM should also be considered within the broader DoD portfolio investment strategy for emerging technologies. Will AAM investments provide more value to DoD than investments in other emerging technologies? As DoD weighs these costs, risks, and benefits, it may also be worth considering the contributions AAM-related efforts can provide to broader goals of sustaining U.S. technological leadership and national security.

While our preliminary research does not answer the question of whether USAF investments in AAM have been cost-effective or if involvement in AAM is more valuable than that of other emerging technologies (for answers to those and other related questions, we point readers to Goldfeld et al, forthcoming), it does indicate DoD's need for additional tools to leverage innovation from a commercially dominated technology market. AAM technologies can provide a useful case study for DoD as it develops such tools and prepares for the next commercially derived, military-relevant technology that is discovered.

Notes

1 For instance, according to data from the U.S. Bureau of Economic Analysis and the National Science Foundation, since 1953, the federal government's share of total U.S. research and development (R&D) spending peaked at a ten-year average of 65 percent from 1957 to 1966. Since then, it has declined to a ten-year average of just over 25 percent from 2010 to 2019. Over the same time frame, the U.S. business sector's share of total U.S. R&D spending increased from an average of just under 33 percent to an average of 67 percent for the same ten-year periods (National Science Foundation, 2021).

2 See SAM.gov, 2021, for the award opportunity.

3 For example, Booz Allen Hamilton, 2018, projected the price per passenger-mile of a five-seat eVTOL aircraft to be about 33 percent higher than luxury ridesharing, while Morgan Stanley, 2021, p. 19, states that many eVTOL companies "are targeting prices comparable to an Uber Black ride."

4 Operational stakeholders discussed, for instance, that existing weapon systems met the relevant capability requirements and, therefore, eVTOL aircraft may be more appropriate to consider at the time of legacy system replacement.

5 Lienert and Bellon, 2021, reports that global automakers plan to invest over $500 billion in battery-powered vehicle technology by 2030, including recent investments in next-generation batteries that are solid state, semi–solid state, or lithium-metal. See also Blois, 2022.

6 We are currently exploring the cost-effectiveness of eVTOL aircraft for various use cases, including those discussed here. These findings will be presented as part of the final report.

7 See, for instance, Morgan Stanley, 2018; Crown Consulting, Inc., et al., 2018; Terry et al., 2019; Hader et al., 2020; Booz Allen Hamilton, 2018.

8 DoD participation in an emerging market in which firms are otherwise largely dependent on investor funding also has several potential drawbacks to consider. For instance, if the firms that find DoD partnership most appealing are firms that investors have concluded are less likely to succeed in the commercial marketplace, DoD might systematically partner with firms that are disproportionately likely to eventually fail. We did not evaluate any such selection mechanisms in Agility Prime participation. Of course, selection could also work in the opposite direction (i.e., DoD partnership might, instead, exhibit selection of the firms most likely to eventually succeed). Assessing potential selection biases of DoD-industry partnership pathways and assessing other unintended consequences of DoD participation in markets for emerging technologies could be areas of future analysis.

9 Such mechanisms include the Defense Innovation Unit; the Agility Prime program's overarching organization, AFWERX; cooperative research and development agreements; and many others. For a review of such mechanisms, see Sargent and Gallo, 2021.

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About This Report

This report provides preliminary insights from a project to assess advanced air mobility (AAM) developments, the potential for AAM technologies to support military missions, and the implications of AAM commercial markets for U.S. Department of Defense (DoD) objectives. It should provide a number of useful insights as DoD explores ways to leverage commercially derived emerging technologies.

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