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FLYING DIRTY: EVTOL CASEVAC ON THE CONTAMINATED BATTLEFIELD

by

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The American military's reliance on manned airpower on the modern battlefield invites a critical vulnerability for great power adversaries to target with chemical, biological, radiological, and nuclear (CBRN) weapons. Modern efforts to increase combat effectiveness are incremental improvements to decades-old technology that fail to fundamentally change how the Joint Force fights in a contaminated environment. Ongoing military adoption of emerging commercial aviation technology could be readily leveraged to shore up this critical vulnerability. By presenting three articles intended to address distinct aspects of this capability, this capstone aims to demonstrate that unmanned electric vertical takeoff and landing (eVTOL) aircraft can remove the aircrews from a dangerous and dirty task, preserving manned combat power for the broader war effort. However, the military must overcome both technical and cultural barriers for adoption to be successful. These barriers can be overcome by establishing and leveraging advocacy networks and tying innovative solutions to operational challenges. To ignore the promise that these future technologies present will risk remaining vulnerable to a credible threat in a future great power conflict.

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ABSTRACT

The American military's reliance on manned airpower on the modern battlefield invites a critical vulnerability for great power adversaries to target with chemical, biological, radiological, and nuclear (CBRN) weapons. Modern efforts to increase combat effectiveness are incremental improvements to decades-old technology that fail to fundamentally change how the Joint Force fights in a contaminated environment. Ongoing military adoption of emerging commercial aviation technology could be readily leveraged to shore up this critical vulnerability. By presenting three articles intended to address distinct aspects of this capability, this capstone aims to demonstrate that unmanned electric vertical takeoff and landing (eVTOL) aircraft can remove the aircrews from a dangerous and dirty task, preserving manned combat power for the broader war effort. However, the military must overcome both technical and cultural barriers for adoption to be successful. These barriers can be overcome by establishing and leveraging advocacy networks and tying innovative solutions to operational challenges. To ignore the promise that these future technologies present will risk remaining vulnerable to a credible threat in a future great power conflict.

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LIST OF ACRONYMS AND ABBREVIATIONS

CASEVAC	casualty evacuation
CBRN	chemical, biological, radiological, nuclear
CBW	chemical and biological weapons
COTS	commercial off-the-shelf
DOD	Department of Defense
eVTOL	electric vertical takeoff and landing
FAA	Federal Aviation Administration
PPE	personal protective equipment
WMD	weapons of mass destruction

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EXECUTIVE SUMMARY

The Joint Force remains vulnerable to the threat of chemical and biological weapons (CBW) on the contaminated battlefield. Although widely absent on the battlefield since World War I, these weapons remain not only a pivotal instrument of deterrence during strategic competition, but also a looming threat that could readily threaten America's reliance on manned airpower during a major conflict.

This report proposes the adoption of commercial aviation technology as an unmanned casualty evacuation platform to preserve invaluable aircrews and limited airpower from contamination. To do so, this report frames the validity of the threat of CBW on the modern battlefield, identifies risk in the current approach to manned casualty evacuation, and showcases the feasibility of emerging technology to preserve the force. Finally, this report identifies the technical and cultural barriers to adoption of this innovative technology.

America's reliance on manned aircraft presents a possible critical vulnerability that invites the use of adversarial CBW. These weapons represent an asymmetric threat capable of impeding freedom of maneuver and rapidly contaminating American combat power and fighting power. Evacuation of contaminated patients forces commanders to balance risk to the casualties against the likely loss of valuable aircrews and aircraft sent to their aid. Loss of aircrews and aircraft in this mission will rapidly degrade the ability to sustain other warfighting domains. Unmanned aircraft provide an expendable option to expedite evacuation and treatment of patients while reducing contamination exposure to manned platforms critical to sustaining the broader fight.

Research highlights the additional risks of manned casualty evacuation in contaminated environments posed by the limitations of current protective equipment and decontamination efforts. Protective ensembles degrade aircrew performance by limiting crew endurance, visibility, communication, and dexterity. These mitigations are necessary to operate in the threat environment but incur tangible risk to aircrew, the patient, and the overall mission. Additionally, service publications explicitly acknowledge that post-

mission decontamination is unlikely to eliminate the residual contamination risks.[1] Commanders will be forced to either abandon and replace contaminated aircraft or accept the continued risk of exposing future crews to the hazards.

This research recommends an unmanned solution to contaminated casualty evacuation. The commercial electric vertical takeoff and landing (eVTOL) market is developing aircraft and associated capabilities that can expendably evacuate patients from point of injury and transfer to manned platforms outside of the contamination hazard. The electric component is promising, not for its use of alternative energy sources, but due to the global competition in the electric vehicle market that will expand the performance envelope and drive down price of these systems. Due to non-disclosure agreements, financial analysis is offered separately, but open-source data suggest operating costs less than $700 per flight hour compared to over $5,000 for a UH-60 or over $25,000 for a CV-22.[2] Most importantly, the remotely piloted or autonomous capabilities offer the true value in removing the human aircrew as well as low-quantity and high-demand aircraft. While experts debate the feasibility of future autonomous platforms on the battlefield, the military can readily leverage the last two decades of experience with remotely piloted aircraft to field an unmanned aircraft for contaminated casualty evacuation.

This capstone focused heavily on both the operational problem and the utility of emerging technology; however, research found that the greatest barriers to adoption will likely be largely cultural rather than technical. Reluctance to use unmanned systems with human passengers, medical objections regarding unsupervised transfer of patients, and cultural hesitance to remove the aviator from the cockpit require the most effort to successfully overcome. Additionally, though the military has invested early in supporting the eVTOL market, it is not yet postured to incorporate them into service. Research points to Special Operations Command as a prime candidate for initial adoption of eVTOL aircraft

[1] Department of the Air Force, *Operations in a Chemical, Biological, Radiological, and Nuclear (CBRN) Environment*, AFMAN 10–2503 (Washington, DC: Department of the Air Force, 2019), https://static.e-publishing.af.mil/production/1/af_a4/publication/afman10-2503/afman10-2503.pdf.

[2] Comptroller of Program/Budget, "Fiscal Year (FY) 2021 Department of Defense (DOD) Fixed Wing and Helicopter Reimbursement Rates" (official memorandum, Washington, DC: Department of Defense, 2021), https://comptroller.defense.gov/Portals/45/documents/rates/fy2021/2021bc.pdf.

for this use case. Alternatively, there may be precedence for operational commanders to contract out casualty evacuation services with emerging unmanned aircraft.

In addition to separate deliverables to the research sponsor, the capstone team submitted three targeted journal articles to highlight the operational demand and opportunity as well as illuminate barriers to military adoption of eVTOL technology. The first article highlights the role for technology in improving the combat effectiveness for the Joint Force to fight and win on the contaminated battlefield. The second article illuminates the classic medical barriers to adoption of unmanned systems for casualty evacuation. The third article frames the technical, regulatory, and cultural barriers to adoption of eVTOL by the Joint Force.

Future research should focus in several areas to bolster military adoption of eVTOL aircraft for this use case. Though wargaming of unmanned casualty evacuation significantly informed this research, quantitative simulation of unmanned eVTOL capabilities and comprehensive financial analysis should be performed as higher fidelity data becomes available. Additionally, efforts should focus on broadening the advocacy network to foster adoption of this innovative technology to overcome current cultural barriers.

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I. UNMANNED CASUALTY EVACUATION ON THE CONTAMINATED BATTLEFIELD

> Whether or not gas will be employed in future wars is a matter of conjecture, but the effect is so deadly to the unprepared that we can never afford to neglect the question.
>
> —General John Pershing[1]

The mission that nobody wants to execute, train to, or plan for: operating in a chemically or biologically contaminated environment against a great power adversary. These weapons pose an asymmetric threat to America's conventional strengths, specifically the reliance on manned aircraft for rapid freedom of maneuver on the battlefield. The U.S. military's reliance on high-demand and low-quantity aviation assets and crews for one of its most dangerous missions, casualty evacuation (CASEVAC), coupled with the risks of a contaminated battlefield creates a potentially critical vulnerability to the U.S. military's ability to sustain major combat operations. While the Department of Defense (DOD) dedicates significant resources to the development of countermeasures and protective equipment to improve the survivability of aircrews and aircraft, these incremental advances have done little to fundamentally change the nature or the risks of warfare on the contaminated battlefield since World War I. However, emerging technology provides a novel solution to decrease the risks faced by the aircrews and aircraft tasked with supporting these operations. Rather than increase the survivability of flight crews with better protective equipment, unmanned electric vertical takeoff and landing (eVTOL) aircraft may remove them altogether from the burdensome and dangerous task of casualty evacuation on the dirty battlefield.

[1] Charles E. Heller, *Chemical Warfare in World War I: The American Experience, 1917–1918*, 91, The Leavenworth Papers (Fort Leavenworth, KS: Combat Studies Institute, U.S. Army Command and General Staff College, 1984), https://www.armyupress.army.mil/Portals/7/combat-studies-institute/csi-books/leavenworth-papers-10-chemical-warfare-in-world-war-i-the-american-experience-1917-1918.pdf.

A. A DIRTY THREAT, A DIRTY JOB

Historical vignettes confirm the operational utility of chemical and biological weapons on the battlefield while modern open-source intelligence illuminates adversarial capabilities and intent to use them. World War I (WWI) saw the first widespread use of chemical warfare, which added "additional strain on every aspect of combat" and illuminated the risks to conventional warfighting doctrine.[2] Though use of chemical weapons was narrowly avoided in World War II, both sides planned to wage chemical warfare to desperately defend against invasion.[3] During the Cold War, the Soviets recognized the vulnerability of NATO forces to fight on the contaminated battlefield and widely integrated offensive chemical and biological weapons (CBW) into their warfighting strategies.[4] More recently, analysts warn of the possible intent of America's adversaries to use chemical or biological weapons on the modern battlefield.[5]

Adversaries armed with CBW pose an asymmetric threat to America's conventional combat power. During conflict, these weapons can be used to deny freedom of maneuver on the battlefield while rapidly degrading available manpower and equipment due to contamination. During competition, these threats act as strategic deterrents by putting America's reliance on manned airpower at risk. To deny a critical vulnerability in conflict and to strengthen its deterrent posture, U.S. doctrine calls for a force capable of "prompt, sustained, and decisive" action to fight and win in contaminated environments.[6]

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[2] Charles E. Heller, 91.

[3] Robert Harris and Jeremy Paxman, *A Higher Form of Killing: The Secret Story of Chemical and Biological Warfare* (New York: Hill and Wang, 1982), 107–14.

[4] Amoretta M. Hoeber, *The Chemistry of Defeat: Asymmetries in the U.S. and Soviet Chemical Warfare Postures* (Cambridge, MA: The Institute for Foreign Policy Analysis, 1981), 21–33.

[5] Al Mauroni, *Envisioning a New Strategy to Counter Great Power Use of Weapons of Mass Destruction*, Future Warfare Series 62 (Maxwell Air Force Base, AL: United States Air Force Center for Strategic Deterrence Studies, 2022), 1–5; and John Parachini, Assessing North Korea's Chemical and Biological Weapons Capabilities and Prioritizing Countermeasures. Santa Monica, CA: RAND Corporation, 2018. https://doi.org/10.7249/CT486.

[6] Joint Chiefs of Staff, *Operations in Chemical, Biological, Radiological, and Nuclear Environments*, JP 3-11 (Washington, DC: Joint Chiefs of Staff, 2018), https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_11.pdf.

While the requirement is valid, achieving such capability while heavily reliant on manned systems remains a complicated challenge.

One of the most dangerous and dirty missions on the contaminated battlefield is casualty evacuation. Without an unmanned alternative, commanders are forced to either commit manned assets to a mission almost certain to contaminate aircraft and aircrew or to delay or refuse higher-level medical care to the ground force. The risks of the patient must be weighed against the risks to the force tasked with their rescue. This dilemma is not unfamiliar to commanders. However, the addition of the dirty environment introduces layers of complexity to a task already fraught with operational danger to the casualty, the crew, and the mission.

B. THE CURRENT SOLUTION

Protecting aircrews from the range of chemical and biological threats starts with the gas mask. In WWI, gas masks were widely utilized to maintain soldiers' combat effectiveness amidst the clouds of chemical agents used to break the stalemate of trench warfare.[7] Over a century later the gas mask has not disappeared, though it has incrementally improved in form and appearance.[8] The enduring requirement to fight and sustain operations by putting humans on the contaminated battlefield has not changed, and with it, the risks widely remain the same.

The U.S. military currently mitigates contamination and exposure risk in three ways: protecting the crew, protecting the aircraft, and decontaminating both. The modern gas mask ensemble for aviators, the Aircrew Eye and Respiratory Protection System (AERPS), improves upon concerns from earlier variants, but remains plagued by

[7] Charles E. Heller, *Chemical Warfare in World War I: The American Experience, 1917–1918*, No. 10, The Leavenworth Papers (Fort Leavenworth, KS: Combat Studies Institute, U.S. Army Command and General Staff College, 1984), https://www.armyupress.army.mil/Portals/7/combat-studies-institute/csi-books/leavenworth-papers-10-chemical-warfare-in-world-war-i-the-american-experience-1917-1918.pdf.

[8] Jeffery K. Smart, *History of the Army Protective Mask* (Aberdeen Proving Ground, MD: U.S. Army Soldier and Biological Chemical Command, 1999), https://apps.dtic.mil/sti/pdfs/ADA376445.pdf.

limitations to visibility, communication, and crew endurance.[9] As a result of the residual risk, multiple initiatives are underway to incrementally improve performance while preparing for modern threat environments.[10] To protect the aircraft itself from contaminated personnel or equipment, the Chemical Aircraft Survivability Barrier (CASB) is an inflatable tent-like structure anchored inside of aircraft that effectively separates the notionally "clean" flight crew from the "dirty" troops or equipment.[11] Finally, both personnel and aircraft are decontaminated after flight to halt the spread of contaminants and sanitize aircraft for future flights. Unfortunately, Air Force publications acknowledge the elephant in the room—that regardless of how rigorous decontamination efforts are, they are unlikely to "achieve operationally significant results."[12]

Though hardly technologically advanced, these applications are intended to protect the aircrew while balancing their need to operate or perform complex flying tasks effectively. However, extensive aviation physiology studies have demonstrated the associated risks and quantified the detrimental impacts on actual human performance. In one ground-based experiment, researchers found that 7 out of 16 pilots could not complete a controlled simulator flight because they overheated in their protective suits.[13] While attempting to decrease the risk of exposure to the flight crew, conceptually, these measures do little more than the gas masks of WWI: they preserve the degraded ability of the warfighter still condemned to operate directly in the contaminated environment.

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[9] Department of the Air Force, *Aircrew Eye Respiratory Protection (AERP) Equipment*, TO 14P3-1-151 (Washington, DC: Department of the Air Force, 2019), https://chub.sofapps.net/airpubs/1sog/1soss/1soss-pubs/vol-4-flight-manuals-technical-orders-checklists-aircrew-aids/afe-tos/14p3-1-151-aerp-equipment.pdf/view.

[10] Dwane R. Young, "DOD Tests CBRN Aircrew Protective Suit Upgrade at Nellis AFB," Air Force, May 12, 2021, https://www.af.mil/News/Article-Display/Article/2604913/DOD-tests-cbrn-aircrew-protective-suit-upgrade-at-nellis-afb/.

[11] Department of the Army, *Chemical-Biological Aircraft Survivability Barrier (CASB)*, TM 3–4240-351-10 (Washington, DC: Department of the Army, 2019), https://chub.sofapps.net/airpubs/stan-eval/master-pubs/vol-6-other-publications/cv-22-efb/survivability/casb/tm-3-4240-351-10-26-feb-19.pdf/view.

[12] Department of the Air Force, *Operations in a Chemical, Biological, Radiological, and Nuclear (CBRN) Environment*.

[13] R. Thornton and J. L. Caldwell, *The Physiological Consequences of Simulated Helicopter Flight in NBC Protective Equipment*, Volume 64 (Fort Rucker, AL: United States Army Aeromedical Research Laboratory, 1993), https://apps.dtic.mil/sti/citations/ADA259909.

There is a constant tradeoff in survivability and functionality in the current model, one that will not significantly change without an innovative solution. Recognizing this, Air Force doctrine now calls for a more robust "contamination avoidance" plan for contaminated environments due to the limitations of current countermeasures.[14] Without offering a true solution, this statement hints that CBW countermeasures may have fallen into a trap that economist Clayton Christensen coined as the "innovators dilemma." This refers to an organizational bias for incremental improvement, or "sustaining innovation," of existing products rather than an aggressive "disruptive innovation" that fundamentally alters the status quo.[15] Introducing an innovative solution to the most "dull, dirty, and dangerous" of chemical, biological, radiological, and nuclear (CBRN) operations would upend this continuous cycle of investment in incremental improvements and create a disruptive option that would remove aircrews altogether.[16]

C. THE PROPOSED SOLUTION

Emerging technology offers a commercial solution that may fundamentally change how the Joint Force mitigates risk on the contaminated battlefield. The global eVTOL industry aims to introduce a flying-taxi service capable of both remotely piloted or fully autonomous passenger flight. The military application of unpiloted flying taxis, originally designed to ferry civilians around the friendly skies, is attractive for several reasons.

First, the capabilities lie at the convergence of electric, vertical takeoff and landing, and autonomous capabilities prime for the unmanned casualty evacuation mission. Electric propulsion promises an ever-expanding performance envelope as battery endurance, power output, and charging capabilities will continue to improve as commercial competition in this field improves. As such, the momentum and potential behind the "little e" in eVTOL is significant. The vertical takeoff and landing capabilities, designed for operating in urban environments, are critical to enabling casualty evacuation at the point of injury, which

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[14] Department of the Air Force, *Operations in a Chemical, Biological, Radiological, and Nuclear (CBRN) Environment*.

[15] Eric Ries, *The Lean Startup* (New York: Penguin Group, 2011), 25–36.

[16] Dean Irvine, "Doing Military's Dangerous, Dull and Dirty Work," CNN, last modified February 16, 2012, https://www.cnn.com/2012/02/15/business/singapore-airshow-drones/index.html.

typically precludes direct pickup by fixed-wing aircraft. The autonomous and remotely piloted capabilities offer the true promise: reliable unmanned solutions to the military's most dangerous jobs.

Second, the DOD is well-positioned to be a fast follower, adopting viable commercial products for battlefield applications rather than following classically slow patterns of adoption for military-specific technology. As the commercial market is globally pressurized to optimize performance and price, it should rapidly offer numerous variants for transition to military use. This adoption and application of dual-use technology will leverage commercial solutions while avoiding costly military research and development.

Third, a capability for unmanned casualty evacuation from the contaminated battlefield mitigates risk beyond the tactical and operational levels of war while incrementally impacting the deterrent posture of the U.S. military. Military adoption of an unmanned solution for casualty evacuation shores up a critical reliance on manned aircraft, decreasing the perceived asymmetric advantage of CBW on the battlefield, and strengthening America's deterrent position against potential adversaries.

D. CAPSTONE INTENT

This capstone project aims to demonstrate the potential for emerging commercial aviation technology to mitigate operational risk on the contaminated battlefield. This report validates the reality of the CBRN threat to the Joint Force, identifies threats in the current reliance on manned airpower, and illuminates the opportunity for unmanned eVTOL aircraft to buy down operational risk. Additionally, this report lays out the likely barriers to military adoption and makes recommendations to overcome them. Finally, this report argues that the introduction of a disruptive use case may open the aperture to broader military adoption of unmanned eVTOL technology.

E. APPROACH

Successful adoption of eVTOL capabilities for unmanned casualty evacuation requires the wide diffusion of the concept and a broad understanding of the promise and the associated challenges offered by commercial technology. To frame this concept, the capstone team engaged with subject matter experts in the fields of CBRN operations, unmanned casualty evacuation, commercial eVTOL aircraft, and military technology adoption. To diffuse these findings and recommendations, the capstone team composed three journal articles–included as appendices–delivering targeted messages to key audiences aimed at bolstering military adoption of this technology.

The first article, **"Flying Dirty: Unmanned Casualty Evacuation on the Contaminated Battlefield"** frames the threat of chemical and biological warfare to the Joint Force, the opportunity offered by commercial eVTOL technology, and the impacts that military adoption could have on the conduct of war and strategic deterrence alike.

"It's a Dirty Job, and Nobody's Gotta Do It: Another Call for Unmanned Casualty Evacuation" introduces the technical and cultural barriers to the adoption of unmanned casualty evacuation platforms and uses the threat of chemical and biological warfare as a disruptive use case to introduce commercial aviation solutions to unmanned casualty evacuation.

Finally, **"eVTOL Adoption: is the 'Tech' Really the Problem?"** identifies the likely barriers to successful military adoption and why the broader DOD will resist this technology in its current state. In his most recent testimony before the U.S. Senate, the Director of the Defense Innovation Unit, Mr. Michael Brown, addressed the military's need to "speed [up] the adoption of commercial technology to our warfighters."[17] While there may not be a one-size-fits-all approach to accomplishing this task, there may be options that the military can leverage to help facilitate the acceptance of eVTOLs.

F. FINDINGS AND RECOMMENDATIONS

Findings and recommendations from this capstone project are binned into three main categories, which are amplified further in the respective appendices.

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[17] *Hearing to Receive Testimony on the Department of Defense's Posture for Support and Fostering Innovation*, Senate, 117th Cong. (2022), https://www.armed-services.senate.gov/imo/media/doc/22-25_04-06-2022.pdf.

1. Unmanned Casualty Evacuation on the Contaminated Battlefield

Chemical and biological weapons remain valid threats to the American way of war. If used in modern conflict, it should be anticipated that contamination and subsequent combat loss of significant quantities of both aircraft and aircrews will degrade the sustained combat effectiveness of the Joint Force against adversaries armed with CBW.

This research proposes that the military is well positioned to utilize commercial eVTOL aircraft for unmanned casualty evacuation on the contaminated battlefield. Successful adoption would decrease the reliance on manned platform and aircrews, decrease operational risk, and bolster America's deterrent posture against adversaries armed with chemical or biological weapons. Though this technology alone will not deter the use of chemical or biological warfare, it has promise to reduce the asymmetric value of CBW to our adversaries. Due to its unique acquisition authorities, mission to counter weapons of mass destruction, and bias for innovative technology, Special Operations Command is well postured for initial application of this use case. Alternatively, there is a precedent for operational commanders to contract out both casualty evacuation as well as remotely piloted aircraft services. A contracted service to provide an unmanned casualty evacuation capability may be attainable and would simultaneously avoid the barriers of military acquired, owned, and operated aircraft.

2. Barriers to Unmanned Casualty Evacuation

There is a tension in the medical community regarding the ethics of unmanned casualty evacuation. An ethically justifiable case for unmanned casualty requires no additional risk to the patient compared to that of a manned platform. The case of contaminated casualty evacuation mitigates this concern by illuminating the comparatively high risks of aircrews operating in their protective equipment. Research demonstrates that the current manned solution increases patient risk due to impaired flight performance of aircrews in their protective ensembles. Unmanned eVTOL aircraft, designed to meet commercial safety of flight standards for civilian passengers, will likely exceed requirements for safe transportation of casualties.

The capstone team believes that the use of unmanned aircraft for contaminated casualty evacuation may serve as a disruptive use case prime for initial entry into military applications. The mission is high in both tactical and operational risk, has increased relative risk to both aircrew and patient, and is well-funded by a research portfolio plagued by incremental innovation. Together, these factors make the contaminated casualty evacuation mission ideal for introduction of unmanned aircraft and future widespread adoption.

3. Resistance to Innovation Adoption

A synergistic relationship exists in the concept of incubators and advocacy networks when it comes to adopting new technologies. Presently, incubators—in the form of AFWERX and Agility Prime—exist to provide the resources for accelerating the development of this technology.

However, to ensure the rapid adoption and employment of eVTOLs, it is recommended that the generation of advocacy networks can overcome the barriers imposed by the Federal Aviation Administration (FAA) and organizational internal resistance.[18] Furthermore, confirming the operational demand signal for this capability, especially for the need to conduct contaminated casualty evacuation, will increase the chances of successful adoption of eVTOLs within the DOD. Finally, military adoption of this technology will serve to bolster the commercial eVTOL ecosystem by demonstrating the reliability and safety of these aircraft. This acceptance will create a positive feedback loop, increasing the chances of wider diffusion of technology in both civil and military applications.

G. CONCLUSION

If the U.S. military wants to fight and win on the contaminated battlefield, the unmanned casualty evacuation mission is an ideal place to start. Application of emerging eVTOL aircraft will decrease tactical and operational risk, impact strategic deterrence, and reduce the asymmetric advantage of CBW. The technology is rapidly developing in a

[18] Benjamin M. Jensen, *Forging the Sword: Doctrinal Change in the U.S. Army* (Stanford, CA: Stanford University Press, 2016), 15–24.

commercial ecosystem driven by global competition, one that can be readily and responsibly leveraged by the U.S. military to increase combat effectiveness of the Joint Force.

APPENDIX A. "FLYING DIRTY: UNMANNED CASUALTY EVACUATION ON THE CONTAMINATED BATTLEFIELD"

This appendix was previously published by *War on the Rocks* on May 11, 2022.[19] It is included here with permission granted from the original publisher.

In recent years, militaries prioritized adoption of unmanned solutions to offload the most dull, dirty, and dangerous tasks on the battlefield.[20] The secretary of the Air Force recently highlighted the need for expendable "uncrewed" aircraft to fight in a future great power conflict, but focused largely on combat aircraft.[21] Leaders should pay closer attention to one of the military's most dangerous and dirty missions: evacuating wounded and dead servicemembers from a battlefield where chemical or biological weapons have been used.

The aviation industry aims to field electric flying taxis within the next decade, targeting both remotely piloted and eventually fully autonomous passenger flight.[22] If adopted by the military, these platforms can offset a critical reliance on conventional manned aircraft, removing warfighters from one of the highest risk missions on the battlefield while enabling the force to fight and win in the face of chemical and biological weapons.

[19] Michael Hicks and John Stoodley, "Flying Dirty: Unmanned Casualty Evacuation on the Contaminated Battlefield," *War on the Rocks*, May 11, 2022, https://warontherocks.com/2022/05/flying-dirty-unmanned-casualty-evacuation-on-the-contaminated-battlefield/.

[20] Dean Irvine, "Doing Military's Dangerous, Dull and Dirty Work," CNN, last modified February 16, 2012, https://www.cnn.com/2012/02/15/business/singapore-airshow-drones/index.html.

[21] John A. Tirpak, "Betting on Unmanned Bomber, Fighter 'Families,'" *Air Force Magazine*, March 23, 2022, https://www.airforcemag.com/article/betting-on-unmanned-bomber-fighter-families/.

[22] Ben Tigner, "4 EVTOL Trends Moving the Air Taxi Industry Closer to Takeoff," *TechCrunch*, March 17, 2022, https://social.techcrunch.com/2022/03/17/4-evtol-trends-moving-the-air-taxi-industry-closer-to-takeoff/.

These weapons are not just novel tools for assassination.[23] They may still be used on the battlefield, perhaps even soon in Ukraine.[24] Chemical and biological weapons remain attractive for a cornered foe. For example, analysts warn of potential North Korean chemical warfare use at the onset of conflict on the peninsula.[25] One expert fears that China's military training to operate in contaminated environments may indicate that "Chinese political and military leaders see operational utility for these weapons on modern battlefields."[26]

A. THE PROBLEM

The use of chemical and biological weapons diminishes combat power by contaminating both warfighters and equipment. American commitments to save its troops from a dirty environment will rapidly deplete the personnel and aircraft available to sustain the broader fight.[27] This creates a dilemma that commanders will already be familiar with: risking valuable resources to save a wounded warfighter. Though some may argue protective measures and decontamination mitigate risks, they may be overly optimistic. Multi-service publications acknowledge the continued risk of using aircraft after decontamination efforts, which cannot completely eliminate residual hazards to future crews.[28]

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[23] Al Mauroni, "Russia's Chemical Romance: Don't Call It a WMD Attack," *War on the Rocks*, March 16, 2018, https://warontherocks.com/2018/03/russias-chemical-romance/.

[24] William J. Broad, "Ukraine's Battlefield Is Haunted by Putin's Chemical Weapons Legacy," *The New York Times*, May 4, 2022, https://www.nytimes.com/2022/05/04/science/russia-chemical-weapons.html.

[25] John V. Parachini, *Assessing North Korea's Chemical and Biological Weapons Capabilities and Prioritizing Countermeasures*. Santa Monica, CA: RAND Corporation, 2018). https://www.rand.org/pubs/testimonies/CT486.html.

[26] Albert J. Mauroni, "Envisioning a New Strategy to Counter Great Power Use of Weapons of Mass Destruction" (Maxwell Air Force Base, AL: Air University, 2022). https://media.defense.gov/2022/Feb/03/2002932493/-1/-1/0/62%20GREAT%20POWER%20WMD%20STRATEGY.PDF

[27] Department of the Army, *Multi-Service Tactics, Techniques, and Procedures for Health Service Support in a Chemical, Biological, Radiological, and Nuclear Environment*, ATP 4-02.7 (Washington, DC: Headquarters, Department of the Army, 2016), 4–2. https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/atp4_02x7.pdf

[28] Department of the Air Force, *Operations in a Chemical, Biological, Radiological, and Nuclear (CBRN) Environment*.

As for the aircrew, current protective measures sacrifice combat effectiveness for adequate protection against chemical and biological threats. Crew endurance, visibility, dexterity, and communication are negatively impacted by the necessary protective equipment required to operate in this environment.[29] A hundred years after gas masks were widely fielded, the American military continues to make incremental improvements but has failed to introduce disruptive options to remove aircrews altogether.[30] Manned aircraft may have replaced the gas mask-wearing pack mules of the First World War, but technology will not eliminate the risk until aviators are removed from dirty battlefield.[31]

Operational vulnerabilities create opportunities for adversaries to leverage these weapons as strategic deterrents to American involvement. A force that is widely impacted, in all aspects of warfighting, by chemical and biological threats is less capable of fighting and winning. This vulnerability builds the adversarial case for chemical or biological warfare in conflict and their own deterrent posture in competition.

B. AN UNMANNED SOLUTION

Military adoption of unmanned aircraft can fundamentally change how the joint force mitigates operational risk. While unmanned aircraft are not new, the urban air mobility market offers a diversity of new capabilities and options.[32] For relevance in this dirty job, the military should look only towards the aircraft that are remotely piloted or fully autonomous, expendable (comparable to current aircraft), and capable of rapidly

[29] Robert Thornton et al., *Effects on Physiology and Performance of Wearing the Aviator NBC Ensemble While FLying the UH-60 Helicopter Flight Simulator in a Controlled Heat Environment*, USAARL Report Number 92–36 (Fort Rucker, AL: United States Army Aeromedical Research Laboratory, 1992), https://apps.dtic.mil/sti/citations/ADA259909.

[30] Dwane R. Young, "DOD Tests CBRN Aircrew Protective Suit Upgrade at Nellis AFB," Air Force, last modified May 12, 2021, https://www.af.mil/News/Article-Display/Article/2604913/DOD-tests-cbrn-aircrew-protective-suit-upgrade-at-nellis-afb/.

[31] "Two German Soldiers and Their Mule Wearing Gas Masks, 1916," Rare Historical Photos, November 19, 2021, https://rarehistoricalphotos.com/two-german-soldiers-mule-wearing-gas-masks-wwi-1916/.

[32] "Urban Air Mobility and Advanced Air Mobility," Federal Aviation Administration, March 3, 2022, https://www.faa.gov/uas/advanced_operations/urban_air_mobility/.

ferrying casualties out of the contaminated environment for transfer to manned platforms.[33]

Urban air mobility aircraft are at the convergence of several key technologies, all of which have the potential to increase in performance and decrease in cost over time.[34] The global trend towards electric vehicles will continue to push the performance envelope in terms of range, speed, payload, and endurance. The parallel advances in autonomy are on their own upward trajectory. By leveraging commercial competition, the military has an opportunity to adopt well-resourced research and development rather than commit to costly and classically slow military-specific solutions.[35]

Speaking of costs, there will be financial benefits in addition to force preservation. To be competitive in the commercial market, leaders are targeting future costs on par with current ride-share applications.[36] One estimate projects aircraft to run around $700 per operating hour versus approximately $3000 for a traditional UH-60 Black Hawk.[37] The biggest savings will not be financial but in mitigating risk by removing the aircrew altogether. It will be up to commanders to decide if incurring the risks of unmanned casualty evacuation is worth preserving a multi-million-dollar helicopter and priceless aircrew whose performance in this environment is already questionable.[38]

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[33] Jen Nevans, "Wisk Aero Secures $450M from Boeing to Advance Autonomous EVTOL Aircraft," evtol.com, January 24, 2022, https://evtol.com/news/wisk-aero-funding-boeing-autonomous-evtol-aircraft/.

[34] Natasha Santha, Mark Streeting, and George Woods, "Advanced Air Mobility — Cost Economics and Potential," February 17, 2021, https://www.lek.com/insights/ei/advanced-air-mobility-cost-economics-and-potential.

[35] Kris Osborn, "Marines Test Fire Scout Drone Alongside Manned Helicopters," *The National Interest*, March 18, 2022, https://nationalinterest.org/blog/buzz/marines-test-fire-scout-drone-alongside-manned-helicopters-201312.

[36] Nick Klenske, "Counting the Cost of Urban Air Mobility Flights," FutureFlight, last modified November 15, 2021, https://www.futureflight.aero/news-article/2021-11-15/counting-cost-urban-air-mobility-flights.

[37] Elan Head, "Here's Why Uber Thinks EVTOL Air Taxis Will Be Affordable," *Evtol.com*, last modified June 13, 2019, https://evtol.com/news/why-uber-thinks-evtol-air-taxis-will-be-affordable/; and Jack E. Edwards, *Defense Management: DOD Needs Better Information and Guidance to More Effectively Manage and Reduce Operating and Support Costs of Major Weapon Systems*, GAO-10-717 (Washington, DC: Government Accountability Office, 2010), https://www.gao.gov/assets/a307413.html.

[38] Thornton et al., *Effects on Physiology and Performance*.

The U.S. military has an established relationship with the domestic urban air mobility market, but the current infrastructure is postured only as an innovation incubator.[39] Special Operations Command is well positioned as a potential adopter due to its special acquisition authorities and its charter to lead the Department of Defense's mission to counter weapons of mass destruction.[40] A more modern approach would be for operational commanders specifically postured against these threats to contract out casualty evacuation as another form of drones as a service.[41]

C. OBSTACLES

Drones aren't new, and neither is the call for unmanned casualty evacuation. If both the capabilities and demands are so obvious, what's barred their use on the battlefield? In 2014, Paul Scharre called out the biggest problem: policy.[42] At the time, medical experts were concerned that unmanned vehicles incurred more risk to the patient than a human pilot. Though still a valid concern, emerging aircraft designed to fly civilian families without an onboard pilot will be safe enough for an urgent casualty movement. To be blunt, if a human pilot is considered the standard for safety, one must consider the impaired abilities of pilots flying in gas masks.[43] The unmanned solution may just be the safer ride.

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[39] Jessica Reed, "The U.S. Air Force Agility Prime Program: Progress in 2021 and Goals for 2022," *Avionics Digital*, January 2022, https://interactive.aviationtoday.com/avionicsmagazine/january-february-2022/the-u-s-air-force-agility-prime-program-progress-in-2021-and-goals-for-2022/.

[40] U.S. Special Operations Command, "USSOCOM: Special Operations Forces Acquisition, Technology and Logistics (SOF AT&L) Overview," *Defense Media Network*, July 7, 2021, https://www.defensemedianetwork.com/stories/ussocom-special-operations-forces-acquisition-technology-logistics-sof-atl-overview/; and Todd McNutt and William E. King IV, "The Risks, and Rewards, for Giving the Counter WMD Mission to SOCOM," *Defense News*, April 6, 2018, https://www.defensenews.com/opinion/2018/04/06/the-risks-and-rewards-for-giving-the-counter-wmd-mission-to-socom/.

[41] Kyle Rempfer, "DOD Exploring Medevac Options for Special Operations Forces within Yemen," *Military Times*, May 8, 2018, https://www.militarytimes.com/flashpoints/2018/05/08/dod-exploring-medevac-options-for-special-operations-forces-within-yemen/; and Mind Commerce, *Drones as a Service Market Outlook and Forecasts 2022 – 2028* (Seattle, WA: Mind Commerce, 2022), https://www.marketresearch.com/Mind-Commerce-Publishing-v3122/Drones-Service-Outlook-Forecasts-31047058/.

[42] Paul Scharre, "Left Behind: Why It's Time to Draft Robots for CASEVAC," *War on the Rocks*, August 12, 2014, https://warontherocks.com/2014/08/left-behind-why-its-time-to-draft-robots-for-casevac/.

[43] W.C. Stophel, "Rotary Wing Operations in a CBRN Environment" (Quantico, VA, United States Marine Corps, Command and Staff College, 2008), https://apps.dtic.mil/sti/pdfs/ADA498147.pdf.

In addition to the concerns of unmanned aircraft, Scharre highlighted the challenges of overcoming the well-intentioned hurdles of medical ethics. Standards for medical evacuation (a level above casualty evacuation that uses dedicated medical aircraft with onboard care) require continuous treatment of patients that cannot yet be met by the capabilities of autonomous or remote medicine in flight.[44] Numerous military initiatives to develop future platforms to meet this standard should rightfully continue, but unfortunately, they will likely remain constrained by high standards of care.[45]

By limiting the scope to casualty evacuation for now, commanders will have an unmanned platform to move "casualties as cargo" that should be precluded from the standards of medical evacuation.[46] This provides commanders an option to expedite patient movement, limit contamination to only the unmanned aircraft, and transfer patients to treatment outside of the threat environment. Fielding unmanned casualty evacuation aircraft now can fill a current vulnerability while leaving medical experts time to integrate and certify unmanned medical capabilities into future aircraft.

D. DOWN AND DIRTY ON THE CONTAMINATED BATTLEFIELD

The urban air mobility market offers an unmanned solution to the challenge of sustaining combat on the contaminated battlefield. The operational requirement is valid, the threats are explicitly stated, and operational improvements will affect both conflict and competition.[47] The commercial ecosystem is driven by global competition and bolstered by rapidly improving technology trends. The military can be a "fast follower" in this

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[44] Larry Smith, "Army Techniques Publication 4–02.13, Casualty Evacuation," U.S. Army, last modified July 8, 2021, https://www.army.mil/article/248294/army_techniques_publication_4_02_13_casualty_evacuation.

[45] Michael R. Davis and Gary R. Gilbert, "Balancing Autonomy and Combat Casualty Care," *Combat & Casualty Care*, Spring 2018, https://lsc-pagepro.mydigitalpublication.com/publication/?i=539634&p=26&view=issueViewer&pp=1.

[46] Michael K. Beebe, David Lam, and Gary R. Gilbert, *Unmanned Aircraft Systems for Casualty Evacuation - What Needs to Be Done*, STO-MP-HFM-231 (Brussels, Belgium: NATO Science and Technology Organization, 2012), https://www.sto.nato.int/publications/STO%20Meeting%20Proceedings/STO-MP-HFM-231/MP-HFM-231-05.pdf.

[47] Office of the Director of National Intelligence, *Annual Threat Assessment of the U.S. Intelligence Community* (Washington, DC: Office of the Director of National Intelligence, 2022), https://www.dni.gov/files/ODNI/documents/assessments/ATA-2022-Unclassified-Report.pdf.

adoption race, by leveraging existing and projected commercial capabilities to enhance combat effectiveness in the most dangerous and dirty of missions.[48]

The technology reduces tactical risk by providing commanders an unmanned alternative that avoids committing priceless aircrews and high-dollar aircraft to contamination or combat loss. The capability for unmanned casualty evacuation alone is not going to deter the use of chemical or biological weapons on the battlefield. However, the adoption of this technology can reduce the attractiveness of chemical and biological weapons by shoring up America's critical reliance on manned airpower.

If the U.S. military truly wants to prevail on the contaminated battlefield, adopting an unmanned solution to the dirtiest job is the place to start. The technological and ethical hurdles of unmanned casualty evacuation will remain challenging, but sticking with the status quo only showcases a critical vulnerability. Instead, the military can disruptively alter the way America wins in a dirty war that hopefully never comes.

[48] Scott D. Anthony, "First Mover or Fast Follower?," *Harvard Business Review*, June 14, 2012, https://hbr.org/2012/06/first-mover-or-fast-follower.

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APPENDIX B. "IT'S A DIRTY JOB, AND NOBODY'S GOTTA DO IT: ANOTHER CALL FOR UNMANNED CASUALTY EVACUATION"

For military leaders looking to win a great power war, there is an opportunity to break the mold preventing the adoption of unmanned solutions from one of the most dangerous jobs on the battlefield: casualty evacuation. While future operating concepts rely heavily on unmanned systems, a blend of cultural and technical challenges still bars the application of innovative solutions to an urgent operational challenge.

We leverage an extreme operating environment–the chemically or biologically contaminated battlefield–to disruptively challenge the classic barriers to unmanned casualty evacuation. Additionally, we highlight the urban air mobility market as offering viable options to field expendable unmanned aircraft to conduct this mission. Due to the commercial safety requirements for these aircraft, we believe they will overcome the concerns of medical experts regarding in-flight patient safety. We believe the adoption of this capability will offset a critical reliance on manned aircraft and aircrews, increasing the combat effectiveness of the Joint Force to fight and win on the contaminated battlefield of the future.

We begin with the counterargument, highlighting the policy and medical concerns that have previously barred unmanned casualty evacuation at large. Next, we chronicle past military efforts into the associated aviation and medical technologies. Then we build a case for the operational threat surrounding chemical and biological warfare and demonstrate the additional risk assumed by aircrews to evacuate contaminated patients. Finally, we introduce the opportunities offered by emerging commercial aviation platforms to overcome classic barriers to unmanned casualty evacuation.

A. THE POLICY PROBLEM

Paul Scharre called out the biggest barriers to unmanned casualty evacuation in 2014: Army policy. He points to two memos from the U.S. Army Medical Center which concluded that unmanned solutions were "not acceptable" and the technology was "not sufficient" to perform casualty evacuation.[49] In summary, Scharre stated that medical experts believed that placing casualties on unmanned platforms constituted medical abandonment and failed to meet moral and ethical standards of care.

On the other hand, a NATO panel concluded that unmanned casualty evacuation would be ethically and operationally permissible so long as the unmanned aircraft did not increase relative risk to the patient.[50] As a result, the panel recommended development of "safe ride standards" for casualty evacuation aircraft that would meet the safety requirements for aircraft certified for human transport that would not exceed the physiological limits observed in current casualty evacuation practice.[51] While this conclusion lays a theoretical foundation for the treatment of "casualties as cargo" on unmanned aircraft, actual progress remains limited.[52]

B. PREVIOUS MILITARY EFFORTS

Significant scholarly literature points to the conceptual utility of unmanned casualty evacuation but fielding an acceptable solution to the battlefield remains a challenge. The closest demonstration of an unmanned and somewhat expendable casualty evacuation platform appears to have been tested by the Israelis in 2018. This platform was flown remotely without onboard medical capabilities and advertised a 1000-pound payload and range of over 30 kilometers.[53]

Defense Department initiatives to field an ideal unmanned solution have unfortunately fallen short. In 2019, the Defense Advanced Research Projects Agency (DARPA) cancelled the Aerial Reconfigurable Embedded System (ARES) which offered

[49] Paul Scharre, "Left Behind: Why It's Time to Draft Robots for CASEVAC."

[50] Beebe, Lam, and Gilbert, *Unmanned Aircraft Systems for Casualty Evacuation*.

[51] Beebe, Lam, and Gilbert.

[52] Beebe, Lam, and Gilbert.

[53] Nitsan Sadan, "Israeli Rescue UAV Completes First Live Demo," *CTECH*, May 29, 2018, https://www.calcalistech.com/ctech/articles/0,7340,L-3739070,00.html.

unmanned multi-mission capabilities due to cost overrun and delays.[54] While both remote and semi-autonomous capabilities have been successfully integrated into current aircraft, they remain pricey modifications to already costly aircraft.[55]

Separate from the aircraft, noteworthy efforts across the medical and defense communities pursue advanced remote medical capabilities to integrate into future unmanned platforms. These initiatives aim to meet the higher standard of medical evacuation which requires continuous medical care during transport.[56] Unlike casualty evacuation, this is a mission governed by the medical community and subject to the standard of care expected of an onboard provider. This research leverages incredible advances in telemedicine technology and will demonstrate enormous impact when the medical community actual endorses its use in unmanned systems. Until then, it will widely remain a research and development initiative absent from operational utility.

C. THE OPERATIONAL CHALLENGE

Widely viewed as weapons of strategic deterrence, chemical and biological weapons remain relevant operational threats to the American way of war. Though not widely seen on the battlefield since the First World War, America's modern adversaries signal both the capability and intent to utilize chemical or biological weapons in the event of great power conflict. U.S. doctrine acknowledges the threat and requires a force capable of fighting and winning on the contaminated battlefield against weapons that disrupt

[54] Frank Wolfe, "DARPA and Marine Corps Cancel ARES Program for Cost Growth, Delays," *Rotor & Wing International*, May 9, 2019, https://www.rotorandwing.com/2019/05/09/darpa-marine-corps-cancel-ares-program-cost-growth-delays.

[55] Oliver Cuenca, "DARPA, Sikorsky Complete Autonomous Flights Using UH-60A Black Hawk," *AirMed&Rescue*, February 10, 2022, https://www.airmedandrescue.com/latest/news/darpa-sikorsky-complete-autonomous-flights-using-uh-60a-black-hawk.

[56] Andrew C. Yoo, Gary R. Gilbert, and Timothy J. Broderick, "Military Robotic Combat Casualty Extraction and Care," in *Surgical Robotics: Systems Applications and Visions*, ed. Jacob Rosen, Blake Hannaford, and Richard M. Satava (Boston, MA: Springer U.S., 2011), 13–32, https://doi.org/10.1007/978-1-4419-1126-1_2; and Michael R. Davis and Gary R. Gilbert, "Balancing Autonomy and Combat Casualty Care," *Combat Casualty Care*, Spring 2018, https://lsc-pagepro.mydigitalpublication.com/publication/?i=539634&p=26&view=issueViewer&pp=1.

freedom of maneuver on the battlefield and degrade both combat power and fighting power.[57]

Multi-service doctrine illuminates the complications associated with casualty evacuation on the dirty battlefield. Doctrine challenges commanders to recognize the risk of losing manned casualty evacuation platforms due to contamination, recommends the use of ground options as expendable alternates to manned aircraft, and requires that "evacuation of patients must continue, even in a [contaminated] environment."[58] Air Force publications warn that decontamination efforts are unlikely to satisfactorily return aircraft to service without significant residual risk.[59]

While medical experts are rightfully concerned that unmanned systems must fly as safely as a human pilot, they may over-estimate the competency of gas mask wearing pilots. Aviation physiology tests and open-source reports highlight what may appear common sense: flying in chemical protective equipment degrades pilot performance.[60] Vision, dexterity, communications, and crew endurance are hampered by the equipment required to protect them from contamination. While "safe ride standards" aspire to match the expertise of an uncompromised pilot, the bar may not be so high for this mission set specifically.[61] Some patients might just prefer the unmanned approach.

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57 Joint Chiefs of Staff, *Operations in Chemical, Biological, Radiological, and Nuclear Environments* (Washington, DC: Joint Chiefs of Staff, 2018), https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_11.pdf.

58 Department of the Army, *Multi-Service Tactics, Techniques, and Procedures for Health Service Support in a Chemical, Biological, Radiological, and Nuclear Environment*.

59 Department of the Air Force, *Operations in a Chemical, Biological, Radiological, and Nuclear (CBRN) Environment*.

60 Robert Thornton et al., *Effects on Physiology and Performance of Wearing the Aviator NBC Ensemble While Flying the UH-60 Helicopter Flight Simulator in a Controlled Heat Environment*, USAARL Report Number 92–36 (Fort Rucker, AL: United States Army Aeromedical Research Laboratory, 1992), https://apps.dtic.mil/sti/citations/ADA259909; and W.C. Stophel, "Rotary Wing Operations in a CBRN Environment" (Quantico, VA: United States Marine Corps, Command and Staff College, 2008), https://apps.dtic.mil/sti/pdfs/ADA498147.pdf.

61 Beebe, Lam, and Gilbert, *Unmanned Aircraft Systems for Casualty Evacuation*.

D. A DISRUPTIVE SOLUTION

As investments in aircraft development for military-specific capabilities continues, the DOD should simultaneously consider the commercial opportunities from the urban air mobility market.[62] Energized by global competition, the market is flush with novel technology optimized for cost-effective urban passenger movement on piloted, remotely piloted, and fully autonomous variants. Military adoption of these flying taxis as expendable casualty evacuation platforms would create an unmanned alternative to offset demands on invaluable aircrews and precious aircraft from the dangers of contaminated casualty evacuation.

To be competitive, these remotely piloted and autonomous aircraft must achieve a safety standard on par with a human pilot. Some aviation experts project that future autonomous aircraft will be safer *without an onboard pilot,* as most aviation accidents involve pilot error as a causal factor.[63] When coupled with the already degraded performance of aviators in their protective equipment, it is easy to see how remotely piloted or fully autonomous aircraft designed to safely transport civilians can improve passenger safety during contaminated casualty evacuation.

If adopted for the battlefield, unmanned aircraft could enter the contaminated environment, receive a patient from the ground force, and transport them out of the threat environment to a medical team for decontamination and treatment. Rather than spend resources and time decontaminating the aircraft, it could be sent back to ferry out additional patients or abandoned on the battlefield. Financial analysis aside, the unmanned nature of this platform is what makes it truly expendable by preserving the aircrews and aircraft required to face this threat today.

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[62] Tigner, "4 EVTOL Trends."

[63] Charles Handford, F Reeves, and Paul Parker, "Prospective Use of Unmanned Aerial Vehicles for Military Medical Evacuation in Future Conflicts," *Journal of the Royal Army Medical Corps* 164 (March 9, 2018): 293, https://doi.org/10.1136/jramc-2017-000890.

E. CONCLUSION

The argument for unmanned casualty evacuation exists at the convergence of a pressing strategic threat, a vulnerability in the reliance on manned aircraft, and an opportunity to leverage unmanned commercial aircraft. The contaminated battlefield offers an extreme–though operationally relevant–thought experiment that forces the reader to grapple with tactical and operational risks at large, and to avoid myopic fixation solely on patient care.

Commanders have an opportunity to cut through the tension between the projected demands of future operating environments and the classic barriers to adoption of unmanned systems. Future concepts envision high casualties while emphasizing preservation of combat power, so the current reliance on manned aircraft is unsustainable. Policy concerns, informed by well-intentioned medical experts, unfairly impede the progress of innovative solutions that offer to both expedite treatment and increase the combat effectiveness of the force.

While the concerns surrounding unmanned casualty evacuation are valid, patient risks must be grounded against the risk to force and risk to mission of the current solution. Sending impaired aviators into near certain contamination incurs risk to the patient, the rescuers, and to force preservation. When faced with accepting that risk or leaving casualties in the field, unmanned solutions provide a viable alternate. The commercial aviation industry is developing that solution, one that can be leveraged appropriately to perform on par with the aviators currently facing the task.

It’s a dirty job for sure, who do you want to do it?

APPENDIX C. "EVTOL ADOPTION: IS THE 'TECH' REALLY THE PROBLEM?"

Since its emergence in 2011, the electric vertical takeoff and landing (eVTOL) market has rapidly expanded, intending to move passengers throughout the urban skies of the world. This development can be credited in part due to the military's contribution to the industry within the U.S. In April 2020, AFWERX launched its division solely devoted to accelerating the progress of this technology—Agility Prime—with a goal to get these aircraft in the skies by 2023.[64] This relationship has been successful and has even resulted in the Air Force issuing its special airworthiness approval to several commercial vendors; a huge step towards making this nascent technology a reality.[65]

However, despite this prosperous partnership, two significant friction points could potentially prevent these aircraft from 'taking off' on battlefields and vertiports—essentially the airport equivalent for eVTOL aircraft.[66] The first is that these commercial aircraft have yet to obtain civilian airworthiness approval, which would prevent them from flying in U.S. airspace as air taxis. Even if this step was to happen, there is still a remaining issue that will prevent these aircraft from gaining traction within the military: the organizational reluctance to adopt this technology.

To better understand these barriers, one must be made aware of the technology itself and the military organization that is assisting in making it a reality. Then, after establishing this basis of the eVTOL and Agility Prime, the problem set will be examined more in-depth. Finally, this article will offer recommendations of how to lower the barriers of adoption of this technology within the DOD through employment of advocacy networks and creation of a demand signal or viable operational use cases for these aircraft.

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64 "Agility Prime," Agility Prime, accessed October 27, 2021, http://agilityprime.com/.

65 Katie Milligan, "AFWERX Agility Prime Program, BETA Technologies Make History with First Airman Flight of Electric Aircraft," Air Force, March 15, 2022, https://www.af.mil/News/Article-Display/Article/2966513/afwerx-agility-prime-program-beta-technologies-make-history-with-first-airman-f/.

66 Tamara Botting, "Urban-Air Port Founder on Building Vertiports for Future EVTOL Operations," evtol.com, April 14, 2022, https://evtol.com/features/urban-air-port-founder-building-vertiports-future-evtol-operations/.

A. THE TECH

eVTOL vehicles have been advertised as being able to deliver a capability that is reminiscent of the Jetsons' flying car concept.[67] These aircraft are intended to be part of the Urban Air Mobility market and while there are currently over 500 designs, one thing remains constant: all are comprised of an electric powerplant.[68] While this rechargeable option offers an environmentally friendly approach to flight, it is not the sole purpose of why the military is pursuing this technology.

To lower the barrier of acceptance by the Federal Aviation Administration (FAA) for unmanned aircraft, many companies are starting the certification process with pilots in the cockpit. However, the long-term goal is to have these aircraft operate fully autonomously.[69] This hands-off operation is where the real benefit of eVTOLs comes. These aircraft have the potential to conduct missions for the military throughout the spectrum of both peacetime and times of conflict. Potential use cases range from the relatively benign movement of cargo and passengers between bases within the U.S. to conducting combat search and rescue on a contested battlefield.[70]

B. AGILITY PRIME

Since the emergence of this aviation technology, the military has recognized the potential benefits it can offer. AFWERX, the Air Force's chief innovation arm, has established a division solely dedicated to fostering eVTOLs: Agility Prime. This group's mission is to accelerate the development and testing of this emerging dual-use technology.[71] In addition to providing testing areas for flight and the Air Force's

[67] Jared Keller, "The Air Force's Flying Car Competition Is Officially Here," Task & Purpose, April 14, 2020, https://taskandpurpose.com/news/air-force-agility-prime-launch-event/.

[68] Vertical Flight Society, "EVTOL Aircraft Directory," Electric VTOL News, accessed October 27, 2021, https://evtol.news/aircraft.

[69] Christiaan Hetzner, "Air Taxis Are Coming Sooner than You Think, Aerospace Giant Airbus Says," *Fortune*, September 22, 2021, https://fortune.com/2021/09/22/air-taxis-evtol-aerospace-airbus-boeing/.

[70] James R Ayers and Alec Wahlman, "A Concept for Next--Generation Combat Search and Rescue," *Air & Space Power Journal* 35, no. 2 (2021): 68–76, https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Volume-35_Issue-2/V-Ayers_Wahlman.pdf.

[71] Agility Prime, "Agility Prime."

airworthiness rating, Agility Prime can begin to explore the employment of this civil technology for prospective military use cases. Furthermore, it can identify potential friction points that exist within the military currently, which will assist in expediting adoption once these machines are certified for broader use.

C. THE PROBLEM

On February 22, 2022, the authors spoke with Dr. Stephen Ellis and MSgt Timothy Nissen, both members of the Air Force Education and Training Command's Detachment 62, to better understand the problems for the military in utilizing eVTOLs. They have focused on developing training standards for these aircraft and assisted in identifying barriers to adoption. They presented two issues impeding progress of this technology within the military: the certification process and the cultural hesitation to remove aviators from the cockpit.

1. The FAA

For an aircraft to operate in the skies under the purview of the Federal Aviation Administration, it must undergo an airworthiness certification process, which is separate from that of the already issued Air Force one. Moreover, if an aircraft will be used primarily for the movement of passengers, the Air Force must acquire an additional level of certification.[72] One reason for the insertion of AFWERX and Agility Prime within the eVTOL ecosystem was to assist companies in navigating this certification process.[73]

As identified in discussion with Dr. Ellis and MSgt Nissen, despite this collaborative effort, the FAA is having issues readily approving eVTOLs on the scale that it is needed to achieve Agility Prime's goal of launch in 2023. One recurring issue is the reluctance to accept the risk necessary to operate these aircraft with human passengers and no onboard pilots. Another is the challenge of how to classify these aircraft, whether as

[72] Department of the Air Force, *USAF Airworthiness*, AFPD 62–6 (Washington, DC: Department of the Air Force, 2019), https://static.e-publishing.af.mil/production/1/saf_aq/publication/afpd62-6/afpd62-6.pdf.

[73] Kenneth I. Swartz, "Agility Prime Accelerates EVTOL Development," Electric VTOL News, March 2, 2021, https://evtol.news/news/agility-prime-accelerates-evtol-development.

helicopters or powered lift aircraft.[74] Therefore, companies are considering moving their certifications overseas to countries with less restrictive regulations. This movement could present a potential security problem, which is likely to be reminiscent of the migration of the small drone market overseas.[75]

2. A Resistant Bomber Jacket Culture

Once past the FAA certification process, there is a potential for considerable organizational resistance to this emerging technology. If utilized as a fully autonomous system, these aircraft would decrease the number of pilots required for operations when compared to traditional aircraft that would conduct the same mission. For example, the CV-22 Osprey operates with four crew members: two pilots and two flight engineers.[76] With eVTOLs, one pilot could oversee the operation of a *network* of aircraft.

When viewing this shift of crew requirements, one possible outcome is that this could solve a long-standing issue of a pilot shortage. Another somewhat more troublesome result for the military is that pilots could oppose the technology for fear of having their mission set replaced. This is not to say that every pilot's opinion will be similar, but measures can be taken to reduce the risk of resistance from those who wear bomber jackets.

D. RECOMMENDATIONS

So how can the military overcome these roadblocks? While it is not probable for the military to control the risk that the FAA will have to accept for implementing these aircraft, a 'network' can be established to advocate for this technology. Furthermore, by creating a need for eVTOLs within the military could showcase the commercial sector a desire for the success of these aircraft.

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74 Elan Head and Jon Ostrower, "FAA Changes Course on EVTOL Certification," *The Air Current* (blog), May 9, 2022, https://theaircurrent.com/aircraft-development/faa-changes-course-on-evtol-certification/.

75 April Glaser, "DJI Is Running Away with the Drone Market," Vox, last modified April 14, 2017, https://www.vox.com/2017/4/14/14690576/drone-market-share-growth-charts-dji-forecast.

76 "CV-22 Osprey," Air Force, accessed May 2, 2022, https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104531/cv-22-osprey/.

1. Forging an Advocacy Network

One recommendation this article proposes is instituting a network parallel to what Benjamin Jensen outlines in *Forging the Sword*. Within his model of *Doctrinal Change and Intervening Institutional Mechanisms* is a system of incubators and advocacy networks.[77] Having both entities present, he asserts, will significantly increase the adoption capacity of an organization. Incubators are intended to generate original ideas; they provide the capacity for innovation to happen.[78] This entity is typically seen in organizations with the name 'innovation' in its title. In the case of eVTOLs, this currently exists within the military in the form of AFWERX and, more specifically, Agility Prime. However, the second part of this model, advocacy networks, are not presently established.

An advocacy network is used to "diffuse and legitim [ize]" a new idea.[79] The exact composition of this network is not the goal of this article. It is, however, our purpose to highlight the critical deficiency that will need to be resolved for a fully autonomous aircraft concept to succeed. These networks will need to take shape on both the military and civilian sides. It is essential to emphasize that this would not just consist of the champions of the idea, or those high-level officers or civilians that support eVTOLs. It would also have to include a separate group of those who would need to advocate for the idea throughout the organization.[80]

One could claim that the advocacy network already exists within AFWERX and Agility Prime. Despite this presence, this needs to happen *externally* to the incubator. For a concept to become successful, it needs to be diffused across all levels of the DOD.[81] This front will then be helpful with the understanding of risk that needs to be accepted to make eVTOLs succeed.

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[77] Jensen, *Forging the Sword*, 17–22.

[78] Jensen, 17–18.

[79] Jensen, 20.

[80] Jensen, 20.

[81] Jensen, 20.

2. Creation of a Demand Signal

The other recommendation that this article proposes, and one that Dr. Ellis and MSgt Nissen presented, is to develop a demand signal for this technology within the DOD. This demand signal could be intertwined with the primary goal of the advocacy network: to push for why the military needs eVTOLs and what relative advantage they offer. Emphasizing a demand signal at the strategic level will not only generate interest in the aircraft but also legitimize a need for it. Part of Agility Prime's goal is not to alter any aircraft designs to meet the needs of the military.[82] Generating a specific demand signal will not shift this focus. This process is intended to examine how the current commercial off-the-shelf technology could fulfill or replace a mission set. While this recommendation does not outright buy down risk, it would advertise a desire from commanders and thereby generate support for this technology.

E. CONCLUSION

While it is difficult to provide a detailed solution to overcome the obstacles associated with eVTOL operation within civil and military spheres, it is possible to propose incremental changes to make progress. By creating an advocacy network and a demand signal for this technology, the DOD can assist in overcoming the bomber jacket mentality and potentially resolve the resistance of a risk-adverse regulatory body. This will likely be a process that will take time, but one that will benefit both sides.

[82] Swartz, "Agility Prime Accelerates EVTOL Development."

LIST OF REFERENCES

Agility Prime. "Agility Prime." Accessed October 27, 2021. http://agilityprime.com/.

Air Force. "CV-22 Osprey." Accessed May 2, 2022. https://www.af.mil/About-Us/Fact-Sheets/Display/Article/104531/cv-22-osprey/.

Anthony, Scott D. "First Mover or Fast Follower?" *Harvard Business Review*, June 14, 2012. https://hbr.org/2012/06/first-mover-or-fast-follower.

Ayers, James R, and Alec Wahlman. "A Concept for Next-Generation Combat Search and Rescue." *Air & Space Power Journal* 35, no. 2 (2021): 68–76. https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Volume-35_Issue-2/V-Ayers_Wahlman.pdf.

Beebe, Michael K., David Lam, and Gary R. Gilbert. *Unmanned Aircraft Systems for Casualty Evacuation - What Needs to Be Done*. STO-MP-HFM-231. Brussels, Belgium: NATO Science and Technology Organization, 2012. https://www.sto.nato.int/publications/STO%20Meeting%20Proceedings/STO-MP-HFM-231/MP-HFM-231-05.pdf.

Botting, Tamara. "Urban-Air Port Founder on Building Vertiports for Future EVTOL Operations." evtol.com, April 14, 2022. https://evtol.com/features/urban-air-port-founder-building-vertiports-future-evtol-operations/.

Broad, William J. "Ukraine's Battlefield Is Haunted by Putin's Chemical Weapons Legacy." *The New York Times*, May 4, 2022. https://www.nytimes.com/2022/05/04/science/russia-chemical-weapons.html.

Comptroller of Program/Budget. "Fiscal Year (FY) 2021 Department of Defense (DOD) Fixed Wing and Helicopter Reimbursement Rates." Official memorandum, Washington, DC: Department of Defense, 2021. https://comptroller.defense.gov/Portals/45/documents/rates/fy2021/2021_b_c.pdf.

Cuenca, Oliver. "DARPA, Sikorsky Complete Autonomous Flights Using UH-60A Black Hawk." *AirMed&Rescue*, February 10, 2022. https://www.airmedandrescue.com/latest/news/darpa-sikorsky-complete-autonomous-flights-using-uh-60a-black-hawk.

Davis, Michael R. and Gary R. Gilbert. "Balancing Autonomy and Combat Casualty Care." *Combat Casualty Care*, Spring 2018. https://lsc-pagepro.mydigitalpublication.com/publication/?i=539634&p=26&view=issueViewer&pp=1.

Department of the Air Force. *Aircrew Eye Respiratory Protection (AERP) Equipment*. TO 14P3-1-151. Washington, DC: Department of the Air Force, 2019. https://chub.sofapps.net/airpubs/1sog/1soss/1soss-pubs/vol-4-flight-manuals-technical-orders-checklists-aircrew-aids/afe-tos/14p3-1-151-aerp-equipment.pdf/view.

———. *Operations in a Chemical, Biological, Radiological, and Nuclear (CBRN) Environment*. AFMAN 10–2503. Washington, DC: Department of the Air Force, 2019. https://static.e-publishing.af.mil/production/1/af_a4/publication/afman10-2503/afman10-2503.pdf.

———. *USAF Airworthiness*. AFPD 62–6. Washington, DC: Department of the Air Force, 2019. https://static.e-publishing.af.mil/production/1/saf_aq/publication/afpd62-6/afpd62-6.pdf.

Department of the Army. *Chemical-Biological Aircraft Survivability Barrier (CASB)*. TM 3–4240-351-10. Washington, DC: Department of the Army, 2019. https://chub.sofapps.net/airpubs/stan-eval/master-pubs/vol-6-other-publications/cv-22-efb/survivability/casb/tm-3-4240-351-10-26-feb-19.pdf/view.

———. Multi-Service Tactics, Techniques, and Procedures for Health Service Support in a Chemical, Biological, Radiological, and Nuclear Environment. ATP 4-02.7. Washington, DC: Department of the Army, 2016. https://armypubs.army.mil/epubs/DR_pubs/DR_a/pdf/web/atp4_02x7.pdf.

The Economist. "Could Russia Use Chemical Weapons in Ukraine?," March 11, 2022. https://www.economist.com/news/2022/03/11/could-russia-use-chemical-weapons-in-ukraine.

Edwards, Jack E. Defense Management: DOD Needs Better Information and Guidance to More Effectively Manage and Reduce Operating and Support Costs of Major Weapon Systems. GAO-10-717. Washington, DC: Government Accountability Office, 2010. https://www.gao.gov/assets/a307413.html.

Federal Aviation Administration. "Urban Air Mobility and Advanced Air Mobility." Federal Aviation Administration, March 3, 2022. https://www.faa.gov/uas/advanced_operations/urban_air_mobility/.

Glaser, April. "DJI Is Running Away with the Drone Market." Vox, Last modified April 14, 2017. https://www.vox.com/2017/4/14/14690576/drone-market-share-growth-charts-dji-forecast.

Handford, Charles, F Reeves, and Paul Parker. "Prospective Use of Unmanned Aerial Vehicles for Military Medical Evacuation in Future Conflicts." *Journal of the Royal Army Medical Corps* 164 (March 9, 2018): 293–296. https://doi.org/10.1136/jramc-2017-000890.

Harris, Robert, and Jeremy Paxman. A Higher Form of Killing: The Secret Story of Chemical and Biological Warfare. New York: Hill and Wang, 1982.

Head, Elan. "Here's Why Uber Thinks EVTOL Air Taxis Will Be Affordable." evtol.com, Last modified June 13, 2019. https://evtol.com/news/why-uber-thinks-evtol-air-taxis-will-be-affordable/.

Head, Elan, and Jon Ostrower. "FAA Changes Course on EVTOL Certification." *The Air Current* (blog). May 9, 2022. https://theaircurrent.com/aircraft-development/faa-changes-course-on-evtol-certification/.

Heller, Charles E. *Chemical Warfare in World War I: The American Experience, 1917–1918*. Fort Leavenworth, KS: Combat Studies Institute, U.S. Army Command and General Staff College, 1984. https://www.armyupress.army.mil/Portals/7/combat-studies-institute/csi-books/leavenworth-papers-10-chemical-warfare-in-world-war-i-the-american-experience-1917-1918.pdf.

Hetzner, Christiaan. "Air Taxis Are Coming Sooner than You Think, Aerospace Giant Airbus Says." *Fortune*, September 22, 2021. https://fortune.com/2021/09/22/air-taxis-evtol-aerospace-airbus-boeing/.

Hicks, Michael, and John Stoodley. "Flying Dirty: Unmanned Casualty Evacuation on the Contaminated Battlefield." *War on the Rocks*, May 11, 2022. https://warontherocks.com/2022/05/flying-dirty-unmanned-casualty-evacuation-on-the-contaminated-battlefield/.

Hoeber, Amoretta M. *The Chemistry of Defeat: Asymmetries in the U.S. and Soviet Chemical Warfare Postures*. Cambridge, MA: The Institute for Foreign Policy Analysis, 1981.

Irvine, Dean. "Doing Military's Dangerous, Dull and Dirty Work." CNN, Last modified February 16, 2012. https://www.cnn.com/2012/02/15/business/singapore-airshow-drones/index.html.

Jensen, Benjamin M. *Forging the Sword: Doctrinal Change in the U.S. Army*. 15–24. Stanford, CA: Stanford University Press, 2016.

Joint Chiefs of Staff. *Operations in Chemical, Biological, Radiological, and Nuclear Environments*. JP 3-11. Washington, DC: Joint Chiefs of Staff, 2018. https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_11.pdf.

Keller, Jared. "The Air Force's Flying Car Competition Is Officially Here." Task & Purpose, April 14, 2020. https://taskandpurpose.com/news/air-force-agility-prime-launch-event/.

Klenske, Nick. “Counting the Cost of Urban Air Mobility Flights.” FutureFlight, Last modified November 15, 2021. https://www.futureflight.aero/news-article/2021-11-15/counting-cost-urban-air-mobility-flights.

Mauroni, Al. *Envisioning a New Strategy to Counter Great Power Use of Weapons of Mass Destruction*. Future Warfare Series 62. Maxwell Air Force Base, AL: United States Air Force Center for Strategic Deterrence Studies, 2022. https://media.defense.gov/2022/Feb/03/2002932493/-1/-1/0/62%20GREAT%20POWER%20WMD%20STRATEGY.PDF.

———. “Russia’s Chemical Romance: Don’t Call It a WMD Attack.” *War on the Rocks*, March 16, 2018. https://warontherocks.com/2018/03/russias-chemical-romance/.

McNutt, Todd, and William E. King IV. “The Risks, and Rewards, for Giving the Counter WMD Mission to SOCOM.” *Defense News*, April 6, 2018. https://www.defensenews.com/opinion/2018/04/06/the-risks-and-rewards-for-giving-the-counter-wmd-mission-to-socom/.

Milligan, Katie. “AFWERX Agility Prime Program, BETA Technologies Make History with First Airman Flight of Electric Aircraft.” Air Force, March 15, 2022. https://www.af.mil/News/Article-Display/Article/2966513/afwerx-agility-prime-program-beta-technologies-make-history-with-first-airman-f/.

Mind Commerce. *Drones as a Service Market Outlook and Forecasts 2022 – 2028*. Seattle, WA: Mind Commerce, 2022. https://www.marketresearch.com/Mind-Commerce-Publishing-v3122/Drones-Service-Outlook-Forecasts-31047058/.

Nevans, Jen. “Wisk Aero Secures $450M from Boeing to Advance Autonomous EVTOL Aircraft.” evtol.com, January 24, 2022. https://evtol.com/news/wisk-aero-funding-boeing-autonomous-evtol-aircraft/.

Office of the Director of National Intelligence. *Annual Threat Assessment of the U.S. Intelligence Community*. Washington, DC: Office of the Director of National Intelligence, 2022. https://www.dni.gov/files/ODNI/documents/assessments/ATA-2022-Unclassified-Report.pdf.

Osborn, Kris. “Marines Test Fire Scout Drone Alongside Manned Helicopters.” *The National Interest*, March 18, 2022. https://nationalinterest.org/blog/buzz/marines-test-fire-scout-drone-alongside-manned-helicopters-201312.

Parachini, John. Assessing North Korea’s Chemical and Biological Weapons Capabilities and Prioritizing Countermeasures. Santa Monica, CA: RAND Corporation, 2018. https://doi.org/10.7249/CT486.

Rare Historical Photos. "Two German Soldiers and Their Mule Wearing Gas Masks, 1916." Rare Historical Photos, November 19, 2021. https://rarehistoricalphotos.com/two-german-soldiers-mule-wearing-gas-masks-wwi-1916/.

Reed, Jessica. "The U.S. Air Force Agility Prime Program: Progress in 2021 and Goals for 2022." *Avionics Digital*, January 2022. https://interactive.aviationtoday.com/avionicsmagazine/january-february-2022/the-u-s-air-force-agility-prime-program-progress-in-2021-and-goals-for-2022/.

Rempfer, Kyle. "DOD Exploring Medevac Options for Special Operations Forces within Yemen." *Military Times*, May 8, 2018. https://www.militarytimes.com/flashpoints/2018/05/08/dod-exploring-medevac-options-for-special-operations-forces-within-yemen/.

Ries, Eric. *The Lean Startup*. 25–36. New York: Penguin Group, 2011.

Sadan, Nitsan. "Israeli Rescue UAV Completes First Live Demo." *CTECH*, May 29, 2018. https://www.calcalistech.com/ctech/articles/0,7340,L-3739070,00.html.

Santha, Natasha, Mark Streeting, and George Woods. "Advanced Air Mobility — Cost Economics and Potential," February 17, 2021. https://www.lek.com/insights/ei/advanced-air-mobility-cost-economics-and-potential.

Scharre, Paul. "Left Behind: Why It's Time to Draft Robots for CASEVAC." *War on the Rocks*, August 12, 2014. https://warontherocks.com/2014/08/left-behind-why-its-time-to-draft-robots-for-casevac/.

Senate. *Hearing to Receive Testimony on the Department of Defense's Posture for Support and Fostering Innovation*, Senate, 117th Cong. (2022), https://www.armed-services.senate.gov/imo/media/doc/22-25_04-06-2022.pdf.

Smart, Jeffery K. *History of the Army Protective Mask*. Aberdeen Proving Ground, MD: U.S. Army Soldier and Biological Chemical Command, 1999. https://apps.dtic.mil/sti/pdfs/ADA376445.pdf.

Smith, Larry. "Army Techniques Publication 4–02.13, Casualty Evacuation." U.S. Army, Last modified July 8, 2021. https://www.army.mil/article/248294/army_techniques_publication_4_02_13_casualty_evacuation.

Stophel, W.C. *Rotary Wing Operations in a CBRN Environment*. United States Marine Corps, Command and Staff College, 2008. https://apps.dtic.mil/sti/pdfs/ADA498147.pdf.

Swartz, Kenneth I. "Agility Prime Accelerates EVTOL Development." Electric VTOL News, March 2, 2021. https://evtol.news/news/agility-prime-accelerates-evtol-development.

Thornton, R., and J. L. Caldwell. *The Physiological Consequences of Simulated Helicopter Flight in NBC Protective Equipment*. Volume 64. Fort Rucker, AL: United States Army Aeromedical Research Laboratory, 1993. https://apps.dtic.mil/sti/citations/ADA259909.

Thornton, Robert, J. Lynn Caldwell, Wayne Clark, Frank Guardiani, and Jose Rosario. Effects on Physiology and Performance of Wearing the Aviator NBC Ensemble While Flying the UH-60 Helicopter Flight Simulator in a Controlled Heat Environment. USAARL Report Number 92–36. Fort Rucker, AL: United States Army Aeromedical Research Laboratory, 1992. https://apps.dtic.mil/sti/citations/ADA259909.

Tigner, Ben. "4 EVTOL Trends Moving the Air Taxi Industry Closer to Takeoff." *TechCrunch*, March 17, 2022. https://social.techcrunch.com/2022/03/17/4-evtol-trends-moving-the-air-taxi-industry-closer-to-takeoff/.

Tirpak, John A. "Betting on Unmanned Bomber, Fighter 'Families.'" *Air Force Magazine*, March 23, 2022. https://www.airforcemag.com/article/betting-on-unmanned-bomber-fighter-families/.

U.S. Special Operations Command. "USSOCOM: Special Operations Forces Acquisition, Technology and Logistics (SOF AT&L) Overview." *Defense Media Network*, July 7, 2021. https://www.defensemedianetwork.com/stories/ussocom-special-operations-forces-acquisition-technology-logistics-sof-atl-overview/.

Vertical Flight Society. "EVTOL Aircraft Directory." Electric VTOL News. Accessed October 27, 2021. https://evtol.news/aircraft.

Wolfe, Frank. "DARPA and Marine Corps Cancel ARES Program for Cost Growth, Delays." *Rotor & Wing International*, May 9, 2019. https://www.rotorandwing.com/2019/05/09/darpa-marine-corps-cancel-ares-program-cost-growth-delays/.

Yoo, Andrew C., Gary R. Gilbert, and Timothy J. Broderick. "Military Robotic Combat Casualty Extraction and Care." In *Surgical Robotics: Systems Applications and Visions*, edited by Jacob Rosen, Blake Hannaford, and Richard M. Satava, 13–32. Boston, MA: Springer U.S., 2011. https://doi.org/10.1007/978-1-4419-1126-1_2.

Young, Dwane R. "DOD Tests CBRN Aircrew Protective Suit Upgrade at Nellis AFB." Air Force, Last modified May 12, 2021. https://www.af.mil/News/Article-Display/Article/2604913/DOD-tests-cbrn-aircrew-protective-suit-upgrade-at-nellis-afb/.

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