SOAR

STATE-OF-THE-ART REPORT (SOAR)
APRIL 2024

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AUTONOMOUS PLATFORMS FOR CASUALTY EVACUATION

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GREGORY NICHOLS

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ABSTRACT

The United States and its allies face the return of large-scale combat operations (LSCO) against peer and near-peer competitors—an environment not seen in over 70 years. The return of LSCO brings about multiple challenges, including the possibility of managing overwhelming numbers of casualties and providing medical care with limited manpower and supplies. Fighting more technologically advanced and prepared adversaries will also bring about tactical and operational issues, such as medical mobilization in contested air space, which would further limit casualty evacuation (CASEVAC) efforts. These issues will most likely delay access to care by trained medical personnel, bringing about a need to evacuate casualties without putting additional troops in harm's way, while minimizing logistical strain. One of the approaches currently underway to address these limitations is to rely on autonomous systems to safely remove and transport casualties to more secure areas where they can be treated by medical professionals. Although autonomous CASEVAC has been explored for several decades, recent developments in artificial intelligence, microelectronics, and advanced materials have made it more feasible for these platforms to become reality. This report explores the state of the art in designing and developing autonomous systems for CASEVAC applications in a variety of modalities and also includes discussion on current limitations, challenges, and barriers to implementation in the field.

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EXECUTIVE SUMMARY

For nearly two decades, the U.S. military has spearheaded dramatic and ground-breaking improvements in combat casualty care (CCC)—partly from necessity to address new realities of emerging medical needs faced during conflicts in Iraq and Afghanistan and partly due to the development and introduction of new technologies. These wars have introduced a bevy of injury types (e.g., blast-force-induced injuries, polytrauma, and systemic infection secondary to wound contamination) consistent with the use of insurgency-style tactics and the introduction of the hallmark weapon of these wars—the improvised explosive device. However, the military medical system faces new challenges in anticipation of future wars, which are theorized to make a return to the tactics and feel of World War II—the last time the United States faced direct combat with peer and near-peer adversaries in large-scale combat operations (LSCO). While the United States and its allies enjoyed many advantages of being technologically superior in recent past conflicts, these advantages will likely not be present in the wars to come. Most notably are the projected limitations to communications, air dominance, logistics, and adequate field medical care.

Around the same time frame (early 2000s–present), the U.S. Department of Defense (DoD) has invested in the development of autonomous capabilities, including its use in CCC. Deemed autonomous casualty evacuation (ACE) or autonomous casualty care and evacuation, the introduction of autonomy in battlefield medicine, particularly for casualty transport, is seen as a potential mitigation strategy to overcome some of the anticipated difficulties in providing medical care in future LSCO. While research and development in ACE have waxed and waned over the past 20 years, there has been a resurgence in the concept within the past 2 years, most likely driven by the emerging maturity of autonomy and artificial intelligence and the recent phase of the Russo-Ukrainian War (February 2022–present), where many of these expected challenges (contested air space, high casualty rate, and supply chain disruption) are already being seen. In fact, this conflict has become somewhat of a testbed and real-time laboratory for autonomous combat capabilities, including ACE.

CCC and evacuation have historically occurred via air, ground, and sea, with the air component being dominant since the Vietnam War Era. Each mode of transport plays a significant part in moving a casualty to the next stage in the evacuation chain—a continuous line starting from the initial point of injury and terminating at a medical treatment facility in the continental United States. ACE has already focused primarily on ground and air vehicles, but the need for expanding littoral and naval evacuation routes (and even space) has taken on a larger role and interest, especially when anticipating potential conflict within the Indo-Pacific Region. Air platforms still dominate, especially with an uptick in the development of new electric vertical takeoff and landing platforms that use rechargeable battery packages (compared to traditional lift systems). Ground vehicles are a close second, and maritime vehicles are closing in; however, the anticipated challenge of peer-level technology and loss of air dominance will likely force the development of alternatives to air evacuation vehicles to reflect anticipated future conflict needs, operational and environmental challenges, and the evolving nature of casualty evacuation (CASEVAC). As U.S. military strategy

EXECUTIVE SUMMARY, *continued*

moves toward a multidomain operations concept, a seamless coordination of autonomous units across air, land, maritime, space, and cyberspace operations will be imperative.

Although the development of capabilities for ACE has greatly improved and matured since the early 2000s, significant limitations and challenges remain; albeit, many of them are not necessarily technical. Among these are defining if/when unsupervised casualty transport would be appropriate, adequate, or feasible; adapting nonmedical multi-use autonomous vehicles for casualty care/transport use; and determining how autonomous vehicles will actually identify, retrieve, and load casualties. Most of the research over the past 20 years has focused on developing the technical expertise and prowess to create autonomous platforms. Current and future research is turning more toward the tactical and operational side, as it has now become apparent that autonomy will play a pivotal role in the wars to come, and ACE will be at the forefront.

This report covers six sections, beginning with an introduction that sets the stage for the current state of ACE. Section 2 discusses the technical challenges and gaps related to the rollout of ACE. The next several sections (3–5) focus on ground vehicles, air platforms, and sea systems. Finally, Section 6 provides conclusions and a vision of what is likely on the near horizon. Two main trends regarding ACE are apparent in this report. First, there is a major trend toward developing multipurpose-use, agnostic autonomous platforms, especially where logistics overlaps with casualty transfer. The second major trend is the need and desire to push the most advanced medical care as practical as close as possible to the point of injury. While the scope of this report is limited to ACE, the future of battlefield medicine is a vision in which most care will consist of closed-loop systems and autonomous transport.

Research and development in ACE moves beyond just providing medical care or transport within the DoD system. Research that is contributing to and can contribute to ACE spans the areas of and provides perspectives in logistical transport, operations in extreme environments, emergency evacuation, and search-and-rescue operations. Relevant efforts are underway inside the U.S. Department of Homeland Security, the National Aeronautics and Space Administration, the U.S. Department of Transportation, the U.S. Department of Health and Human Services, and the U.S. Department of Commerce, as well as across industry and academia. While most of this research appears to be taking place in the United States, other notable developments are occurring in Australia, China, Estonia, Israel, Russia, and the United Kingdom. ACE has seemed to ebb and flow in a convoluted pattern of winters and summers, but the actual tactical use of autonomous systems in CASEVAC by both Ukrainian and Russian forces since 2022 has brought the future to the present, offering a glimpse of wars to come in the here and now.

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SECTION 01 INTRODUCTION

1.1 BACKGROUND

U.S. and allied forces were engaged in major combat operations in Iraq and Afghanization for approximately 20 years (2001–2021). These conflicts involved engaging an enemy that used small arms and improvised explosive devices, fought in smaller groups, and used classic insurgency tactics. The types of injuries sustained (i.e., polytraumatic wounds from blasts, burns, systemic infections, and traumatic brain injuries) were typical of these classes of weaponry and battle strategy. U.S. forces suffered nearly 40,000 casualties (killed and wounded) [1], with the majority being injuries that could ultimately be treated expeditiously. The nature of these types of conflicts allowed casualties to be treated in theater by medical personnel when needed and evacuated out of theater with relatively little interference from enemy forces. The end of these conflicts coupled with recent geopolitical developments in key areas (eastern Europe, southeast Asia, and the Middle East) have led to reemerging concerns of U.S. forces engaging in large-scale combat operations (LSCO), especially against peer and near-peer adversaries—a scenario that has not been seen since the end of World War II (WW II).

The re-emergence of LSCO will bring a familiarity of sorts to the WW II era style of combat, with a few plot twists. Unfortunately, high casualty rates are a common occurrence of LSCO when engaging with peer/near-peer adversaries. U.S. military casualties during WW II surpassed 1 million killed and wounded (an average of more than 800 every day for 4 years). However, in a U.S. Army war-gaming scenario held in 2023 (Figure 1-1), greater than 21,000 casualties were sustained in a 7-day period (an average of 3,000 casualties per day) [2]. This high volume of casualties is along the lines of what military leaders predict for a future conflict. Another expected challenge of fighting technologically advanced adversaries is contested air space, which would make it more difficult to deliver medical equipment and other supplies to the front and to evacuate casualties from the battlefield to higher levels of medical care. Finally, future conflicts will take place across multiple domains, even simultaneously. An era of multidomain operations (MDO) will see fighting not just across traditional domains (i.e., land, air, sea) but also using space and cyberspace. Information

Figure 1-1. Paratroopers Conduct Air Medical Evacuation (MEDEVAC) Training Using UH-60 Black Hawk Helicopters at Grafenwoehr, Germany, on 23 August 2023 *(Source: South [2])*.

sharing, sensing, real-time data analysis, and communications will be vital in this new era, but these domains will also be contested and crowded. These new (or re-emerging) challenges will push logistics and mobility to their limits and most likely cause disruption on the front lines and even back to supply depots and command centers.

While not often thought of from a uniquely logistical perspective, medical equipment, medical care, and medical personnel need to be "delivered" to injured warfighters at their point of injury (POI) and wounded warfighters typically receive care throughout the entire chain of evacuation (being "delivered" to the next point of care). Anything that causes disruption to medical access will delay treatment and lead to poor outcomes, including an increase in disabilities and deaths. Unfortunately, the nature of LSCO will intrinsically lead to contested logistics, complicating casualty evacuation (CASEVAC). Fighting in dense urban environments (e.g., the current conflicts in Ukraine and Gaza or potential military action in Taiwan) and/or extreme, remote, and austere environments (e.g., the Arctic or the Pacific) could further complicate logistic supply chains. In fact, this is expected to be such a huge problem that senior military medical leaders are anticipating that the gold standard of providing advanced medical care to the injured in less than 60 minutes (deemed the "Golden Hour") will likely be impossible and are instead preparing field medical personnel to be prepared for treating casualties for at least an entire day before being evacuated to more definitive care [3]. This new time period (called the "Golden Day") will take on an entirely new strategy and perspective in terms of training, technology, and equipment, and, in fact, a new paradigm is already being worked out across the armed services.

Complicating the issue is the ability for military units to deploy enough trained medical personnel to clear the battlefield of the most severe casualties, get wounded warfighters back into the fight as soon as possible, and provide adequate care on site and throughout the entire evacuation [4]. Personnel shortages can be a result of several issues, including failure of the services to meet recruitment or retention goals (during wartime, this could also be affected by conscription), especially for medical personnel, as well as the possibility for medical staff to be injured themselves and unable to perform their missions, further impacting the ratio of expected casualties to medical-support personnel. An example comes from Army experience in Italy during the COVID-19 pandemic, when Army medical personnel found it increasingly challenging to treat patients when staff attrition rates reached 15–20%, as medical personnel became ill from exposure to SARS-CoV-2 and were unable to achieve maximum efficiency [3].

A general solution to these supply and personnel challenges involves stretching resources, partly using warfighters with less medical training to sustain medical support when trained medical personnel are unavailable and partly relying more on autonomous solutions to fill in the gaps—a general solution to quality and cost issues that the U.S. Marine Corps is taking very seriously [5] and has already been factored into U.S. Air Force operations (Figure 1-2). Remote medical solutions such as augmented-reality headsets with increased telemedicine capabilities and autonomous and semi-autonomous medical devices using artificial intelligence (AI) are currently being explored. Eventually, battlefield medicine may achieve complete autonomy with no medical personnel responding to the POI and total closed-loop systems could be the standard of care at some point in the future. However, that vision still remains somewhat distant, although the gap is closing. For now, the first logical step is to continue development of autonomous platforms for CASEVAC and ensure their successful deployment.

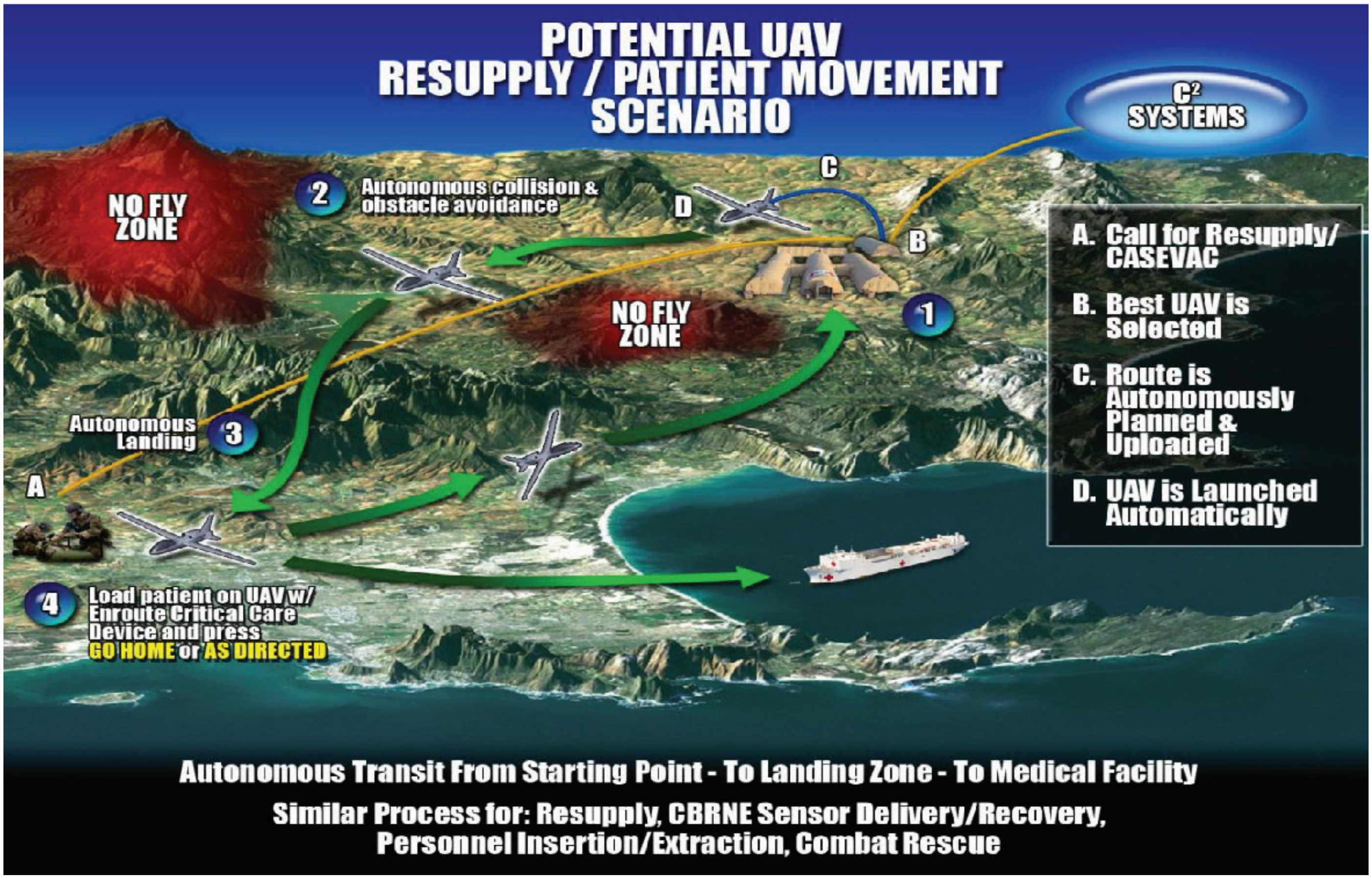

Figure 1-2. Air Force Concept of Operations for Patient Evacuation in Denied Environments *(Source: Office of the Air Force Surgeon General [6])*.

1.2 CASEVAC, MEDEVAC, AND AUTONOMY

An important distinction needs to be made between terms that are often used in combat casualty care (CCC) and how they fit into proposed technological advancements. One of the core components of CCC is evacuation of the injured, deemed casualties. CASEVAC involves only the movement of the sick and injured, with no medical care rendered during transport. This has been and remains one of the key research areas of focus for improving CCC outcomes and addressing the major challenges previously described. CASEVAC that involves the use of autonomous platforms and systems is referred to as autonomous casualty evacuation (ACE), and this is a key component of research and development not only for medical departments across the services but also for other areas including ground combat vehicles, aviation, logistics and combat support, and ships. A complement to or improvement upon CASEVAC is MEDEVAC, which involves the application of medical care to a casualty by trained medical attendants from the POI throughout the entire evacuation chain. The terms CASEVAC and MEDEVAC are often used interchangeably, but there is a clear distinction that not only exists technically but also in practice. As autonomy (sometimes referred to as robotic and autonomous systems [RAS]) is introduced more into both CASEVAC and MEDEVAC, the distinction is being more blurred and also debated. There is not always a perfectly clear border between the two, nor is there a clear distinction as to what would be something like CASEVAC+ (i.e., CASEVAC with minor medical monitoring, especially necessary for autonomous transport of the critically injured) and the more sophisticated MEDEVAC. In fact, some argue that there is no pure ACE and, rather, it would be more appropriate to refer to it as autonomous casualty care and evacuation (known as ACCE) [7]. While autonomous medical care is beyond the scope of this report, it is important and necessary to discuss the beginnings of its integration into autonomous platforms and CASEVAC in general. At the very least, ACE is in itself a viable path to handling the medical challenges of LSCO (Figure 1-3) and can also be a launching point for the operational integration of more sophisticated autonomous closed-loop medical systems and MEDEVAC capabilities. As Army Techniques Publication 4-02.2 on MEDEVAC puts it [8]:

> [CASEVAC] and MEDEVAC are complimentary capabilities, and when used efficiently and effectively reduce Soldier mortality. Having CASEVAC capable platforms does not negate the need for planning for and using organic MEDEVAC assets. As complimentary capabilities, they enhance the maneuver commander's options and ability to clear their wounded from the engagement area, while ensuring that the more severely wounded have access to the increased lifesaving capabilities provided in the MEDEVAC platform.

In general, autonomous systems and, in some cases, their application to CASEVAC specifically, play a role in the autonomous strategies of the Army, Navy/Marine Corps, Air Force, and even the Coast Guard (especially for search-and-rescue efforts). However, all the services across the U.S. Department of Defense (DoD) are working on autonomous systems and applications for battlefield medicine. Autonomy plays a key part of both the most recent Defense Health Agency Strategic Plan [9] and Army Medical Modernization Strategy [10]. Autonomous casualty care research has spanned at least 20 years (Figure 1-4) and has roots back to as early as 2003, with projects being introduced by the Defense Advanced Research Projects Agency

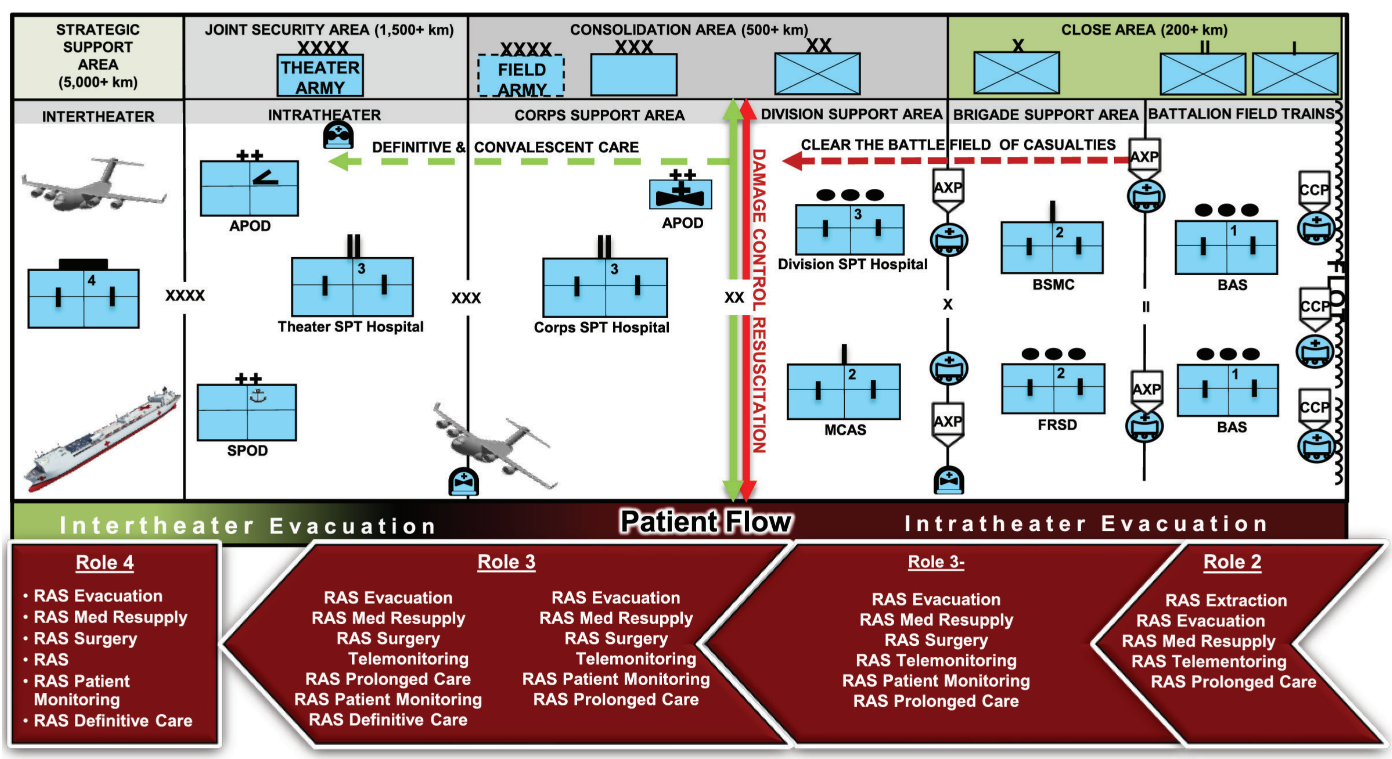

Figure 1-3. RAS MEDEVAC Concept for LSCO *(Source: U.S. Army [11])*.

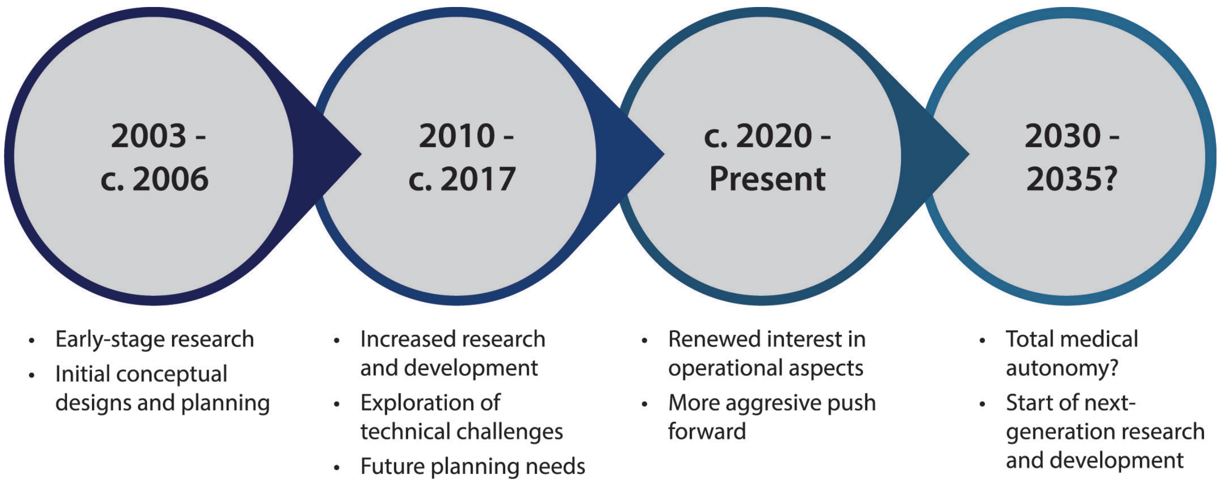

Figure 1-4. Historical Periods of ACE Research *(Source: Gregory Nichols)*.

(DARPA). Approximately 10 years later, research efforts expanded and were pushed by the Army's Telemedicine and Advanced Technology Research Center (TATRC) and even had strong involvement from the North Atlantic Treaty Organization (NATO). During this time (approximately 2010–2018), a unique and important trial was conducted in 2016 at Fort Liberty, NC (formerly Fort Bragg), where an autonomous golf cart was used to transport injured soldiers between their barracks and medical appointments. The trial was a success, and efforts expanded in 2018 with great improvement in the efficiency of care and a significant decrease in missed and late appointments. Research and funding in ACE seem to fade by the end of the decade, with a capstone meeting and report in late 2017 from the Armed Services Biomedical Research Evaluation and Management Community of Interest [12]. However, there appears to be a resurgence in interest starting around 2020 and growing since the start of the War in Ukraine from February 2022. In fact, 2022 seems to be an extremely important year, as several major events regarding ACE (and other military autonomous actions) took place.

One of the most significant exercises that took place was Project Convergence 2022 (PC22), which is an annual exercise (first held in 2020) that aims to improve coordination among Army, Marine Corps, Navy, Air Force, Space Force, and U.S. Special Operations Command regarding joint all-domain command and control [13]. Autonomous solutions were a main focus area for PC22, especially during the first-ever technology gateway. Part of this demonstration involved operational exercises using a fully autonomous Black Hawk helicopter (Figure 1-5), a DARPA-funded project known as ALIAS (aircrew labor in-cockpit automation system), involving MATRIX Technology developed by Sikorsky Aircraft that can convert any aircraft into an autonomous machine [14]. ALIAS is not a vehicle but rather a system designed to convert any aircraft into an autonomous system. According to DARPA, ALIAS "aims to support execution of an entire mission from takeoff to landing, even in the face of contingency events such as aircraft system

Figure 1-5. Autonomous Black Hawk With Medical Resupply and Simulated Casualty With Remote Monitoring During PC22 *(Source: Fricks [15])*.

failures" [16]. The ALIAS test conducted at Yuma Proving Ground demonstrated the successful possibility of ACE by air. A second part of PC22 was held in San Deigo and included the demonstration of technology for ACE by sea, using an unmanned surface vehicle (USV) designed by MARTAC [7].

Aside from PC22, a whole host of other related exercises and projects related to ACE have taken place since 2022. The British Army has conducted several trials using autonomous platforms through its Army Warfighting Experiment (AWE) program and Project Theseus. In 2022, through AWE, a Malloy Aeronautics T-400 cargo drone was used to transport an injured mannequin at Portsmouth Naval Base [17], and part of the Project Theseus demo tested an unmanned ground vehicle (UGV) designed by Horiba Mira, Ltd. (Nuneaton, UK), loaded with a dummy that was taken back to a command station [18]. In August of 2022, the Australian Army held its annual Innovation Day that specifically called for unmanned aerial vehicle (UAV) concepts that could carry certain weights over a set distance and CASEVAC was one of the potential use cases in mind [19]. Additional CASEVAC applications are generally explored at the annual European Land Robot Trial, which alternates between military and civilian applications [20]. Even China has conducted drills for CASEVAC using drones; although, it is unknown whether or not any autonomous systems are being trialed [21].

Closer to home, a variety of UGV and UAV solutions for CASEVAC were demonstrated at the Expeditionary Warrior Experiment in March 2022 at the Army's Maneuver Battle Lab at Fort Benning, GA [22]. In September 2024, the Army will hold the 10× Dismounted Infantry Platoon Project (also known as "10×") at Fort Moore, GA. The goal of the event is to utilize technical solutions to improve the efficiency of an Army platoon by a factor of 10 [23]. A variety of autonomous solutions will likely be on display; although it is not known if ACE will be a focus or not, this could be another opportunity to continue to test and develop the capability. However, Boston Dynamics has already committed to bringing "Spot," the same robot used in the NYC parking garage collapse in 2023 [24], to the event. The U.S. Special Operations Command held the Research, Development, and Acquisition Experiment (known as RDAX) Dragon Spear in 2023 at Joint Expeditionary Base Little Creek-Fort Story (Virginia Beach, VA) and evaluated 40 different technologies "in realistic operational scenarios" [25]. While not CASEVAC specifically, some of the technologies at this event do have crossover to casualty retrieval and closely align with search-and-rescue operations. The continued development of ACE platforms and operational testing of such is extremely important now, as these types of platforms are known to currently be in use in active war zones and are already shaping the future of battlefield medicine and tactics.

1.3 WAR IN UKRAINE

On 24 February 2022, Russian forces invaded Ukraine, with both sides using similar tactics, including the use of tanks, artillery, and bombing campaigns but with more modern adaptations, including drones and autonomous vehicles. The conflict has lasted more than 700 days (as of the time of writing), and estimates of military casualties on both sides are nearly 550,000 dead and injured (nearly 790 casualties/day) [26]. These numbers are consistent with what military leaders expect for casualties in LSCO but are still only one quarter of the daily casualty count projected from the previously mentioned Army war-gaming scenario in 2023. However, the current conflict has involved the use of autonomy on a scale never before seen in modern conflict, especially for CASEVAC operations by Ukrainian and Russian forces. Although still in its infancy, applications of ACE underscore the importance of this conflict as it applies to casualty management for LSCO and what lessons can be learned for the United States and its allies. One extremely interesting development in this context that also aligns with U.S. strategy is the use of autonomous vehicles originally outfitted for weapons capabilities that have been modified for use in CASEVAC.

Specific details are not readily available, but limited information can be found for some platforms seen in operation. The Ukrainian Army has been open about its use of ACE to some degree [27]. It is known that some sort of UAV is being used, but it is not clear which platform it is. Reports only specify that it is a commercially available vehicle that can carry 397 lb (180 kg) [28]. Speculation suggests it could be something similar to the BAE/Malloy T-650 heavy-lift electric unmanned aircraft systems (UAS) concept vehicle. However, it is well known that the Estonian company Milrem Robotics (Talinin) has provided 15 of its UGVs—tracked hybrid modular infantry system (THeMIS)—to Ukraine (Figure 1-6 [A]) [29, 30]. They are being used for a variety of purposes, most notably for CASEVAC. The Russian Army is also deploying some sort of UGV for CASEVAC, but information is even murkier. Photos taken on the frontlines in the Avdiivka Region appear to reveal an ACE platform in use by the 87th Rifle Regiment (Figure 1-6 [B, C]), possibly a knockoff of the THeMIS with an attached Volnorez electronic warfare system [31, 32].

It is well known that the Russians are interested in obtaining autonomous technologies, and the Ministry of Defence even awarded a $3.6-million contract in June 2020 for developing medical robots to clear battlefield casualties [33]. In September 2022, Ruslan Pukhov, the director of Moscow's Centre for Analysis of Strategies and Technologies (CAST), publicly stated that, "the conflict in Ukraine has demonstrated that modern warfare is unthinkable without the widespread use of unmanned vehicles...we are falling behind" [34]. Following the introduction of THeMIS into the conflict, CAST offered a 1-million-ruble ($11,000) cash reward to anyone in the military or law enforcement who would be able to capture one of the units by any means necessary [35]. In February 2024, Pukhov announced that the bounty had been raised to 2 million rubles ($22,000) [29].

(A)

(B)

(C)

Figure 1-6. Milrem Robotics THeMIS UGV in Live Demonstration (A) and Russian UGVs Carrying a Wounded Soldier (B, C) *(Source: Army Recognition [30] [A], [32] [B, C])*.

1.4 METHODOLOGY AND STRUCTURE OF THE REPORT

The research for this report covered three areas: (1) literature review, (2) online search, and (3) interviews with experts and key personnel. The search dates generally ranged from 2020 to the present to capture the most relevant and recent information; although, historical documents of significance were reviewed and included when appropriate. A cursory online search was conducted using Google to identify relevant recent news, documents, and experts related to ACE. Additionally, other sources to identify peer-reviewed and gray literature included Google Scholar, the Defense Technical Information Center Research and Engineering Gateway, and other searchable scientific and engineering databases. The following terms were used for the searches:

- Aeromedical evacuation
- Air ambulance
- Automated patient evacuation
- Automated medical evacuation/MEDEVAC
- Autonomous air ambulance
- Autonomous casualty evacuation/ACE
- Autonomous patient evacuation
- Autonomous medical evacuation/MEDEVAC platforms
- Autonomous medical evacuation/MEDEVAC systems
- Casualty evacuation/CASEVAC
- Combat casualty care/CCC
- Combat casualty evacuation/CASEVAC
- Manned-unmanned teaming
- Medical evacuation/MEDEVAC
- Prehospital transport
- Search and rescue
- Unmanned vehicle
- Unmanned patient transport
- Unmanned evacuation
- Unmanned casualty evacuation/CASEVAC systems
- Unmanned air ambulance
- Unmanned patient evacuation

Based on the search, nearly 120 relevant articles and documents and more than 200 websites were identified and reviewed. Additionally, through the search by reviewing documents and from referrals, individuals across academia, government, and industry were identified at the following organizations and interviews were conducted to gain additional insight:

- Air Force Research Laboratory (AFRL), 711th Human Performance Wing (HPW)
- Army Futures Command, Next Generation Combat Vehicle Cross Functional Team
- Boston Dynamics
- Combat Casualty Care Research Program
- Department of Homeland Security, Science and Technology Directorate
- DARPA
- Medical Capability Development Integration Directorate
- National Aeronautics and Space Administration (NASA)
- Near Earth Autonomy
- Office of Naval Research, Naval Force Health Protection Program
- Program Executive Office (PEO) Combat Support & Combat Service Support (CS&CSS)
- PEO Ground Combat Systems
- TATRC
- University of Pittsburgh, Center for Military Medicine Research
- U.S. Army Institute of Surgical Research (USAISR)

- U.S. Army Medical Materiel Development Activity, Warfighter Health, Performance & Evacuation Project Management Office
- Vita Aerospace

The amount of information uncovered during the research phase of this report was overwhelming and much more than the author anticipated; in fact, in some cases, it was much more than some of the interviewees expected as well. In order to provide the most useful information without creating a convoluted and voluminous report, the decision was made to focus on primary technical challenges and gaps and then narrow down the selection of platforms that are currently in use or have been championed by the DoD, allies (when applicable), and other extremely relevant designs (e.g., search and rescue or industrial when direct potential application to military CASEVAC could be warranted). There are many ways that the output of this report could have been arranged. In the interest of simplicity, it was decided to divide it into sections that closely align with the mode of vehicle (i.e., ground, air, or water). However, there are any number of ways this could have been done and perhaps future efforts will seek to arrange solutions by another category, such as function or the stage in evacuation from POI to an outside/inside continental U.S. medical treatment facility (MTF) (i.e., Role 4). The report overall is divided into six sections, beginning with this introduction. Section 2 discusses technical challenges and other issues related to the rollout of ACE. Sections 3–5 focus on the vehicles and platforms across different modes, with Section 3 covering ground vehicles, Section 4 introducing air platforms, and Section 5 addressing sea systems. Finally, Section 6 provides conclusions and a vision of what could be next.

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SECTION 02 CHALLENGES AND GAPS

2.1 OVERVIEW

Designing and developing platforms for ACE is not a simple endeavor. There are complex layers to the process that is complicated by a constant struggle to find balance across operational needs. During the writing of this report, several challenges and gaps were identified as barriers to the successful development and implementation of autonomous solutions for CASEVAC, primarily provided through candid and open responses from interviewees (Table 2-1). Although this list seems daunting and the challenges numerous, everything can be broken down into two key categories: (1) information and (2) design.

2.2 INFORMATION

Information, especially data, is one of the most important parts of ACE. The collection of data for autonomous vehicles (i.e., through sensing) is not much of a problem, but it is the curation of

Table 2-1. Challenges and Gaps in the Development and Implementation of ACE

Challenges	Gaps
• Strain of network • Allocation of bandwidth • Robotic combat vehicle (RCV) platform controlled by stations; lots of intricate communications • Nongovernment item platforms • Autonomous mobility and decision-making • Data curation • Ethics and policy discussion • U.S. Food and Drug Administration approval • Policy and ethical issues (autonomous systems making care decisions) • Hard-to-get wireless signal when rotor goes off • Requirements creep • Downwash • Brownouts • On the medical side, no control of platform • Question of how to make sure people develop things for bullets and can still have requirements for casualty care	• Continuation of perception sensors • Computing at the edge • Procurement • Quantitative assessment of new concepts and how they actually affect outcomes • Test outcomes—mapping back • Keeping a human in the loop • No communications or wide open • Communication with vehicle transport and casualty health • Data training models (prehospital)

that data that is a key gap. It takes a large amount of data to build accurate models to construct algorithms. Another challenge is keeping contact with the vehicle or ensuring it can operate independently while running a route.

2.2.1 Communications

The transfer of information is critical for successful ACE, primarily to ensure vehicles can safely and effectively move to waypoints along the evacuation chain. As more battlefield devices use advanced sensing, bandwidths are becoming crowded, making communications more complicated, especially as more connected devices are used in theater. DARPA has been working on this problem for at least a decade and continues the work with the recently launched Processor Reconfiguration for Wideband Sensor Systems (known as PROWESS) [36] and Wideband Adaptive Radio Frequency Protection (known as WARP) [37] programs.

2.2.2 Navigation and Path Planning

Autonomous vehicles require open lines of site or relatively unobstructed lines of site with little interference. This is becoming more challenging in an age of electronic warfare. It is also anticipated that some battle zones may include Global Positioning System (GPS)-denied or degraded environments, so autonomous vehicles will have to rely on other methods to establish positioning, navigation, and timing (Figure 2-1). Communications is one area in which commercial and military applications of autonomy cannot necessarily be compared, as military operations will almost always have to contend with a complete breakdown of connectivity at some point in time and in some locations.

In 2017, the Army set up the Expedient Leader Follower Program (ExLF) to fit existing vehicles with an autonomous solution that would essentially create a convoy-style system with several vehicles following a lead vehicle to a target destination. As of 2021, 60 leader-follower systems were distributed to the 41st Transportation Company. However, in 2023, the Army announced that it would shutter ExLF in favor of searching for existing commercial technologies through the Autonomous Transport Vehicle System program and PEO CS&CSS [38]. The new initiative is known as the Ground Expeditionary Autonomous Retrofit System (called GEARS) project, managed by Defense Innovation Unit to retrofit 41 palletized load system vehicles with autonomous kits. In late 2023, it was announced that Carnegie Robotics, Neya Systems, and Robotic Research were selected as the lead vendors to spearhead prototyping [39]. While not specifically known why ExLF was shuttered, two possibilities come to mind as to why the program ended and why the Army is looking to commercial solutions. First, there have been concerns that leader trucks could be high-value targets and

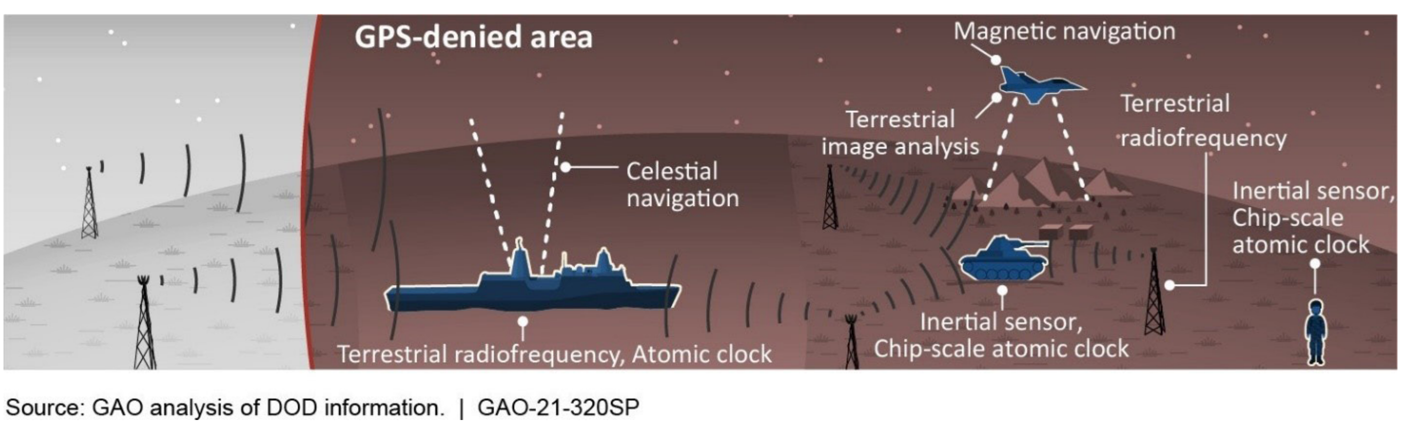


Figure 2-1. Technologies That Could Be Used in GPS-Denied Environment *(Source: U.S. Government Accountability Office [40])*.

disabling one could put the entire convoy at risk. Second, during the same period the Army was developing ExLF, commercial entities leapfrogged technology and had created vehicles (especially taxis) capable of acting independently, thus removing the risk and necessity of having a leader vehicle [41].

Ironically, one potential solution for operating autonomous vehicles in the extreme environments often seen in combat comes from NASA's Jet Propulsion Laboratory (JPL) (Pasadena, CA). Networked Belief-aware Perceptual Autonomy (NeBula) is an autonomous solution that allows multirobotic systems to operate in extreme and uncertain terrains and environments [42]. It is a software solution with seven features:

1. Verifiable risk-aware autonomous decision-making
2. Modularity and mobility-based adaptation
3. Resilient navigation
4. Single-robot and multirobot simultaneous localization and mapping (known as SLAM) and dense three-dimensional mapping
5. Traversability over extreme terrains
6. Multirobot operations and mesh communication
7. Autonomous skill learning

JPL has utilized NeBula to power robots as part of DARPA's subterranean challenge and specifically lists search-and-rescue application as a goal of the platform [43].

2.3 DESIGN

One of the most challenging and intriguing aspects of ACE is that the medical staff and biomedical engineers do not necessarily have a say in which platforms will be utilized. There is no specific manufactured medical vehicle—all medical platforms are adapted from something else. Many autonomous programs either have or will have a CASEVAC requirement at some point in their development, but the vehicles are still initially intended for a general defense purpose. A generalized sentiment of most interviewees for this report can be summarized along the lines of, "We don't pick the vehicle." From this arises an interesting and complex situation, especially given the fact that many autonomous vehicles will not start off with the same foundation. Many vehicles intended for CASEVAC operations may also simultaneously be used for logistics or some other function.

Regarding autonomous vehicle design, four strategies are emerging from both the literature and discussions with experts:

1. Conversion of existing vehicles to autonomous platforms (adding autonomous modules)
2. Manufacture/design of autonomous-capable or autonomous-ready platforms that retain full human control
3. Manufacture/design of semi-autonomous platforms
4. Manufacture/design of fully autonomous systems

In these strategies lie various levels of flexibility for technical sophistication, financial needs and constraints, and operational functionality. These strategies can be and are fluid across multiple vehicles (e.g., UAVs like the Black Hawk with ALIAS vs. K-MAX) and, in some cases, even the same vehicle, as is the case with the expeditionary fast transport (EPF) (i.e., EPFs 1–12 vs. EPF 13 vs. EPFs 14+). The design of the initial vehicle should take into consideration the CASEVAC/MEDEVAC functionality from the beginning, although this is not always the case; most of the time, it is not. The question/problem then becomes "How does this vehicle or can this vehicle be used for transporting casualties?" From there is where some of the technical and nontechnical challenges arise and often remain through the life cycle (Figure 2-2).

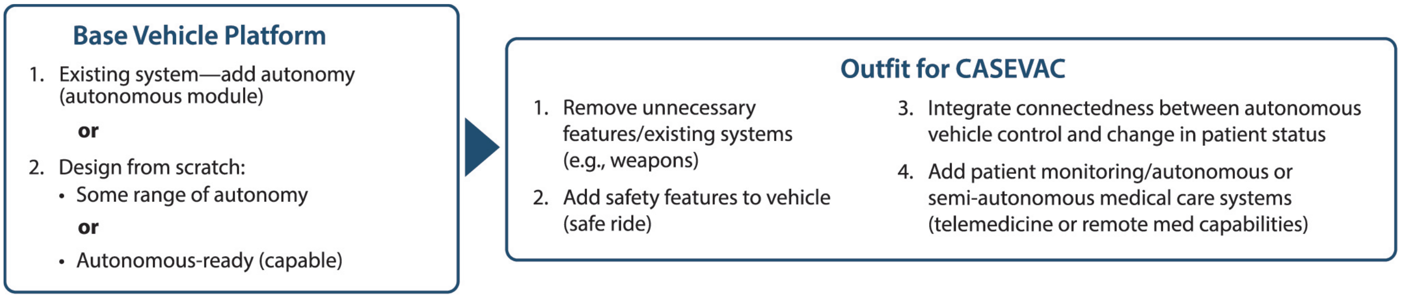


Figure 2-2. Design Considerations for ACE Vehicles *(Source: Gregory Nichols)*.

2.3.1 Safe Ride Protocols

One of the most important aspects of using a vehicle for CASEVAC (and/or MEDEVAC) is how best to safely transport a casualty. In an agnostic fashion, ignoring the level of severity and types of injuries, a minimum safety standard should be established. As early as 2012, a NATO group developed a framework for safe ride protocols that could be adopted for autonomous aerial CASEVAC (Table 2-2). There is not a comparable standard per se on the ground vehicle side; however, the NATO Reference Mobility Model (NRMM) that was developed and validated in the 1970s has been updated and improved using physics-based models to replace empirical data from the original NRMM [44]. While not completely dedicated to safe rides, ET-148 does include safety considerations in autonomous vehicle design. There does not appear to be anything comparable for naval or littoral vessels. In 2023, a working group meeting convened at Fort Rucker (now Fort Novosel) focused on "Safe Ride Standards for Patient Evacuation using Unmanned Aerial Vehicles." Agenda topics for this meeting included [45]:

- The development and flight characteristics of UAVs
- The control mechanisms (remotely piloted vs. onboard programming) for UAVs
- The use of UAVs for CASEVAC
- The G-tolerance and rate-of-onset tolerance of patients with differing medical conditions
- In-flight medical monitoring

Even for transport only, it is imperative that the vehicle "take care of" the patient and respond to status changes unless it is an extremely nonurgent or totally stable case. There is the desire of some researchers and engineers to integrate something like a "human-on-board" or "patient-on-board" button into an autonomous vehicle that could be pressed or somehow initiated once a casualty is on board, triggering the safe ride protocols and transforming from a nonmedical/nonhuman mode to a casualty-transport mode [46].

2.3.2 Integration of Medical Platforms

Apart from the safe ride protocols that will likely be needed in all cases of ACE, the next integral design component would be the point to which actual medical equipment or capabilities are integrated into the vehicle. These features can be manual, semiautonomous, or fully autonomous at some point. Open and free communication challenges will be key here for a few reasons. First, even if there is an autonomous vehicle that carries a crew (professionally trained medical staff or not), there is an increased desire within the DoD to improve that crew's ability to respond and to have access to much higher levels of medical and surgical care sooner (think trauma surgeon immediately available at the POI). Much of this is being done with mixed-reality headsets and improved audio capabilities [46, 47]. These features can provide a vast improvement to the telemedicine that currently exists. The next intervention would be improved monitoring capabilities to determine patient status. Finally, future equipment was

Table 2-2. Safety Criteria for NATO UAS CASEVAC *(Source: NATO, Science and Technology Organization [48])*

Medical/Safety/Human Factors Criteria	Standards
Inherently Safe	The UAV should be inherently safe or designed to mitigate risk to a casualty (e.g., no exposed sharp edges, no exposed high-temperature surfaces)
Safety Rating	NATO or national air regulations
Air Quality	Air quality in compartment must be in accord with usual aviation standards—no exhaust contamination, etc.
Noise/Acoustic Levels	The UAV should be designed to not exceed the 8-hour time-weighted occupational exposure limit of 85 dBA within the "passenger compartment;" noise levels above 115 dBA should not be exceeded for any duration without hearing protection
Vibration Levels	Should not exceed current UH-60 vibration levels
Acceleration	Acceleration < 0.25-G/s G-onset rate, <2 Gs in any axis at any time when carrying a casualty
Flight Control	Remotely piloted (autonomous takeoff and landing)
Interior Configuration	Sufficient space for the casualty lying on folding stretcher or NATO litter without comfort mattress or vibration mitigation technology
Interior Environmental Temperature	Passive measures (e.g., warming/cooling blankets for casualty)
Immobilisation	A minimum of three (chest, hip, and knee) litter straps or other patient-retention devices per stretcher or litter to prevent longitudinal or transverse dislodgment of the casualty during UAS transit; some system must be available to firmly attach the litter to the aircraft to preclude movement of the casualty within the "passenger" compartment during flight
Egress	Provide the capability with a mechanism for unassisted casualty emergency egress
Number of Casualties	1
Oxygen	If available at casualty point of origin and needed in flight, portable patient O_2 must be able to be secured in the "passenger" compartment
Lighting	Adequate lighting for observation and to preclude patient perception of being stuffed into a "cold, dark box"
Fluid Containment	Body or treatment fluids should be easily contained within the "passenger" compartment, which should be able to be easily cleaned and disinfected after use if exposed to fluids (e.g., disposable absorbent blankets/mats or disposable litters)
Communication	Communication between the UAS controller and the medical coordinator on the ground is desirable
Usable Payload Weight	>500 lb

planned to be semi-autonomous or autonomous, in which AI will guide the diagnosis of the patient and the interventions used with a human-in-the loop or possibly in a completely closed-loop system. Either way, connections with a central hub will be needed and integrating these features into a platform that may have initially been designed to carry a weapons system must also be taken into consideration. Research into this aspect is active with TATRC, University of Pittsburgh, USAISR, and others.

2.3.3 Ethical, Legal, and Social Issues

One of the primary challenges for ACE is actually not even a technical challenge. The introduction of ACE will inevitably introduce new challenges to ethical, legal, and social norms and traditional conventions faced in battlefield medicine. There is an ongoing debate regarding the ethics of autonomous care. One perspective postulates whether it could be patient abandonment or failure to meet a standard of expected care or even a duty to act if a casualty is not attended to by professional medical staff from the POI until handoff to higher-level medical care. For quite some time, this conundrum precluded military research in this area and still limits some of it even today. Further challenges regarding the limitations of ACE in LSCO can be framed as decision-making challenges. One such challenge according to Wissemann is as follows [49]:

> Lack of air superiority coupled with anti-access/area denial will foster a dependence on ground-based evacuation systems, both manned and autonomous. However, these too will be degraded. A 19-year-old Fleet Marine Force corpsman, faced with a potential of 50 percent casualties, may have to decide which casualties are loaded and which will die. Main supply routes clogged with casualties flowing back and supplies flowing forward will limit the effectiveness of autonomous systems such as the Squad Multi-Equipment Transport casualty evacuation platform employed by the Army and Marine Corps. Those same clogged roads will also present a robust targeting opportunity for a near-peer adversary.

One final challenge could involve the Geneva Convention, which clearly defines how vehicles transporting the sick and injured are to be marked and that they are off limits for attack. However, if autonomous vehicles are being used to transport ammunition and casualties, it appears that this could create a fuzzy scenario with no clear, easy answer.

Despite the challenges and gaps listed here, there have been many successful designs of autonomous vehicles, specifically for CASEVAC. As the technology improves and vehicles continue to be manufactured, testing has shown that many of these platforms will likely "fit the bill" so to speak. Apart from some of the existing technical and operational challenges come more strategic challenges as well, including a major transition from years of fighting with counterinsurgency tactics in a desert or mountain environment to possibly fighting in jungle or island environments. Tactics and vehicles go hand in hand; thus, the strategies are dictating where the vehicle design is going and what functionality is necessary to address new environments and new tactics.

SECTION 03 GROUND SYSTEMS AND VEHICLES

3.1 INTRODUCTION

Ground systems have been used routinely for CASEVAC since at least the early 19th century. Early systems obviously used rudimentary platforms consisting of a horse-drawn cart but rapidly evolved as technology improved, especially into the early 20th century through World War I. UGVs, in general, started to become a theoretical reality in the early 2000s, with a series of grand challenges from DARPA. Around this time, interest in UGVs grew in both the military and commercial sectors, culminating in a wide variety of vehicles available today, ranging from combat systems to autonomous electric trucks. The interest in using UGVs for CASEVAC dates to around 2006 but has certainly gained even more interest since the expansion of MDO and the concerns for contested air space, hampered logistics, and lack of qualified medical personnel. Interestingly enough, automotive-type vehicles (i.e., cars and trucks) are not the only type of solution available for ground CASEVAC. Robotic devices that crawl or walk are also being investigated for use in CASEVAC, although these devices are not as well developed for evacuating humans from the battlefield compared to something like a truck. However, they could still play a role, especially with extraction, and do appear to have more utility in civilian search-and-rescue operations and may yet contribute to more robust miliary CASEVAC operations in the future.

3.2 CRAWLING/WALKING SYSTEMS

Robotic systems that move more like people or animals instead of wheeled vehicles have been under consideration for CASEVAC, mainly due to their ability to move more efficiently over uneven terrain. While there have been some useful glimmers of hope on this front, most of these platforms are not currently practical for battlefield use. Over a decade ago, DARPA initiated a program called BigDog and its predecessor, the Legged Squad Support System (known as LS3), to find solutions that could serve as robotic pack mules to support warfighter operations. However, these programs were eventually suspended indefinitely due to a variety of factors; most notably, their products were deemed too noisy for combat operations. Some of these systems have more to offer in search-and-rescue operations, particularly with extraction and identification, and, perhaps as their use increases in this area, the technology will become more refined and could be more relevant for military use at some point in the future. While fully autonomous evacuation with crawling/walking systems will likely not be feasible for quite some time, there are two potential applications where these types of systems could be useful. The first involves using robotic systems for the loading and unloading of casualties (this could be a fully autonomous robotic platform interacting with a human or with another fully autonomous transport platform). The second application is the use of these animal-like robots to serve as casualty identifiers, to be more advanced responders to mark the spot where an autonomous transport platform would need to arrive in order to pick up a casualty. A recent example involves the use of a four-legged dog-type autonomous robot named "Spot" developed by robotics company Boston Dynamics (Figure 3-1). It was deployed by the New York City Fire Department (FDNY) in response to the collapse of a parking structure in lower Manhattan on 18 April 2023 [50]. Spot was designed to enter spaces deemed too dangerous for first responders and identify casualties that needed rescuing. A similar function could be used on the battlefield to determine where casualties are located and where UGVs need to be deployed for evacuation without putting warfighters or medical personnel in harm's way.

Figure 3-1. FDNY's Robotic Dog *(Source: Osborne [50])*.

3.3 EXPEDITIONARY MODULAR AUTONOMOUS VEHICLE (EMAV)

The Marine Corps recently tested one of its UGVs, the EMAV, at Marine Corps Air-Ground Combat Center in Twentynine Palms, CA, on 21 October 2023 during Exercise Apollo Shield, making a 50-km journey and showcasing its features [51]. One of the remarkable capabilities of the EMAV is its ability to navigate extremely steep slopes. Although not conducted at this event, the Marine Corps has, in the past, demonstrated the ability of the EMAV to transport casualties quite effectively (Figure 3-2). Its versatility and ruggedness make the EMAV a leading candidate for ACE, particularly for Marine operations.

Figure 3-2. Marine Corps Staff Sgt. Claude Henderson Role-Playing as a Casualty on an EMAV During a MEDEVAC Scenario at Camp Lejeune, NC, 24 June 2021 *(Source: Gray [52])*.

3.4 MISSION MASTER

American Rheinmetall is a commercial provider of military vehicles and offers a series of three autonomous unmanned ground vehicles (A-UGVs) (Figure 3-3). According to Rheinmetall's website, "the Mission Master platforms can be fitted for tactical overwatch, fire support, MEDEVAC, [chemical, biological, radiological, and nuclear] CBRN detection, communication relay, and any other type of missions that may require the support of an A-UGV. Each Mission Master vehicle is already networked with both Rheinmetall's soldier system and the Rheinmetall Command and Control Software, which are compatible in any user's battle management system" [53]. Rheinmetall also distributes its PATH-A Kit, an AI-powered navigation system "that brings autonomous capabilities to any vehicle" [54]. Mission Master underwent autonomy trials in Estonia in July 2023 [55].

Figure 3-3. Marine Rotational Force—Darwin Participates in Exercise Talisman Sabre 23 *(Source: Daniel [56])*.

3.5 ROBOTIC COMBAT VEHICLE (RCV)

The RCV is the U.S. Army's answer to a unified UGV that can be used across the service. Originally, the plan was to have multiple sizes and weights, but that plan has been modified to solely focus on the development of a light-class vehicle (10-ton platform). The current requirements are to include payloads for tether UAS and CROSS-J systems with electronic warfare and counter-UAS missions; however, there have been discussions for including CASEVAC as a mission area but there is currently no requirement for this [57]. In September 2023, the Army announced that it down selected the design for the RCV to four companies: (1) General Dynamic Land Systems, (2) Oshkosh Defense, (3) HDT Global, and (4) Textron Systems (Figure 3-4). Production is scheduled for 2027, with the first units expected to be ready in 2028 [58].

Figure 3-4. Vehicle Design Protypes for the Army's RCV From General Dynamic Land Systems, Oshkosh Defense, HDT Global, and Textron Systems *(Source: Heckman et al. [59])*.

3.6 SMALL MULTIPURPOSE EQUIPMENT TRANSPORT (S-MET) AND MULTI-UTILITY TACTICAL TRANSPORT (MUTT)

The S-MET and MUTT UGVs are complimentary vehicles developed by General Dynamics Land Systems for the Army and Marine Corps, respectively. They are designed to help manage loads carried by individual soldiers, squads, or units. The platform uses Forterra's AutoDrive® to integrate the autonomous capability. It is a type of vehicle known as a "robotic mule" and contains a hybrid-electric powertrain. The S-MET can carry up to 2,500 lb and can also serve as a mobile power supply [60]. The MUTT UGV features a robust, lightweight, and low-cost design. It is available in 4×4, 6×6, and 8×8 chassis configurations based on both wheels and tracks (Table 3-1).

"General Dynamics builds the squad multipurpose equipment transport for the Army and was on track to deliver 675 platforms by October 2024 since winning the initial $249-million production contract in 2020, Breaking Defense reported" [61].

3.7 THeMIS

As mentioned previously, THeMIS has already been deployed to Ukraine and is likely the first UGV to be used in combat, especially for CASEVAC operations. THeMIS is produced by MILREM Robotics (Tallinn,

Table 3-1. Comparison of Various S-MET and MUTT Models *(Sources: South [61] and Army Technology [62])*

Model	Carrying Capacity	Range	Speed
Arion-S-MET	1,200 lb	62 mi (100 km)	27 mph on paved roads and 14 mph on unpaved roads
MUTT—4 × 4 Tracked Variant	600 lb	60 mi (97 km)	Unknown
MUTT—6 × 6 Tracked/ Wheeled Configuration	900 lb	60/36 mi (97/58 km)	Unknown
MUTT—8 × 8 Tracked/ Wheeled Configuration	1,200 lb	60/36 mi (97/58 km)	Unknown

Estonia). Fifteen of the platforms have already been sent to Ukraine, and reports show that at least seven vehicles have been used for CASEVAC. THeMIS weighs just over 1,600 kg (nearly 3,600 lb) and can travel at 20 kph (just over 12 mph) [63].

SECTION 04 FLIGHT SYSTEMS AND VEHICLES

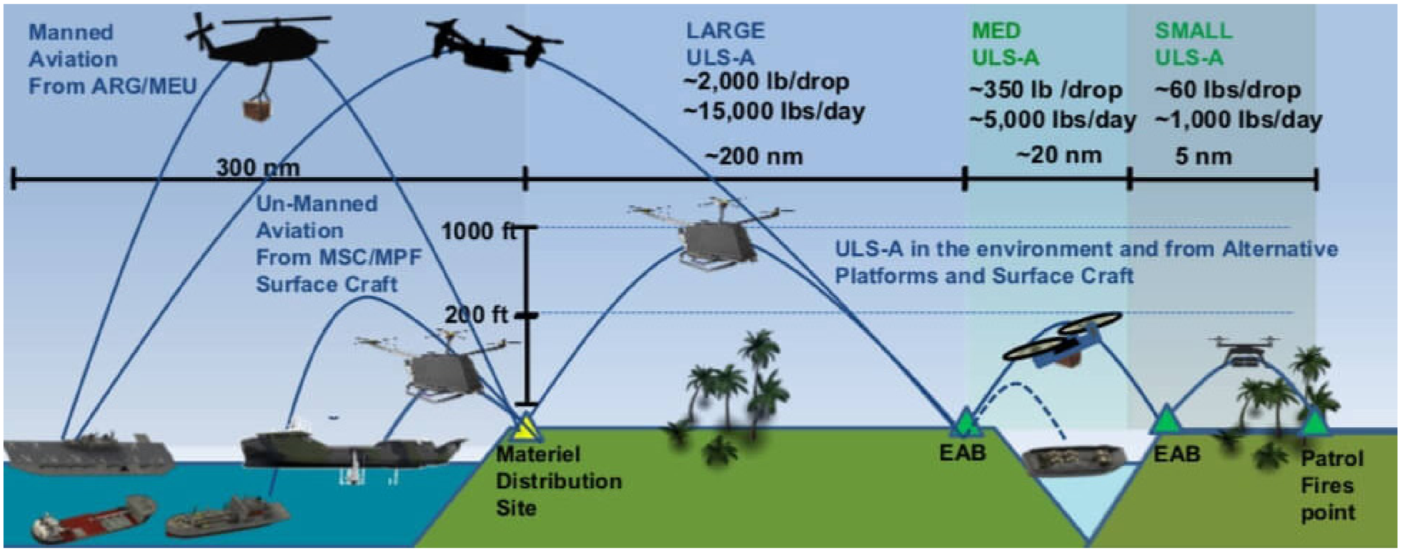
4.1 INTRODUCTION

Since the Korean War, aeromedical and aerial CASEVAC has been a mainstay of U.S. combat operations. Generally, the rule is to split between the Army covering intratheater air operations and the Air Force in charge of intertheater operations. However, as previously mentioned, the notion of not having air superiority will potentially limit the availability of air CASEVAC operations for both services, or at least force the hand of DoD to look at not only alternative methods beyond air but also at creative solutions within air platforms themselves to make them more rugged, more mobile and maneuverable, and better situated to handle direct attacks.

The workhorse of aeromedical evacuation is the HH-60 Black Hawk, a modified version of the UH-60 and an extremely versatile system that has been used for decades. Most likely, this is the reason the ALIAS program chose the Black Hawk as the platform for testing an autonomous conversion module. However, the Black Hawk is not the only air vehicle used for evacuation. The UH-72 Lakota is another commonly used helicopter for medical missions, and a variety of fixed-wing aircraft is also commonly used for long-range transport. However, as the military transitions into MDO and prepares for LSCO, new types of systems have been researched and are under development. Primary among these are vertical takeoff and landing (VTOL) aircraft, especially versions that have electric power systems, deemed eVTOL. VTOLs, in general, dominate the current airside of ACE development and draw inspiration from transitional defense contractors as well as commercial companies.

A variety of programs exploring VTOL and eVTOL solutions exist across the services. The Navy/Marine Corps established the Future Vertical Lift program back in 2014, and, while the two programs have different operational needs, there are some areas of overlap. The Marines intend to use UAS primarily for logistics, and, as discussed previously, if casualties can be seen as a special case of logistics, one could see how an unmanned CASEVAC system using UASs would theoretically look (Figure 4-1). Likewise, the Air Force has been working on similar systems through its Agility Prime initiative managed by AFWERX. Two key developments from Agility Prime have been the ALIA electric aircraft developed by BETA Technologies (Burlington, VT) and a prototype eVTOL from Joby Aviation (Santa Cruz, CA). While these programs form some of the basis for future ACE platforms, they are responsible for developing agnostic systems that could be used for a variety of purposes.

In 2023, the AFRL, 711th HPW began a deeper, more focused exploration and launched the Combat Autonomous Injury Transport program. This is a collaboration with Battelle and the Johns Hopkins University Applied Physics Laboratory to explore the research needs for the development of a patient transport pod incorporating autonomous closed loop control patient care. The early stage is focused on information gathering [47].



Note: ARG/MEU = Amphibious Ready Group and Marine Expeditionary Unit, and MSC/MPF = Military Sealift Command Maritime Repositioning Ship

Figure 4-1. U.S. Marine Corps Graphic Showing How Small, Medium, and Large Unmanned Logistics Systems—Air (ULS-A) Could Provide Distribution Capabilities Within the Expeditionary Advanced Base Operations Environment in Conjunction With Conventional Aircraft *(Source: Head [64])*.

4.2 ALIA PLATFORM

The ALIA is a vehicle developed by BETA Technologies through AFWERX's previously mentioned Agility Prime program and is available in both a fixed-wing (conventional takeoff and landing [CTOL]) and rotary wing (VTOL) version. It is a semi-autonomous, all-electric system with a 50-ft wingspan and is capable of carrying up to five people plus a pilot [65]. The platform achieved a 255-mile range and a high-endurance flight time of just over 2 hours in 2022 [66]. In January 2024, the Air Force conducted a test of the ALIA for CASEVAC. A crew from an HH-60W Jolly Green II landed in a clearing at Moody Air Force Base, GA, disembarked with a simulated casualty on a litter, and was met by a crew from the ALIA (Figure 4-2). After loading the "patient" on the ALIA, it immediately took off, bound for Duke Field, delivering the casualty to a medical unit [67]. Figure 4-2 shows the "BETA technologies team [carrying] a simulated casualty into their aircraft at Eglin Air Force Base, FL, on 11 January 2024. The two aircraft and crews participated in a casualty evacuation exercise with the HH-60 dropping off and the ALIA, an electric [CTOL] aircraft, picking up the simulated patient for higher-level care" [68].

Figure 4-2. Electric ALIA Carrying out a CASEVAC *(Source: King [68])*.

4.3 AERIAL RECONFIGURABLE EMBEDDED SYSTEM (ARES)

The ARES program is a VTOL module system originally designed by Piasecki Aircraft Corporation (PiAC) and Lockheed under a DARPA program (Figure 4-3); however, it is currently continuing development solely under PiAC [69]. Per the original DARPA vision, ARES is "designed to have its own power system, fuel, digital flight controls,

Figure 4-3. ARES and the M4 Prototype *(Source: Falls [69])*.

and remote command-and-control interfaces. Twin tilting ducted fans would provide efficient hovering and landing capabilities in a compact configuration, with rapid conversion to high-speed cruise flight" [70]. One of the three operational areas for ARES specifically is CASEVAC. The ARES platform utilizes a Mobile Multiple Mission Module (M4) prototype as a demonstration of a capability for CASEVAC and was developed by the Army's TATRC. ARES is expected to have a load capacity of 3,000 lb. The ARES program is currently managed by AFRL/Aerospace Vehicles Division. It was expected to reboot a hover test in December 2023, with a planned schedule of 9 months from hover test to payload, but a tethered hover flight test was delayed until March of 2024 [69, 71].

4.4 BELL V-280 VALOR

In December 2022, the U.S. Army awarded Bell the future long-range assault aircraft (FLRAA) contract to develop its V-280 Valor tiltrotor aircraft [72]. The V-280 will be a replacement for part of the Army's current UH-60 Black Hawk helicopter fleet, including intratheater aeromedical evacuation [73].

The FLRAA serves the role of fulfilling another Army vision—future vertical lift—similar to the strategic vision of the other services. The V-280 is powered by Rolls Royce AE 1107F engines [72] and is capable of autonomous flight, having demonstrated limited capabilities using a software patch similar to what was used in the Marine Corps V-247 scout drone [74]. The initial prototype of the V-280 will be delivered to the Army by 2025, with the first unit equipped with the Valor by 2030 (Figure 4-4). A panel discussion with experts from Bell "emphasized that, in the case of the V-280, nothing has come as an afterthought—every capability has been designed in, and sophisticated MEDEVAC capabilities are part of that" [75].

Figure 4-4. Bell V-280 Valor *(Source: Langfield [75])*.

4.5 CORMORANT

The Cormorant is a VTOL designed by Israeli company Tactical Robotics, a subsidiary of Urban Aeronautics, Ltd. (Yavne, Israel). It is the culmination of several upgrades from previous decisions (Figure 4-5). The Cormorant is made with carbon fiber to reduce its radar profile and has other features to help limit its heat signature. The vehicle has been partially supported by the U.S. Army [76]. It has two rotors and is primarily designed to function on the front lines, with a range of 20 miles and speeds over 100 mph. The aircraft is destined for delivery to the Israel Defence Forces

Figure 4-5. The Cormorant Carrying Cargo and a Medical Training Mannequin, Proving Its Potential Usefulness on the Battlefield *(Source: Stewart [77])*.

Figure 4-6. The DP-14 Designed to Carry 430-lb Useful Payload With a Large 23-ft^3 (Over 6 ft Long and 10 in Wide) Internal Cargo Area *(Source: Dragonfly Pictures Inc. [78])*.

and can operate in mountainous, wooded, or urban environments, with a capacity to transport over 1,000 lb [77].

4.6 DP-14 MULTIMISSION UAS

As early as 2016, the Army has been exploring autonomous CASEVAC using the DP-14 from Dragonfly Pictures Inc. (known as DPI) UAV systems (Essington, PA). The DP-14 is a twin-rotor vehicle that looks similar to a small-scale version of a Chinook. It can carry payloads of more than 400 lb and can travel 80 miles, with a maximum speed of 105 kt (Figure 4-6) [78]. In 2017, the platform was tested for human transport using the environmental factors data acquisition system, which measures shock, vibration, noise, temperature, pressure, acceleration, and pitch of the aircraft [79]. Unfortunately, as of 2019, the DP-14 is not being pursued for further operations, as it crashed during a test [71].

4.7 KARGO

In October 2023, the Army awarded a team comprising Near Earth Autonomy, Inc., (Pittsburgh, PA) and Kaman Air Vehicles, a division of Kaman Corporation (Bloomfield, CT), a contract to develop a heavy VTOL UAS with the capability of moving at least 800-lb loads and flying distances over 100 miles [80]. This heavy-lift UAS will be based off Kaman's KARGO UAV and will be used for CASEVAC and to move supplies. The KARGO UAV was selected by the Marines in 2022 for the medium ULS-A program and will be tested at Project Convergence 2024.

4.8 K-MAX/K-MAX TITAN

The K-MAX is a rotary-wing aircraft developed by Kaman Air Vehicles (Bloomfield, CT) that has been in use since the early 1990s (Figure 4-7). Kaman worked with industry partners to develop an unmanned version of the K-MAX that was purchased by Naval Air System Command in 2010. From 2011 to 2014, two unmanned K-MAX aircraft operated in Afghanistan performing logistics and resupply missions for the Marine Corps. Originally expected to be deployed for only 6 months, the two K-MAX vehicles operated for nearly 3 years, despite a crash in 2013. The K-MAX can carry loads of approximately 6,000 lb [81] and has been tested for CASEVAC capabilities [82]. In 2021, Kaman announced it was developing the K-MAX TITAN, a commercial version of its helicopter for use in firefighting operations. However, in January 2023, Kaman announced it was discontinuing production of the K-MAX but would continue to service, train, and repair currently operating vehicles for the foreseeable future [83].

Figure 4-7. K-MAX Helicopter *(Source: Machosky [84])*.

4.9 MERT-R

The MERT-R MEDEVAC UAV debuted at the Defense and Science 2022 Exhibition in Bangkok, Thailand (Figure 4-8). MERT was developed and assembled by the Royal Thai Army's Medical Department and Pulse Science (Nonthaburi, Thailand). MERT-R is a quadrotor, with a total of eight rotors, and can carry a maximum payload of 100 kg [85]. The body of the MERT-R is comprised of carbon fiber and titanium to minimize weight, keeping the vehicle around 100 kg [86]. It can move at speeds of 60 kph for a range of 30–50 km and has a video camera to send images back to a control station.

Figure 4-8. MERT-R MEDEVAC UAV Designed to Carry a Patient to a Medical Facility *(Source: Nondhasa [86])*.

4.10 SKYF

The SKYF is an unmanned heavy-lift industrial type aerial drone originally built by Russian company ARDN Technology, which dissolved (at least in the United Kingdom) in 2021 [87]. However, in 2018, ARDN signed an agreement with ZTO Express (Shanghai, China), one of the largest logistics companies in China, to purchase the SKYF platform when it became available for sale [88]. There is no indication that SKYF is being used by a military, nor was it ever necessarily intended for CASEVAC. Although the current state of ARDN is unknown, recent news appears to show that SKYF has perhaps been adopted as the name of the company, which has entered into an agreement with Swedron (Gothenberg), a Swedish company, to operate in northern Europe and pursue a UAV license from the European Aviation Safety Agency [89]. The technology does have some merit and capability relevant to CASEVAC operations. According to ARDN, SKYF uses the gasoline engines for lift and electric motors for control and stabilization, allowing for a 400-lb (181 kg) payload capacity, a range of up to 350 km (217 miles), and a total of 8 hours flight time.

4.11 T SERIES UAS

In February 2024, BAE systems announced that it had acquired Malloy Aeronautics (Berkshire, England), the manufacturer of several models of unmanned systems, including several of which are able to support CASEVAC operations:

- T-650: has a payload of 300 kg, can travel up to 140 kph, and has a range of up to 80 km [90]
- T-600: has a payload of 200 kg, can travel up to 140 kph, and has a range of up to 80 km (depending on payload) [91]
- T-400: has a payload of 180 kg, can travel up to 126 kph, and has a range of up to 70 km [92]

A smaller version, the T-150 tactical resupply vehicle (known as TRV), has been under development by the Army through Malloy/BAE's U.S. partner, SURVICE Engineering. While not capable of supporting the weight and functionality needed to transport a person, the success of the T-150 already in the Ukrainian War has demonstrated the utility of these particular vehicles. The British Army has tested the T-400 for CASEVAC (Figure 4-9), and there are reports that it could be deployed to Ukraine sometime in the near future [93].

Figure 4-9. Screenshot Images of a Demonstration for the TRV-400 *(Source: Long [94])*.

SECTION 05 WATERBORNE SYSTEMS AND VEHICLES

5.1 INTRODUCTION

Autonomy will play a huge role in multiple aspects of naval strategy in the near- and long-term. Currently, the Navy has two groups of autonomously controlled ships deployed for testing and evaluation of teaming with unmanned systems. Task Force 59 was launched in September 2021 and operates as part of the U.S. 5th fleet, utilizing a variety of vessels [95]. In November 2023, a group of four unmanned vessels (Seahawk, Sea Hunter, Ranger, and Mariner) (Figure 5-1) reached its destination of Sydney Harbor (Australia) after completing a lengthy cruise across the western Pacific. Known as Integrated Battle Problem 23.2, the exercise achieved a number of naval milestones to include marking the first time a group of unmanned vessels traveled that far together, even managing to stop at several ports along the way [96].

Figure 5-1. Clockwise From Top Left: Unmanned Surface Vessels Seahawk, Ranger, Sea Hunter, and Mariner *(Source: Seapower Staff [96])*.

These platforms will lead the way in advancement of autonomous systems for all sorts of applications, including ACE. Transporting casualties from land to sea-based vehicles is not necessarily an easy process, especially in LSCO and with the expected challenges of MDO and operations in shore environments. Further complicating the matter would be planning for possible action in the Pacific (as previously mentioned). Preparation for a conflict as early as 2025 is not just on the minds of Navy and Marine Corps leadership; even the Air Force has begun planning for MEDEVAC operations across the Pacific [97, 98]. Casualty transport brings up not just the issue of contested air space but also the difficulties of operating in a contested littoral environment [99]. This is an area where autonomous surface vehicles could make life easier. Small vehicles such as the common unmanned surface vehicle (CUSV) could be used to ferry casualties from the shore to larger ships (manned or unmanned) [100], and larger unmanned surface vessels could provide platforms where the sick and injured could be safely transported away from combat operations and even back to the nearest MTF.

Several recent exercises have tested autonomous capabilities to transport casualties, including a test of a ship-to-ship transfer of a mannequin using the MARTAC T38 Devil Ray unmanned surface vessel [101]. While not autonomous, the Navy awarded Austal USA a contract to complete the design and begin construction of a new class of ship—the Expeditionary Medical Ship (EMS) (Figure 5-2).

Figure 5-2. Artist Impression of EMS *(Source: Vavasseur [102])*.

The first member of the class will be designated the USNS *Bethesda* (EMS 1) [102]. What is interesting about the design, however, is the fact that the EMS will be modeled after the existing EPF class. The 13th member of the class, the USNS *Apalachicola* was outfitted during construction to include autonomous-ready capabilities [103], so it is not a far stretch to imagine that the EMS could also be outfitted with capabilities to become autonomous or semi-autonomous if desired.

5.2 CUSV

The fourth-generation CUSV is a small "multimission- and multipayload-capable vehicle" produced by Textron Systems [104]. It has a towing capacity of 4,000 lb of force at 20 kt and can operate for 20+ hours. While not specifically designed for CASEVAC, it does have the capabilities needed to identify survivors and ferry casualties to a larger vessel or to a safe area of the shoreline (Figure 5-3) [100]. It could be possible to "collect stranded sailors" by synchronizing UAVs with USVs like the CUSV to identify survivors using their GPS coordinates and relaying that back to surface drones [100].

5.3 EPF

The EPF program is charged with building 16 planned ships (Spearhead class) intended for rapid intratheater transport of personnel and cargo [105]. The ship design consists of a shallow-draft aluminum hull in a catamaran style. According to Naval Sea Systems Command, "EPFs enable the rapid projection, agile maneuver, and sustainment of modular, tailored forces in response to a wide range of military and civilian contingencies such as Non-Combatant Evacuation Operations (NEO), Humanitarian Assistance, and Disaster Relief (HADR)" [105]. The design and intended function of EPFs make them a potentially desirable vehicle for transporting casualties. While not originally intended to be unmanned, the thirteenth ship in the class (USNS *Apalachicola*) (Figure 5-4) was retrofitted during construction by Austal USA (the shipbuilder), L3 Harris, and General Dynamics Mission Systems to add in the autonomous capability and was given extensive sea trials to test the new function. The next ship in the class, USNS *Cody* (EPF 14), is the start of EPF Flight II, which was intentionally designed to be autonomous and has L3Harris' ASView system. The USNS *Cody* (and all Flight II ships) is also outfitted with more advanced medical capabilities to include surgical suites and limited radiology and laboratory facilities [106].

Figure 5-3. CUSV Image *(Source: Hall [100])*.

Figure 5-4. USNS *Apalachicola* (EPF 13) Underway in the Gulf of Mexico *(Source: LaGrone [103])*.

Figure 5-5. MARTAC T38 in Action *(Source: Maritime Tactical Systems, Inc. [108])*.

The EPFs are 337 ft (103 m) in length, but the new Flight II models are slightly longer at 360 ft [106]. They are able to carry 660 short tons and travel 1,200 nautical miles at an average speed of 35 kt [105]. Flight II models have additional capabilities to support V-22 Osprey operations [107] (and one can imagine this could be used for any type of aerial systems, including UAVs and other VTOLs transporting casualties). The USNS *Cody* and future EPFs will be able to fill a Role 2 medical capability. All of the EPFs to date have been built by Austal USA in Mobile, AL.

5.4 T38 DEVIL RAY

The T38 Devil Ray unmanned surface vessel by MARTAC (Melbourne, FL) is already being used as part of Task Force 59 and has been used in tests to demonstrate CASEVAC capabilities at sea. The vehicle is 38 ft in length, with a maximum payload of 4,000 lb and burst speeds ranging from 70 to 100 kt (Figure 5-5) [108].

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SECTION 06 CONCLUSIONS

Imagine a scene where a platoon of injured soldiers lies in an open field. A mechanical sound begins to emanate from the distant horizon. Suddenly, a massive vehicle hovers above the platoon, almost silent, with a gentle rush of air from the quadrotors blowing down on the group. A large cargo door opens from the bottom of the craft and slowly lowers several platforms. Some of the soldiers are able to roll on to the platforms themselves but carefully drag the most injured and incapacitated soldiers to the platforms first. Once all members of the platoon are loaded, the platforms rise back up into the air. The cargo door closes as the wounded soldiers begin to connect themselves to advanced monitoring equipment that starts transmitting health data to the central medical station for this sector of the battlefield. Once all passengers are secured, the crewless vehicle gently glides away to its predetermined destination. This may seem like a scene from a science fiction novel or movie, and maybe it is, but it is also a vision that many senior leaders have for ACE. While this may seem like a cool idea, it is also extremely difficult to do, as Pilgrim and Fitzgerald relate, "While theoretically very appealing, the practicalities of retrieving a potentially incapacitated or unconscious casualty pose real difficulties yet to be entirely overcome" [109].

Through the course of research for this report, two main trends in the development of ACE were identified. First, there is a major trend toward developing multipurpose-use autonomous platforms, especially overlapping logistics with casualty transfer. The development of agnostic vehicles for military service that can serve multiple purposes is not necessarily new, but, in the case of ACE, it is simultaneously solving a problem while creating one. On the surface, it makes sense for a platform to pull "double-duty"—transporting supplies to a forward location, offloading them, picking up casualties, and transporting them back to a medical station. However, as one interviewee put it, "There is a big difference between transporting a person and transporting bullets" [46]. This is the crux of the issue of using multipurpose vehicles, and it opens the door for more complicated needs, including the introduction of safe ride protocols, advanced patient monitoring, and even new ethical policies.

The second major trend is a self-fulfilling prophecy in a way—pushing advanced medical care closer and closer to the POI. Navy corpsmen and Army medics have always served this purpose in some capacity, but, realistically, resources are limited and will be more limited during the mass-casualty scenarios of anticipated LSCO. The vision here is to not just provide advanced first aid and hemorrhage control but to immediately begin providing complex care, such as what would be received from a trauma surgeon at the POI. This can be accomplished in many ways. One is to augment forward-deployed medical staff with advanced headsets and mixed-reality capabilities to coordinate directly with physicians and surgeons, perhaps even in the continental United States in real time. Another method is to develop medical systems with AI that can analyze a patient's vital signs and, with some input from field medical personnel, could diagnose and recommend treatment or even begin treatment using semi-autonomous or fully autonomous medical equipment. Autonomous vehicles could play a role in this, either during the initial response or during transport back to a medical facility (Figure 6-1). While the scope of this report is limited to ACE, the future of battlefield medicine is a vision in which most care will consist of closed-loop systems and autonomous transport [110].

The near future of ACE may include additional platforms, features, and information not included in this report due to an unclear need presently or immature research data. While not a present challenge, underwater vessels (e.g., the HUGIN and the Orca) could be used at some point to transport casualties in contested air and surface environments. Although there are currently no military operations in space, developments in this domain could be a necessity in the future and provide valuable insights into developing more efficient and effective ACE systems now. Both the United States and China are developing autonomous vehicles that can operate in space (X-37B Orbital Test Vehicle-6 [known as OTV-6] and the Shenlong spaceplane, respectively). Additionally, NASA has been working on AI-based and autonomous medical systems to treat astronauts on long-term missions to the moon or to deep space [111]. These advancements could provide useful insight for dealing with casualty challenges of a near-term LSCO environment.

As alluded to previously in Section 2, the next step is to incorporate more semi-autonomous or autonomous medical features to diagnose and treat casualties in transport. A beginning stage for improving autonomous casualty care, even if it is just evacuation, is to better understand which casualties may need to be evacuated first. This process, known as triage, has been a staple of

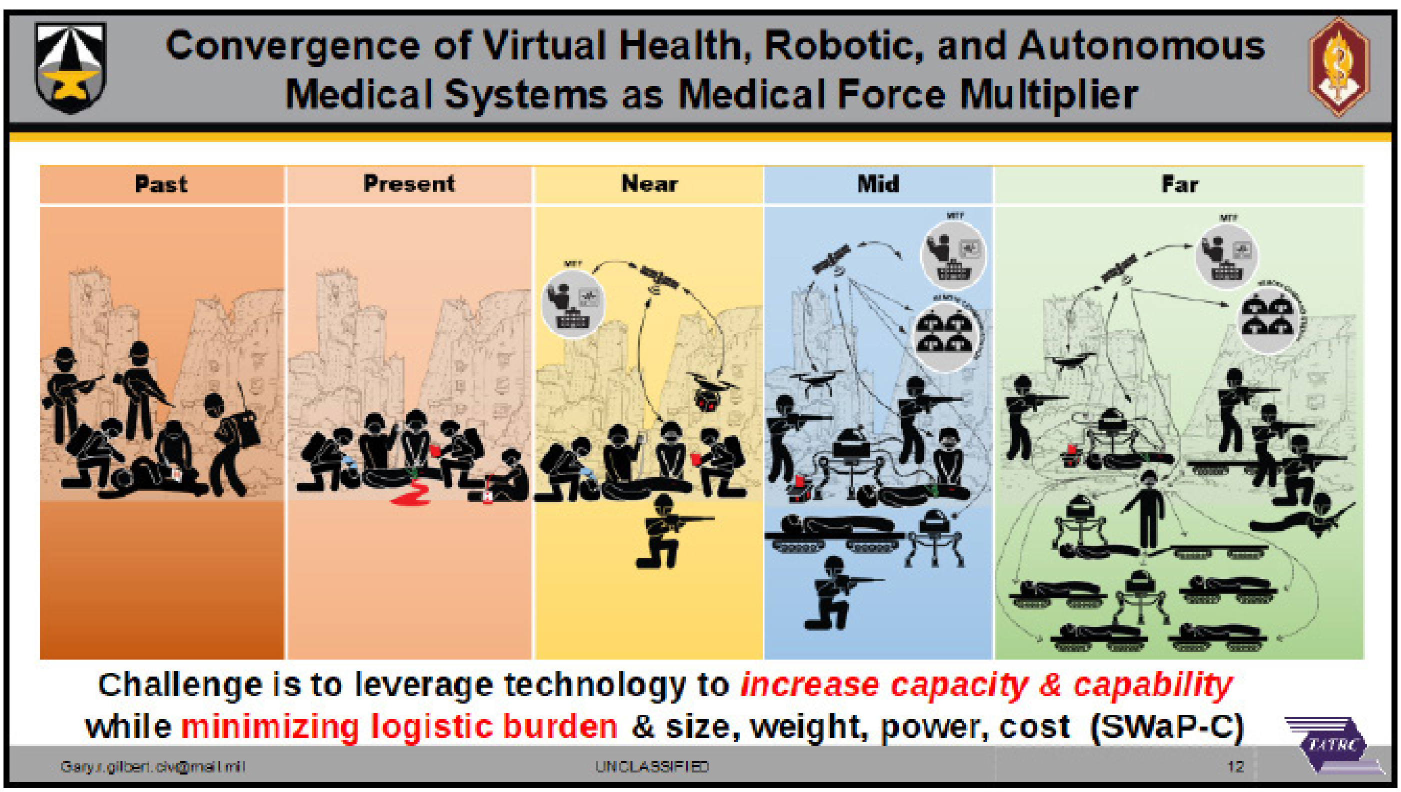

Figure 6-1. Leveraging Technology for MDO *(Source: The National Academies of Sciences, Engineering, and Medicine [112]).*

battlefield medicine for centuries; however, little data regarding CCC and physiological changes in the human body during combat-related trauma are actually available. Efforts are underway to address these gaps and improve casualty response. The DARPA Triage Challenge (DTC) is a program comprised of stages—a primary stage supporting the development of sensos on UAVs or robots that can analyze data and identify casualties with urgent needs and a secondary stage to predict life-saving interventions [113]. A related program, Research Infrastructure for Trauma with Medical Observations (known as RITMO), "aims to combine large-volume multimodal sensor, intervention, and medical outcome data obtained from trauma patients during the early post-injury period into a single database" and will support DTC [114]. A similar program is taking place in the United Kingdom, led by Edge Hill University (Ormskirk, Lancashire). A Trustworthy Robotic Autonomous system to support Casualty Triage (known as ATRACT) is scheduled to run in 2026 and will focus on four areas: (1) identification of injured soldiers using drones in challenging terrains, (2) a novel sensing and recognition platform; (3) real-time monitoring of vital signs and condition; and (4) enabling of more effective resource management and casualty prioritization [115].

In many ways, developing more autonomous care is not just a next logical step in battlefield medicine and CCC but also a way to fill current gaps until more advanced technology and care protocols can be developed. It is an ironic problem-solution cycle but one that will be absolutely necessary to address anticipated mass-casualty challenges of LSCO, especially through the evolution of autonomous casualty care (Figure 6-2). Common themes in this area neatly align with several programs and projects currently underway across the triservices:

- Enhancing decision-making skills of front-line medics and corpsmen through providing better connectivity with advanced providers using mixed-reality headsets and displays
- Understanding the physiology of trauma and the deterioration of casualties from a near-molecular level and converting those data into something that can be monitored and used effectively to make diagnostic and treatment decisions

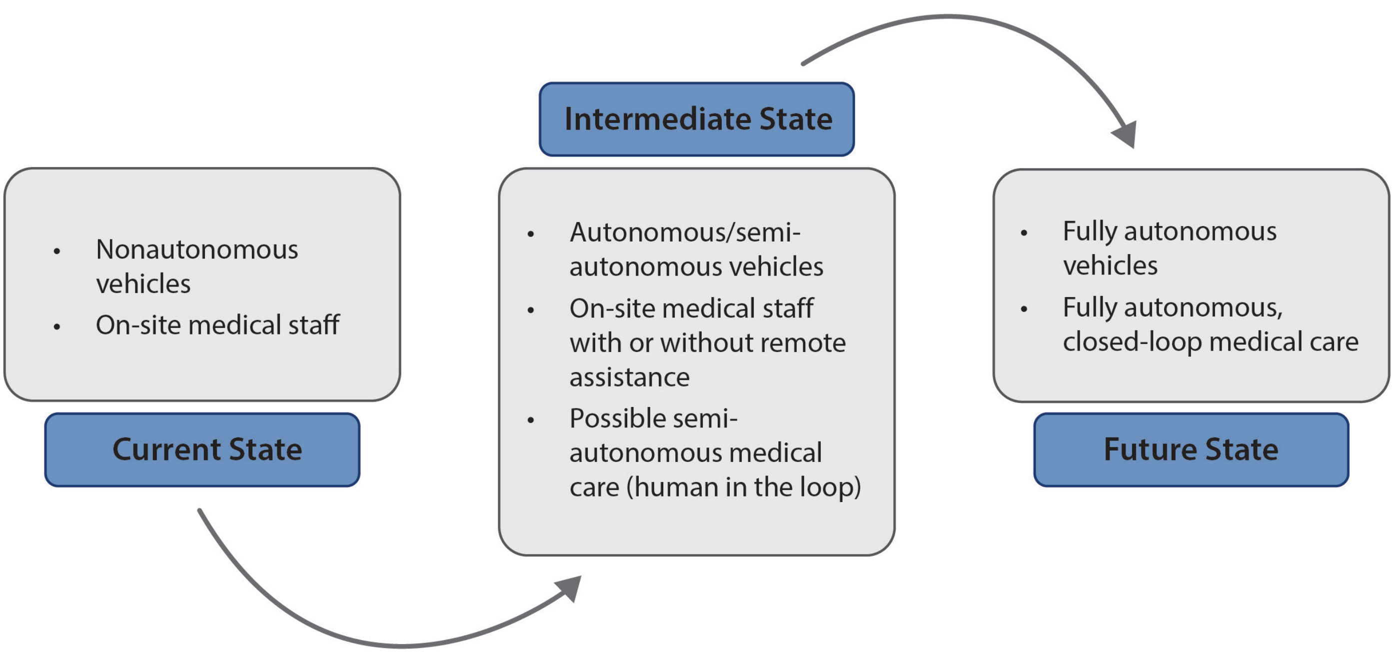

Figure 6-2. Evolution of Autonomous Casualty Care *(Source: Gregory Nichols)*.

- Utilizing AI to diagnosis and make treatment recommendations in real time
- Integrating semi-autonomous and/or autonomous systems into medical decision-making and treatment while also synchronizing individual platforms to ensure no contradictory actions occur that would jeopardize or endanger casualty management
- Improving the human-machine interface to more effectively pair medical staff with medical equipment and casualties with transport platforms

Although ACE seems like and is a necessary and significant thing, it is important to not lose sight of the goal to find solutions for dealing with mass-casualty situations in LSCO and, in acknowledging this problem, perhaps ACE could be a solution, maybe even one of many. Wissemann frames the issue by writing, "The way of warfare will fundamentally change from irregular warfare with infinite resources to high-intensity conflict with limited capabilities. Creative solutions will be necessary to ensure timely logistical support. Evacuation will shift to platforms of convenience, potentially supplemented with autonomous vehicles" [49]. A 2023 article [116] argues that given the "the lack of true understanding of the prolonged casualty care environment and the wider implications that LSCO will have on [CCC] and overall combat end strength secondary to gaps in current capabilities" CCC research should focus on five things moving forward:

1. Doing more with less
2. Rapidly clearing the battlefield
3. Optimizing return to duty
4. Provisioning en route care with low-profile evacuation platforms
5. Optimizing training and sustainment methods to ensure that maximal tactical CCC is delivered at the POI

Perhaps, inspiration can arise not only from specific combat needs but also from other related government and commercial areas. As previously discussed, there is and has been a shared interest in technologies, challenges, needs, resources, requirements, and gaps across areas that could improve autonomous CASEVAC:

- Search-and-rescue operations can provide insight into autonomy and its use in casualty identification and extraction
- Operations in extreme or austere environments (e.g., space or deep sea) can help promote clever and creative approaches to managing communications and navigation issues as well as perfecting unmanned operations in general
- Logistical transport addresses improvement in infrastructure needs and flow of people and vehicles

As the United States and its allies continue to navigate shifting and ever-complex geopolitical and technological developments, it will continue to be paramount that the end vision is never lost—providing the best medical care at the POI, reducing further casualties, and eliminating preventable deaths. Perhaps autonomy is the new frontier of battlefield medicine.

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AUTONOMOUS PLATFORMS FOR CASUALTY EVACUATION

By Gregory Nichols

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