Unmanned Aircraft Systems for Casualty Evacuation - What Needs to be Done

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ABSTRACT

Scenario: *Remote Cooperation and Warfare & Telemedicine*

Level: *Role I- Role II.*

Relevance: *The HFM-231 Program Objectives states "This Research Symposium is designed to evaluate new and emerging technologies and methods that could break down the tyranny of time and space ...(and) in which coordinated research efforts are required." A rudimentary capability to evacuate a casualty (CASEVAC in U.S. joint force terminology) via a vertical takeoff and landing (VTOL) unmanned aircraft system (UAS) currently exists within United States military forces. The potential for this capability will only expand as more VTOL UAS systems are developed and deployed by U.S. and NATO forces (e.g., U.S. Navy MQ-8C Fire Scout VTOL UAS).*

Rationale: *Aerial evacuation has become the standard for casualty evacuation. The aircraft flight parameters are controlled by their pilots, and thus are usually within the tolerance limits of casualties. However, there is no internationally recognized set of tolerable physiological standards for casualties or supporting data. Helicopter casualty transport, which has been used since the end of WWII, may or may not cause additional injury- there is no quantifiable data either way. This is of concern regarding VTOL UAS employment for CASEVAC since some UASs may have the ability to create physiological stresses in excess of those of most current evacuation aircraft. If UAS are to be employed for CASEVAC missions, it is necessary to have an agreed set of physiological parameters. Although CASEVAC is usually an adhoc,* *come-as-you-are mission, it is prudent to inform VTOL UAS manufacturers and operational commanders of specific medical issues or requirements which should be considered if the UAS could conceivably carry a casualty.*

Methods, Results, and Observations: *The NATO Technical Panel HFM-184- "Safe Ride Standards for Casualty Evacuation Using Unmanned Aerial Vehicles (UAVs)," completed its work last year and the final report was published in December 2012. The panel's purpose was to investigate and make recommendations regarding the use of UASs for casualty transport. The panel concluded "that the ... use of UAS for CASEVAC is ethically, legally, clinically, and operationally permissible, so long as the relative risk to the casualty is not increased." The panel identified research scope and gaps regarding physiological standards for VTOL UAS CASEVAC. These include: casualty stabilization, casualty preparation for movement, and impact of the in-flight environment (e.g., acceleration, vibration, acoustics, temperature, etc.). This paper describes a plan to conduct the HFM-184 panel's identified research needs, using a coordinated approach by NATO members.*

Conclusions: *The employment of VTOL UAS for casualty evacuation will soon be a reality and eventually commonplace in the battle-space. By conducting the research proposed in this paper, NATO members will be ready.*

1.0 INTRODUCTION.

The use of Unpiloted Aerial Vehicles (UAVs) has shown great progress in multiple roles in recent years. The U.S. Department of Defense, the various Combatant Commands, and the Services are awakening to the revolutionary possibilities offered by unmanned systems, not just for the traditional Intelligence, Surveillance and Reconnaissance missions, but for logistics delivery, combat search and rescue, special operations team insertion/extraction, etc., and it appears evident that logistics mission oriented UAVs capable of carrying casualties will be present on the battlefield in the forces of several Nations within the short to medium-term. Many personnel in both research and military development are already planning for the use of these aircraft for casualty extraction or evacuation on “back-haul”, after the UAVs have delivered their cargo. This potential usage falls into two distinct categories. The use of medically-equipped and staffed aircraft to move casualties is called “Medical Evacuation” or “MEDEVAC”, while the use of vehicles of opportunity, without medical care in flight is referred to as “Casualty Evacuation” or “CASEVAC”. While not all NATO nations make this distinction, the concept does exist in NATO doctrine. The distinction is critical, since any analysis of such usage must examine the potential use of UAVs in both these roles.

The use of aircraft for casualty evacuation was first proposed around 1908, and became feasible in 1910-1912, but the concept occasioned such opposition that every nation and military force rejected further consideration of the concept. Since 1915, when air evacuation of casualties first became a reality, nearly every airframe capable of carrying a patient has been used for casualty evacuation. In current military operations, the impact of helicopter evacuation times is a significant factor when it comes to casualty survival, which is at the highest level ever seen in military history. This fact has contributed to bringing the survival rates of U.S. Forces’ casualties in Afghanistan and Iraq up to 89.9% compared to 69.7% in World War II. It appears that the next aircraft type to be used in this role may well be the UAV.

Combat medical missions such as resupply and casualty evacuation are dangerous missions. This is especially true for the ‘high demand/low density’ helicopter flight crews bringing in the supplies and evacuating the wounded and the medical personnel on the ground who have to rescue and treat the wounded. Medical “first responders” have often become casualties themselves while trying to rescue or treat their comrades. This has been true since the beginning of armed conflict; perhaps there is a better way. Fielding robotic and unmanned systems to include UAVs which can perform these missions and tasks will: (1) Provide tactical commanders with increased tactical and operational flexibility; (2) Allow the execution of these missions in conditions that manned platforms cannot (or should not) operate in, such as “zero-zero” weather or a contaminated environment; (3) Husband critical medical “first responder” resources; and (4) Act as a force multiplier of scarce “high demand/low density” medical evacuation assets.

The development and deployment of unmanned systems throughout the military forces of the world is rapid, accelerating and “game-changing.” The U.S. Army Medical Research and Materiel Command's Telemedicine and Advanced Technology Research Center (TATRC) is conducting research and development of robotic/unmanned systems designed for combat medical missions such as critical item resupply, casualty extraction, casualty evacuation, and contaminated human remains recovery. These systems will also be applicable to logistics delivery, combat search and rescue, special operations team insertion/extraction, and civilian “first responder" missions. This potential use of UAVs as a solution to the need for evacuation demands the creation of safe ride standards for such use. The NATO Research and Technology Organization (RTO) determined to investigate this issue and in 2009 established RTG-184 with the task of looking into all aspects of this potential usage. The final report was published by NATO in December 2012. Accordingly, this paper reviews both the initial research & development efforts of the TATRC & the US Department of Defense (DoD) in exploiting emerging UAV technologies for medical missions, and the work of the NATO RTG-184 panel to explore research directions for development of safe ride standards for UAV-carried patients.

2.0 CAPABILITY GAPS & DOCUMENTATION OF NEED.

Enacted in 2006, Public Law 109-364 SEC 941 (John Warner National Defense Authorization Act for Fiscal Year 2007) requires a preference for unmanned systems in acquisition programs for new systems, including a requirement under any such program for the development of a manned system for a certification that an unmanned system is incapable of meeting program requirements (5). In response the U.S. military services are looking into the future and identifying “placeholders” for Unmanned Air Systems (UAS) by documenting capability gaps including those for casualty evacuation. For example, the Marine Corps Concept of Operations for UAS Family of Systems describes *“…a CASEVAC system (which) will relieve the reliance on manned platforms to evacuate casualties from combat zones. The systems will move a wounded Marines or soldier from the site of his injury within the “golden hour” immediately following the trauma. This system will transport one to two stabilized, wounded Marines to an appropriate medical facility in an environmentally controlled atmosphere to eliminate exposure to the elements and variances in temperature.”*

The 2008 version of the U.S. Army Training and Doctrine Pamphlet (TRADOC) PAM 525-66, ”Future Operating Capability 09-06, Health Services Support” says, *“Future Soldiers will utilize unmanned vehicles, robotics and standoff equipment to recover wounded and injured Soldiers from high-risk areas, with minimal exposure.”* Published that same year, the “U.S. Army Capability Concept Plan for Army Aviation Operations 2015-2024”, TRADOC PAM 525-7-15 says, *“Army aviation capabilities will contribute to achieving the future Modular Force sustain capability requirements…… the capability of UAS to provide rapid movement of planned logistics support that enables precise delivery of supplies to forward battlefield locations..... Unmanned aircraft will ….also be capable of extraction of wounded“.* These initial capabilities documentation publications were followed in February 2012 by the “Army’s Initial Capabilities Document for Unmanned Systems” which stated: *“Force health protection capability gaps include the inability to safely diagnose, recover, and transport casualties with enroute care from areas where manned systems are denied entry or unavailable….. The force lacks the capability to provide standoff Health Services and Force Health Protection where manned systems are denied entry or unavailable”.* This was followed in 2012 by the Army’s “Unmanned Ground Systems (UGS) Annex to the Army Campaign Plan 2013” which states, *“Continued improvements in the UGS will focus on decreasing combat medic’s role in patient extraction from the battlefield and more on supporting the treatment of the casualty by the combat medic.”*

Perhaps these documents prompted the Army Medical Department to publish several policy memorandums, the latest being March 2013, which state that: "The AMEDD does not support the use of unmanned systems in accomplishing direct medical care tasks or medical evacuation without human accompaniment. The safety requirements for putting human beings aboard vehicles or aircraft without an on-board pilot must be at least as stringent and effective as those for piloted vehicles or aircraft", the policy memorandum also stated that: The AMEDD recognizes the potential of [unmanned systems] on the future battlefield…[and].. supports the development of [unmanned systems] for Army Health System support use in Roles 1 through 3, but will be limited to tasks that are … dull, dirty, dangerous, routine, or monotonous (e.g., casualty extraction, logistical resupply, etc)….The AMEDD lacks sufficient autonomous ground, air, and maritime logistics and distribution capability to provide responsive, assured, class VIII supply and services to highly dispersed units across the extended operational environment (OE). Unmanned systems can potentially fill a portion of this capability gap…. The AMEDD lacks the capability to extract casualties where manned systems are denied entry or unavailable. Most active combat situations create significant challenges (dangerous situations) for combat lifesavers or combat medics at the point of injury (POI)….[unmanned systems] can potentially conduct extraction and/or retrieval of combat casualties on behalf of the first responder and deliver the wounded Soldier (within a short distance) to a safer location."

3. 0 CHALLENGES.

There are significant technical and non-technical issues that must be addressed before a viable unmanned medical resupply and patient movement capability can be fielded. These include:

- Autonomous navigation and operations
- Robust command and control
- Unmanned systems sensors
- Power
- Standoff casualty assessment and triage
- Autonomous or extremely rapid tele-operations for casualty handling
- Tactile feedback for unmanned casualty handling systems so additional harm isn't inflicted
- Closed-loop, portable critical care enroute care systems
- Medical standards for transporting casualties on unmanned systems
- International Treaties and individual nation/NATO doctrine and policies

Below is a subjective, but informed, assessment of the maturity of the various technical components necessary to field an unmanned medical resupply and casualty movement capability.

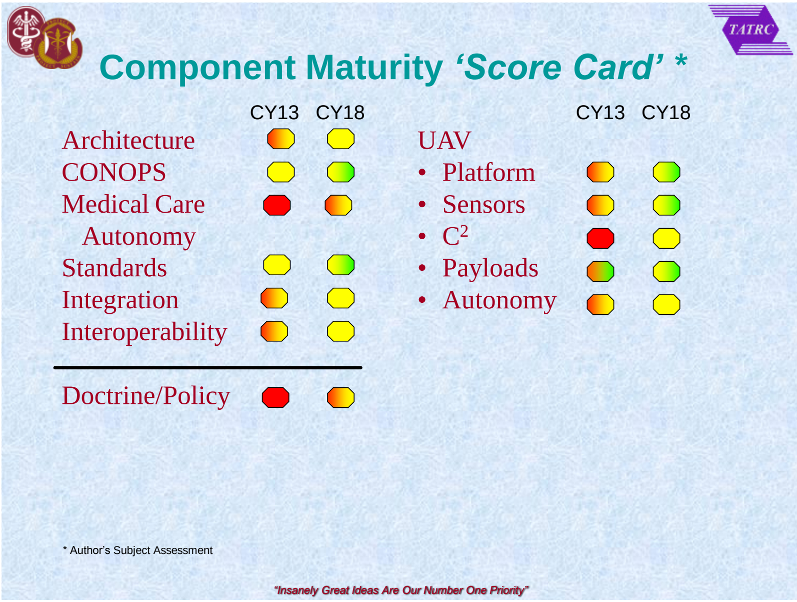

Figure 1: UAV CASEVAC Concepts & Technology Component Maturity "Score Card"

4.0 US DOD RESEARCH IN UAS MEDICAL RESUPPLY & CASEVAC.

The U.S. Army Telemedicine and Advanced Technology Research Center (TATRC), part of the U.S. Army Medical Research and Materiel Command (MRMC) has established a technology development strategy contributing to the attainment of a long term Autonomous Combat Casualty Care vision. TATRC is implementing this strategy by leveraging Department of Defense (DoD) Science and Technology funding programs such as the Small Business Innovative Research (SBIR) and Science and Small Business Technology Transfer Research Program (STTR). Close collaboration is maintained with the various DoD and Service organizations, for example – The Robotics Systems Joint Project Office, the Army Maneuver Battle Lab, The Marine Corps Warfighting Laboratory, the Office of Naval Research, the Air Force Surgeon General's office for modernization, and the U.S. Special Forces Command Surgeon. Great emphasis is placed on developing transition paths that will take the products of these R&D efforts and move them into fielded systems or commercial products.

4.1 ombat Medic UAS for Medical Resupply and Evacuation SBIR Projects.

One project looking exclusively at the employment of unmanned aircraft systems (UAS) for medical resupply, casualty extraction, and CASEVAC missions was the Combat Medic UAS Small Business Innovative Research (SBIR) Project. Two companies – Dragonfly Pictures and Piasecki Aircraft (and their partners) developed and demonstrated UAS technologies which may lead to fieldable medical resupply and CASEVAC capabilities. These included UAS autonomous navigation, flight, landing zone selection, takeoff and landing; and on UAS/medical personnel C^2/interaction. A notional concept of operations for these missions is included below (figure 4). Both companies, Dragonfly Pictures and Piasecki Aircraft, integrated commercial-off-the-shelf laser imaging detection and ranging systems (LIDAR), with their respective Unmanned Air Vehicle (UAV) flight control and mission management systems. The LIDARs (figures 1 & 2), mounted under the chin of the each vehicle, scan in both the horizontal and vertical planes, looking for flight path and landing zone obstacles. Coupling this LIDAR/autopilot system with digital terrain maps allows the UAS to takeoff, navigate, transit, select a landing site, and land – all autonomously. The Piasecki Aircraft project conducted in conjunction with Carnegie Mellon University resulted in the first ever totally autonomous flight of a man-rated rotary-wing aircraft with humans on board in 2010. The Dragonfly pictures project resulted in development of a medium capacity tandem rotor unmanned helicopter with projected range of 100km, usable payload of 450 lbs, and capable of autonomous flight.

Figure 2: Dragonfly Pictures 100m SICK LD-LRS LIDAR and Servo

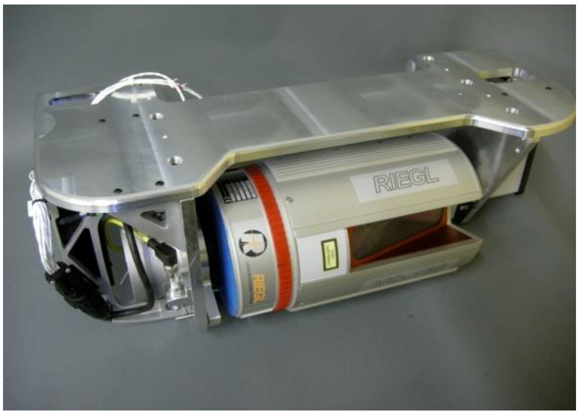

Figure 3: Piasecki Aircraft RIEGL VQ-180 LIDAR

4.2 Joint Medical Distance Support & Evacuation (JMDSE) Joint Capabilities Technology Demonstration (JCTD).

TATRC also served as the Deputy Technical Manager for the U.S. Joint Forces Command Joint Medical Distance Support and Evacuation (JMDSE) Joint Capability Technology Demonstration (JCTD). One of the JMDSE products was a Joint Unmanned Casualty Evacuation (JUME) concept of operations document for combatant commander, service, and individual UAS program managers. It describes the potential use of cargo capable, unmanned aircraft systems to provide medical re-supply, casualty extraction, casualty evacuation, and the transport of personnel with suspected or actual chemical, biological, radiological or nuclear contamination.

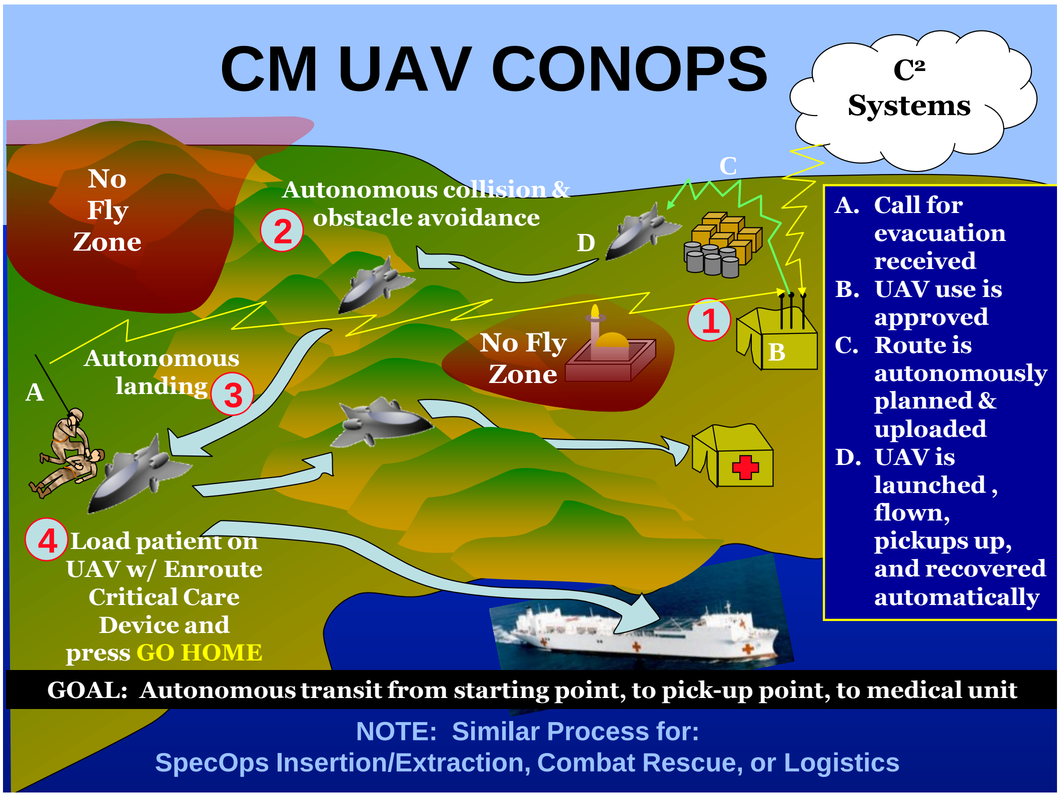

Figure 4. Combat Medic UAS SBIR Notional Concept of Operations

4.3 U.S. Marine Corps Limited Objective Experiments (LOE).

The U.S. Marine Corps is aggressively pursuing an Air Cargo UAS capability to meet real world mission requirements. Medical resupply and CASEVAC are of course, subsets of the larger logistics mission. In 2011, the Marines deployed a K-MAX Air Cargo UAS system into the Afghanistan area of operations. To support this fielding effort the Marine Corps Warfighting Laboratory (MCWL) previously had conducted three flight demonstrations. The first – Limited Objective Experiment 3.3 – Enhanced Company Operations, in May 2009, employed a Boeing Unmanned Little Bird UAS to delivery supplies (water, food) and evacuate a casualty (weighted mannequin), carried in an outboard cargo pod. The results were encouraging and *"validated both the unmanned resupply and CASEVAC concepts…CASEVAC and resupply TTPs (tactics, techniques and procedures) require further experimentation for refinement, (and) has potential, but requires technical improvement before undergoing further experimentation."* The MCWL recommended integrating this unmanned capability into their Sea Basing Concept. The next flight demonstration took

place in January 2010, at the Dugway Proving Grounds in Utah. The first demonstration employed the Kaman/Lockheed Martin K-Max UAS and successfully demonstrated autonomous and teleoperated takeoffs, flight, delivery of sling loaded cargo, and landing. The third and last flight demonstration took place in March 2010, again at Dugway, employing the Boeing A-160 Hummingbird UAS. Initially funded as a Congressionally Directed Special Interest project, the Advanced Multi-Missions and CASEVAC project is now supported by the MCWL, the Air Force Research Laboratory, and TATRC and is being conducted by Advanced Tactics Inc. based in California. The project is aimed at conducting research, development, and demonstrations of several multi-rotor combined UAS and UGV concepts with potential for both logistic operations and CASEVAC missions.

Figure 5: Unmanned Little Bird at Marine Corps Mountain Warfare Training Centre

Figure 6: Kaman/Lockheed Martin K-Max UAV in Afghanistan

Figure 7: Advanced Tactics Inc. "Black Knight" UAV/UGV Conceptual Design

5.0 NATO RESEARCH DIRECTIONS[1].

In 2009, the Human Factors and Medicine Panel of the NATO Research and Technology Organization (now called the NATO Science Organization) established RTG-184 with the task of looking into all aspects of patient safety during evacuation flights on board UAS (whether in MEDEVAC or CASEVAC modes). Four nations participated in the work (Germany, Israel, United Kingdom, and the United States), and completed their work in mid- 2012. The final report of this task group was published by NATO in December 2012, and has been chosen to receive the NATO Science Achievement Award for 2013 as an

[1] Much of this portion of the paper has been extracted directly or paraphrased from the Final Report of HFM-184, December 2012.

outstanding piece of work which will have a significant impact upon NATO doctrine, policy, and operations in the future.

The work of this group involved a review of all technical and medical aspects of this type of vehicle, the legal and ethical considerations for such use, the operational and clinical considerations, and the development of possible scenarios in which such use could be beneficial to the casualty. This study resulted in recommendations for doctrine development by various NATO bodies and clinical guidelines for such usage, as well as in a set of recommendations for future research and development to support such potential usage.

After discussion with many line, aviation, and medical military personnel, the group came to believe that these aircraft will be used for casualty movement soon after their appearance on the battlefield, with or without doctrinal guidance. NATO and national Special Operations Forces have clearly indicated their interest in such use, when regular aerial evacuation means are either not available or are operationally undesirable, as have several nations' conventional military forces. This potential use of UAVs as a solution to the need for evacuation demands the creation of safe ride standards for such use. A set of guidelines to make this modality safe to use in certain circumstances was developed by RTG-184. The goal of the group was to investigate the potential use of UAVs for this purpose, and to develop clinical and operational criteria as to when such evacuation could be considered and safely accomplished. Obviously, a traumatized patient should not be placed in a vehicle which routinely uses a 7-G climbing spiral to take off, but what other flight and patient care parameters need to be taken into account? The RTG addressed all these topics, and provided recommendations for further necessary research. RTG-184 also studied the current and future technology of UAVs, and determined that while the aircraft technology is nearly ready for use in CASEVAC roles, the medical equipment and knowledge which is critical for the use of UAVs in the MEDEVAC role is not yet available.

One surprising discovery was that there is not currently available any internationally recognized set of tolerable physiological standards for casualties which can be used in development of flight profiles for Unmanned Aerial Vehicles (UAVs) – this is of special concern since some UAVs have the ability (like fighter aircraft) to potentially create physiological stresses far in excess of those produced by most current evacuation aircraft. Potential use of these vehicles for this purpose will likely be far-forward, and will involve the transport of freshly wounded, unstable, casualties, who may be more susceptible to physiological stresses than would be stabilized casualties. If UAVs are to be used in a casualty evacuation role, it is necessary to have an agreed set of physiological, flight, and materiel parameters which can be used by decision-makers to decide whether or not a casualty is suitable for evacuation by means of a UAV, or conversely, if a specific UAV is suitable for evacuation use. This potential use of UAVs as a solution to the need for evacuation demands the creation of safe ride standards for such use. The group developed a set of guidelines to make this modality safe to use in certain circumstances.

The group considered the flight characteristics of potentially suitable UAVs and current aeromedical platforms, as well as aeromedical factors which must be met to ensure that any such evacuation is not detrimental to the casualty. An agreed prerequisite was that UAVs for this purpose must meet the same safety standards as currently used in man-rated rotary wing aircraft (crashworthiness, redundant flight systems, etc.), and that they must not exceed the physiological parameters (e.g. G-Loading and Acceleration) which are imposed by currently-used air evacuation aircraft.

The group reviewed not only the current state of UAV development, but NATO doctrine and policy addressing this issue, legal, ethical, and regulatory issues, as well as the clinical aspects of such transport, and it presented a set of recommendations for NATO and the RTO which the RTG believes will ensure that when such use becomes reality, it will be without detriment to the casualties being moved. The RTG has recommended changes and additions to NATO doctrine in this regard, as well as proposing continued research which is necessary to develop truly evidence-based safety-of-flight recommendations. They identified improvements in medical equipment which are necessary before any detailed consideration can be given to future use of UAVs for true medical evacuation, which can offer care in flight. In describing the characteristics of UAVs and how they may affect UAV utilization as an evacuation platform, the group identified needed additional research in order to make such capability an acceptable modality and to allow it to become a viable addition to NATO's evacuation chain.

Specific topics covered during the RTG discussions included:

- Status of Development and Flight Characteristics of UAVs (current, developmental and projected);
- Control Mechanisms for UAVs, including Remotely Piloted Vehicles (RPV) and controlled by onboard programming (Artificial Intelligence);
- The potential use of UAVs for casualty evacuation – operational, ethical, doctrinal, and logistical considerations;
- Human Systems Integration (HSI) for UAVs used for casualty evacuation;
- G-tolerance and rate-of-onset tolerance of casualties in various axes and with differing medical conditions;
- Psycho-Physiological Stresses potentially encountered;
- In-fight medical support capabilities; and
- Possible scenarios in which UAVs could serve in casualty evacuation.

The RTG concluded that the potential use of UAVs for casualty evacuation (CASEVAC) is ethically, legally, clinically, and operationally permissible, so long as the relative risk for the casualty is not increased through the use of the UAV. The group reported that use of this type of aircraft for Medical Evacuation (MEDEVAC) which requires care in flight is neither technologically possible nor acceptable at this time (primarily due to lack of capability of in-flight medical equipment), and the group identified needed additional research in order to make such capability an acceptable modality and to allow it to become a viable addition to NATO's evacuation chain.

Unfortunately, development of a full set of mandatory limits on flight parameters to be met could not be successfully accomplished, as being beyond the research capabilities of an RTG. Although most types of aircraft have been successfully used for the movement of casualties for many years, there is a dearth of evidence-based data which actually shows the safety of current aeromedical evacuation practices, and which can be used for comparison. The fact that most casualties survive their aerial journeys, and that most practitioners believe that this means of transport is the best possible transportation means in a combat environment, does not prove that such transport is not in any way detrimental. For example, we can demonstrate that casualties with head injuries can survive transport by helicopter, but it has never been convincingly demonstrated that such individuals do not suffer additional damage from the stresses experienced in flight. The RTG identified and recommended the accomplishment of future medical research necessary to definitively prove this, though actually carrying out this research was beyond their capabilities.

The concept of "casualty as cargo", or the carriage of a casualty in an aircraft not specifically designed to carry people, adds multiple requirements to the normal "cargo design requirements", such as litter tie-down capability and ambient noise management. Essentially, successful adoption of this concept will require the addition of some specific design requirements to ensure casualty safety. RTG-184 believes that any aircraft to be used for UAV CASEVAC must at a minimum meet safety, environmental conditioning, and reliability standards of current manned helicopters. Paramount to designing standards for previously unmanned systems to be "manned" with precious human cargo is the concept that all precautions and risk-reducing measures must be installed, and certainly no expense should be spared to ensure that the aerial system is safe for manned flight.

The scope of needed research can be categorized as clinical investigative research, medical technology research and development, and operational research. The scope of such research is applicable to both standard and non-standard transport vehicles.

- Clinical Investigation Research: Evaluate in controlled groups the efficacy, safety of novel medical technologies or clinical protocols contributing to improved outcomes of patients transported by UAV. Tasks may span the translational continuum to include early translation into Phase I/II trials, late translation into Phase III/IV trials and regulatory approval, health services research, dissemination to providers and communities, and adoption by providers, patients and the public.
- Medical Technology Research and Development: Research, development, and operational testing of novel devices, systems, and other medical products related to use of UAVs, such as future patient transport pods.• Operational Research: Modelling, simulation, research, and analysis of clinical or operational procedures and processes related to environmental and occupational stressors, team performance, training effectiveness, or diagnosis of clinical health problems of concern to beneficiaries of military healthcare and expeditionary operations.

To improve our technical capability to meet casualty movement requirements, we will have to depend on enhancements in:

- Portable medical equipment;
- Adaptation of clinical capabilities for employment on any available and appropriate Air Evacuation transportation platform;
- Patient management and regulating systems; and
- Clinical and Operational Training.

Characteristics of the movement environment directly affect human physiology, and more understanding is needed of these effects on patients with comprised physiological systems. The above research areas are applicable to both manned medical transport vehicles and to UAVs.

One of the original tasks of this RTG was to review the clinical knowledge to develop recommendations for evacuation, based on specific clinical conditions and the stresses of flight. Unfortunately, we have found that there is very limited evidence-based data available for such evaluation – This subject has simply never been examined adequately. There is a general assumption among those with experience in aeromedical evacuation that in the absence of <u>severe</u> stress (e.g. vibration, acceleration, hypoxia) air evacuation does not pose any significant effects on the patient. However, this has not been adequately demonstrated in any evidence-based way. When additional research on the clinical effects of aeromedical evacuation is proposed, the response is often “But we already know all that!” Unfortunately, that assumption is fallacious. Although the U.S. Army pioneered large-scale helicopter evacuation during the Vietnam era and has evacuated tens of thousands of patients in the current conflicts over the past decade, meaningful research examining the physical impact of rotary wing evacuation in the combat setting is generally lacking. The fact that most casualties with any given condition survive their evacuation (and have a higher survival rate than patients who are not evacuated, for many reasons) does not imply that they are not in fact harmed in any way by the evacuation. We simply have no data which proves that the stresses of rotary wing evacuation do not cause deterioration of patient conditions, even though the vast majority of patients survive their flights. Thorough understanding of the interactions of environmental extreme conditions and patient aeromedical care onboard current medical transport vehicles is necessary to provide baseline knowledge for possible future transport vehicles such as UAVs, whether in the CASEVAC or the MEDEVAC mode. The evidence-based data generated by studies of evacuations carried out on current aerial platforms can be applicable to and can be extrapolated to UAVs.

One example of an area which needs evidence-based research is the clinical management (pre-transport) and transport of patients with head and spine injuries, which is discussed in detail in the RTG-184 report. The current standard of care is based on WWII through Vietnam era practices which may or may not produce an optimal medical outcome. A research program is needed to address the patient health hazards associated with vehicle vibration and repeated shock which is believed by some researchers to have unintended consequences for a large population of wounded soldiers. To mitigate shock and vibration exposure, a patient's exposure limits to whole body vibration need to be defined. There is no data available on vibration exposure criteria for patients, and this too may be another major area of risk to injured patients and injured tissue susceptible to increased inflammatory processes and cascades.

Problems which need to be addressed, solely with regards to this aspect of evacuation, include:

- Vibration and shock exposure criteria for supine patients with head and spine injuries are unknown. Furthermore, no current vibration mitigation technology, as an interim solution, is available;

- Very little evidenced-based data exists on proper spinal immobilization and transport; and

- Very little evidence-based data exists on cervical collar use in patients with spinal injuries in a high-vibration environment.

What is needed is a vibration mitigation strategy along with improvements in the additional identified areas of evidentiary weakness in care – namely, cervical collars and immobilization devices. By solving all three areas, the knowledge and techniques gained will be implemented into safe clinical management and transport of patients with head and/or spine injuries. The purpose of the research is to prevent exacerbation of existing injuries of patients during en route care and validate standard of care to improve patient outcomes. The research plan should utilize vibration and patient movement Subject-Matter Experts (SMEs) with research collaborations among the military, academic, and industry partners, from all our Nations. The goal is to identify the vibration and shock exposure criteria for supine patients and improve clinical management and transport of patients with head and spine injuries. To get this issue moving forward, an RTO Activity focused solely on this issue would be of great benefit.

Future work should investigate the biodynamic response of healthy supine humans with and without immobilization under simulated vehicle shock and vibration. Animal models with head and spine injuries due to blunt and/or blast impacts should be considered. Additionally, the use of cadaver models under shock and vibration exposure should be considered. The complete work would produce acceptable industry standards defining mechanical shock and vibration exposure criteria for transporting patients as well as determining appropriate standards of care. The goal is to produce meaningful evidence-based data which can be used by NATO, the national military services, civilian, and scientific communities to improve casualty evacuation, resulting in lessened morbidity and mortality. This information is critical to the design of all future casualty transport systems and vehicles.

There are several test standards for medical equipment used by various NATO Nations, and harmonizing these standards is critical for successful interoperability and equipment use throughout the Alliance. It should be noted that all test standards, in general, address somewhat similar electromagnetic and environmental extremes. Test standards describe, in detail, the test procedures for medical equipment that will be used onboard military transport vehicles during en route patient care. In general, the standards include a baseline performance assessment, laboratory tests, and an in-flight assessment. The baseline performance assessment verifies that the test article operates in accordance with the manufacturer's specifications. The two main goals of laboratory testing are to identify the potential safety concerns that the test article may pose for the aircraft, patient, and crew and to also identify the physical or functional degradation that the test article may experience within the operational environment. Laboratory tests include but are not limited to vibration for air and ground vehicles, electromagnetic interference, climatic, altitude, rapid decompression, explosive atmosphere, acceleration/crash, blowing dust, blowing sand, and blowing rain. After completion of laboratory testing, the test article is evaluated for "fit, form, and function" as well as EMC compatibility with the aircraft during actual aircraft flights by test personnel, medical personnel, and qualified medical flight crew to validate laboratory findings and assess human factors. The lack of a standard NATO system for ensuring such analyses is a critical defect. Therefore, it would appear useful to discuss this issue within the NATO Aeromedical community, with the objective of gaining agreement to standardizing these processes as an Allied Medical Publication.

6.0 SUMMARY

Robotic and unmanned systems, especially unmanned air systems, are being developed and fielded in rapidly increasing numbers. The numbers and rate of deployment of unmanned air vehicles will continue to accelerate as missions other than the current intelligence, surveillance and reconnaissance, and predator missions are addressed. One such mission area is combat medical resupply and casualty evacuation. Employing unmanned or pilotless aircraft and combined unmanned air/ground systems for these missions will provide additional operational flexibility, protect critical medical assets and personnel, and will be truly "game changing" in the operational space of the 21st century.

As regards needed research, RTG-184 pointed out that: "In summary, there are many ongoing and necessary RDT&E initiatives for manned en route care, as well as for CASEVAC without en route care. The information gathered from those initiatives will be critical to the successful use of UAVs as life-saving platforms. Many knowledge and interoperability gaps remain that need to be addressed. With the help of this group, the opportunity to save lives with UAV platforms is closer to reality."

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