Aerial Delivery of Fresh and Stored Blood Products

01 Dec 2025

Presentation of requirements to change standard operating procedures for utilizing airdrop to deliver blood products to first responders and various medical teams treating hemorrhaging patients in austere environments.

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Executive Summary

This Operational Planning Guidance (OPG) presents requirements to change standard operating procedures for utilizing airdrop to deliver blood products to medics and various medical teams treating hemorrhaging patients in austere environments when timely evacuation to higher levels of care or ground resupply is not feasible. As military operations shift toward Large-Scale Combat Operations (LSCO) and denied environments, the ability to rapidly resupply blood products becomes a critical capability to sustain combat casualty care. This OPG provides a framework for planning, executing, and evaluating the use of aerial delivery – via fixed-wing aircraft, rotary-wing aircraft, and unmanned aerial systems (UAS) – to ensure that whole blood (WB) and packed red blood cells (pRBCs) reach point-of-injury (POI) care providers as quickly and safely as possible. In absence of WB or pRBCs, additional consideration could be made for delivery of other hemorrhage support adjuncts such as Freeze-Dried Plasma (FFDP), Fresh Frozen Plasma (FFP), and Prothrombin Complex Concentrates (PCC) and/or Tranexamic Acid (TXA). The specific product delivered should be made utilizing the good, better, best framework. These adjuncts have a longer shelf life than WB or pRBCs but do not improve oxygen carrying capacity to reduce acidosis but can improve the coagulopathy leg of the "Lethal Diamond."

Hemorrhage remains the leading cause of preventable death on the battlefield, with studies showing that 91% of potentially survivable deaths are due to uncontrolled bleeding.[1] Every minute of delay in administering blood products increases mortality by 5%, underscoring the need for immediate access to transfusion-capable blood supplies.[2] While medics often carry WB or rely on pre-screened donor protocols (e.g., Ranger O Low-Titer [ROLO]), these solutions are not always sufficient, especially in prolonged casualty care (PCC) scenarios or mass casualty incidents. Aerial resupply via airdrop offers a viable alternative when traditional resupply chains are disrupted or when casualty evacuation (CASEVAC) is delayed or impossible.

A comprehensive review of existing research confirms that aerial delivery of blood products is feasible and a safe method for prehospital transfusion support. Multiple case-controlled studies including *Operation Blood Rain (2021-2022)*[3,4] and the *UK C-130 Parachute Study (2021)*[5], demonstrate that blood airdrop does not result in clinically significant hemolysis or degradation of blood components. Additionally, findings from the *Joint Medical Distance Support and Evacuation Study (2010-2011)*[6] and *ILAR Event 8 (2005)*[7] confirm that properly packaged blood products maintain viability even when airdropped from altitudes ranging from 200 ft to 21,000 ft above ground level (AGL). Medical supply delivery (via unmanned systems) was an identified capability gap in Combat Casualty Care (JROCM 061-21). Emerging research on UAS-based blood delivery, such as *Project Crimson (2021)*[8] and the *Zipline UAS Study (2023)*[9] highlights the potential for precision drone resupply, further expanding options for rapid blood delivery in contested environments.

This OPG is designed for use by:

- First Responders (medics and corpsmen and Role 1 medical providers who require blood resupply at or near the POI.
- Tactical and operational planners responsible for integrating blood airdrop into medical logistics.
- Aviation and UAS operators tasked with executing aerial blood resupply missions.
- Medical logistics personnel managing blood storage, packaging, and quality assurance for aerial delivery.
- Medical planners and logisticians developing plans, policies, and procedures for sustainment of blood resupply in LSCO and denied areas.

This guidance provides a systematic approach to blood airdrop operations, covering:

- **Blood Product and Adjunct Considerations** – Selection of WB vs. pRBCs, cold chain management, and transfusion viability.

- **Airdrop Delivery Methods** – Fixed-wing, rotary-wing, and UAS platforms with specific drop altitude and speed recommendations.
- **Packaging & Handling** – Use of BloodBoxx™ Evac coolers, Golden Hour Containers, and parachute deployment systems to ensure blood viability upon impact.
- **Tactical Considerations** – Planning and execution phases, including weather assessments, drop zone coordination, and retrieval procedures.
- **Performance Monitoring** – Quality control metrics, post-drop laboratory testing, and integration with the Department of Defense Trauma Registry (DoDTR).
- **DOTMLPF-P Integration** – Considerations for doctrine, training, leadership, and policy development to institutionalize blood airdrop as a validated capability.

Background & Justification

Uncontrolled hemorrhage remains the primary cause of preventable combat deaths. Mortality studies from the Afghanistan and Iraq conflicts confirm that 91% of potentially survivable battlefield deaths result from hemorrhage.[1] Every minute of delay in administering blood products increases mortality by 5%, reinforcing the necessity of immediate transfusion at or near the POI.[2, 10]

Whole blood (WB), particularly low-titer O whole blood (LTOWB),[11] is the gold standard for prehospital resuscitation due to its oxygen-carrying capacity and clotting properties. Although combat medics are increasingly trained to administer WB in prehospital settings,[12] on-hand blood supplies are limited, and traditional resupply mechanisms are often inadequate in PCC scenarios, mass casualty incidents, and LSCO. The development of Air Drop and UAS blood, especially WB and LTOWB, delivery systems architecture could significantly augment amphibious, littoral and riverine combat operations. Naval platforms implementing the Donor Support for Department of the Navy Blood Program (OPNAVINST 6530.2E; MCO 6530.1A) could act in maritime support capacity as a large source of WB and LTOWB delivered through fixed wing (FW)/rotary wing (RW)/UAS to the forward line of troops (FLOT).[36] This could prove invaluable for forward support in large scale, distributed expeditionary warfare operations in contested maritime operations.

Limitations of Current Blood Supply Systems

Currently military blood resupply systems face logistical and operational challenges that hinder timely delivery. Several factors contribute to these limitations:

- **Limited Prehospital Blood Availability:** Combat medics and Role 1 medical providers are often restricted to **small quantities of WB**, which may be insufficient for multiple casualties or prolonged field care.
- **CASEVAC Delays in LSCO and Contested Environments:** Unlike counterinsurgency conflicts, **near-peer warfare scenarios** will likely see increased disruption of air superiority and conventional medical evacuation (MEDEVAC) routes.
- **Prescreened Whole Blood Donor Programs (e.g., ROLO):** Programs like **Ranger O Low-Titer (ROLO)** provide an on-demand blood source but are **resource-intensive** and dependent on personnel availability. They also require **trained personnel, screening protocols, and logistical planning**, which may not always be feasible in high-intensity operations.
- **Challenges in Cold Chain Management:** Maintaining **whole blood at 1°C to 10°C** is critical to ensuring viability. Traditional supply chains for refrigerated blood are not suited for dynamic battlefield conditions, particularly when supply lines are compromised.

- **FDA Approval and Off-Label Use:** U.S. Food and Drug Administration (FDA) has issued an Emergency Use Authorization (EUA) to permit the emergency use of Centre de Transfusion Sanguine des Armées Leukocyte-Depleted Freeze Dried Plasma (French FDP) for U.S. military forces for the treatment of hemorrhage or coagulopathy during an emergency involving agents of military combat (e.g., firearms, projectiles, and explosive devices) when plasma is not available for use or when the use of plasma is not practical. The EUA also permits use of French FDP if needed to treat other individuals, such as allied military personnel operating with Department of War. Prothrombin complex concentrates (cyroprecipitates) and commercially available 4-factor product (KCentra™ - is FDA approved for warfarin-related bleeding and can be considered for off-label use in treating trauma patients).

The increasing risk of contested logistics environments, denied airspace, and prolonged field care scenarios necessitates alternative solutions for delivering blood products. Aerial resupply via airdrop and UAS provides rapid, flexible, and scalable method to support forward deployed casualty care:

- **Overcoming Logistics Disruptions:** Fixed-wing, rotary-wing, and UAS-based blood delivery can bypass **maritime and terrain obstacles, contested airspace, and enemy interdiction**, extending medical reach to frontline units.
- **Enhancing Prolonged Casualty Care (PCC) Capabilities:** In LSCO, prolonged static trench warfare and delayed evacuations increase the need for sustained medical treatment at or near the POI. In distributed maritime operations, logistics support centers may be far-removed or non-linear. Aerial delivery of blood supplies mitigates these challenges by providing **on-demand resupply without requiring dedicated evacuation assets**.
- **UAS and Precision Resupply:** Current state of research on **UAS-based delivery** (e.g., **Project Crimson**[8], **Zipline UAS Study**[9]**, and SnowGoose CQ-10A trials**)[7] and employment of UAS-based delivery in the 2022-ongoing Russian-Ukraine war demonstrates the feasibility of **precision drone resupply** of blood products, even in **low-visibility, GPS-denied, or contested environments**.
- **UAS Tactical and Strategic Distribution of Scarce Blood Capability**: Whereas in the past conflicts medical forces relied on large, prepositioned volume of WB, fresh frozen plasma (FFP) and other components which often had to be wasted if no casualties materialized. Rapid ability to deliver exact products and volumes to achieve specific resuscitation may be beneficial in maintaining larger central blood and product bank and avoid wasting by expiration.

Several military and academic studies confirm the viability and safety of aerial blood delivery:

- **Operation Blood Rain (2021-2022):** Demonstrated that WB airdropped from C-145 and C-130 aircrafts remained within transfusion parameters, with no evidence of hemolysis or degradation of clotting factors.[3,4]
- **UK C-130 Parachute Study (2021)*:*** Showed that parachute delivery of pRBCs and WB from 250-400 ft AGL resulted in no significant hemolysis or loss of transfusion viability.[5]
- **Joint Medical Distance Support and Evacuation Study (2010-2011):** Confirmed that blood airdropped at altitudes up to 21,000 ft AGL remained viable for transfusion, with no significant metabolic degradation.[6]
- **ILAR Event 8 (2005):** U.S. Army research demonstrated that pRBCs airdropped in Collins and Golden Hour Boxes sustained no adverse effects and met transfusion standards.[7]
- **Zipline UAS Study (2023):** Evaluated the impact of UAS-based delivery of WB and found no statistically significant differences in hemolysis, clotting function, or blood gas parameters between flown and control samples. A 2022 meta-analysis of studies and articles found that across 27 UAS-

based delivery studies of blood products, minimal blood product degradation was found when packages were thermoregulated and with atraumatic delivery.[9]

Operational Framework for Blood Airdrop

Both WB and pRBCs must be stored at 1°C to 10°C to maintain viability. Blood coolers such as Collins Box, BloodBoxx™ Evac, and Golden Hour containers maintain these conditions during aerial delivery. Temperature monitoring via integrated sensors ensures blood remains within transfusion-appropriate parameters.

Multiple studies confirm that airdropped blood remains within transfusion viability limits. Key findings include:

- No significant increase in hemolysis, potassium, or lactate levels post-drop
- Stable pH and coagulation profiles
- No significant difference in blood viability between airdropped and conventionally transported units.

Delivery Platforms

- **Fixed-Wing Aircraft (FW***)* provide rapid delivery over long distances and are suitable for LSCO.
- **Rotary-Wing Aircraft (RW)** provide more flexible, immediate delivery options for battlefield blood resupply.
- **Unmanned Aerial Systems (UAS)** technology enhances precision delivery, while reducing risk to personnel in contested environments.

Airdrop Packaging and Handling

To ensure the viability of blood products during aerial delivery:

- **Protection from Impact Forces**: Blood products must be shielded from high-impact landings and vibrations during transit.
- **Maintenance of Proper Transport Temperatures:** Blood must be kept within a safe temperature range (typically 1°C to 10°C) to prevent degradation.
- **Prevention of Contamination or Damage Transit:** Blood products must remain sealed, and external conditions such as humidity, air pressure, and contamination risks must be mitigated.

Packaging Solutions from Studies: Several packaging methods have been tested and validated for airdrop delivery of blood products.

- **BloodBoxx™ Evac Coolers with Cooling Packs:** Used in *Operation Blood Rain*, these coolers demonstrated their ability to maintain temperature stability and protect blood units from impact damage.
- **Golden Hour Containers for Extended Storage:** Designed for prolonged temperature regulation, these containers were successfully deployed from altitudes of 21,000 ft.
- **Collins Box***:* Used in high-altitude airdrops (7,000 ft and 21,000 ft AGL)
- **PeliCase.**

Parachute Deployment Systems: Airdrop missions utilize various parachute systems to ensure controlled delivery of blood products.

- **Standard Airdrop Training Bundle (SATB) Chutes:** Used for controlled descent of smaller payloads
- **68-in Pilot Chutes***:* Ideal for precision low-altitude drops
- **Ram Air Canopy Systems:** Used in guided airdrop deliveries

Tactical Considerations and Execution Plan

Pre-Mission Planning

- **Coordination with Medical and Logistics Teams:** Effective aerial resupply of blood products requires close coordination between medical personnel and logistics teams to ensure optimal storage, packaging, and delivery conditions. Blood units must be properly packaged to maintain temperature stability and integrity during flight and airdrop.
- **Coordination with the Air Mission Commander / J3**
- **Aircraft/UAS Selection Based on Mission Requirements:** Selection of the appropriate aerial platform is dictated by mission-specific considerations such as range, operational environment, and the need for precision delivery. Options include:
    - Fixed-Wing Aircraft
    - Rotary-Wing Aircraft
    - UAS
- **Echelon level delivery considerations** with larger supply loads as described in Armed Services Blood Program Joint Blood Program Handbook[13] being delivered to higher headquarters or even Role 2 locations. The 463L pallets carry pRBC - 3,600; RCF/FFP/FP24 - 1,800, CRYO – 3600 units per pallet. With each Collins box weighing pRBC - 44 pounds; RCF/FFP/FP24 - 39 pounds respectively. Numbers do not currently exist for French FDP due to limited availability.
- **Blood storage locations and availability by unit**. Currently managed by the Joint Blood Program Office (JBPO) or Area Joint Blood Program Office (AJBPO) and distributed by specialized blood support detachments. Placement of WB at forward treatment locations with proper refrigeration and transfer containers for rapid distribution in accordance with JP 4-02. Blood program officers must be thoroughly integrated with Division level planning and logistics to manage distribution changes and resupply.
- **Terrain.** Ground conditions, presence of obstacles, and the ability for recipient teams to recover blood units.
    - Delivery launched from surface/subsurface platforms will need to consider tactical and environmental conditions in the transition from open sea to the littoral zone.
    - Further research with viability markers (i.e. lactate dehydrogenase) and thermoregulation if containers are submerged in salt and fresh water is needed. Once available, the viability of those delivery means can be considered in the platform deployment planning.
- **Drop Zone (DZs) Suitability:** Pre-selected DZs allow for safe efficient recovery, considering enemy threat levels, proximity to First Responders/medical teams, and GPS accuracy.

Post-Drop Recovery and Blood Viability Testing

- Recovery Procedures
    - Secure units from the DZ and verify packaging integrity.
    - Document time from drop to recovery

    - Ensure storage temperature is within 1-10°C to maintain viability.
- Quality Assessment for Hemolysis Markers
    - Current Association for the Advancement of Blood and Biotherapies (AABB) guidelines on acceptable levels of hemolysis for stored pRBC units is <1%.[14]
    - All airdropped and control blood units in the studies reviewed met criteria for blood transfusion per WB transfusion guidelines as outlined by the Joint Trauma System (JTS) Whole Blood Transfusion Clinical Practice Guideline (CPG)[15] and the AABB Circular of Information for the Use of Human Blood and Blood Components.[14] There were no signs of hemolysis on peripheral smear or on visual analysis of spun samples used for chemistry testing. Additionally, there was no evidence of hemolysis on ancillary assays to include LDH, potassium, or indirect bilirubin.
    - While all studies reviewed demonstrated safe transfusion parameters of airdropped blood products can consider, if situation and resources permit, assessment for hemolysis to assure viability of the blood units prior to transfusion. Hemolyzed product above FDA threshold of 1% can contain an excess of potassium, which when infused rapidly can induce cardiac arrest. Can consider a quick, accessible point-of-care test prior to use of airdropped blood.
    - Lactate dehydrogenase (LDH) is a traditional marker for hemolysis that has been used in impact and storage condition studies to determine the degree of hemolysis in UAS transported specimens.
    - Drawbacks of utilization of LDH as a traditional marker for hemolysis. However, existing field-deployable testing units (i.e. Abbot Labs iSTAT), are unable to test for LDH. Alternative markers (potassium directly) or testing units that can measure LDH need to be assessed.
- DoD Trauma Registry / JTS Reporting & Data

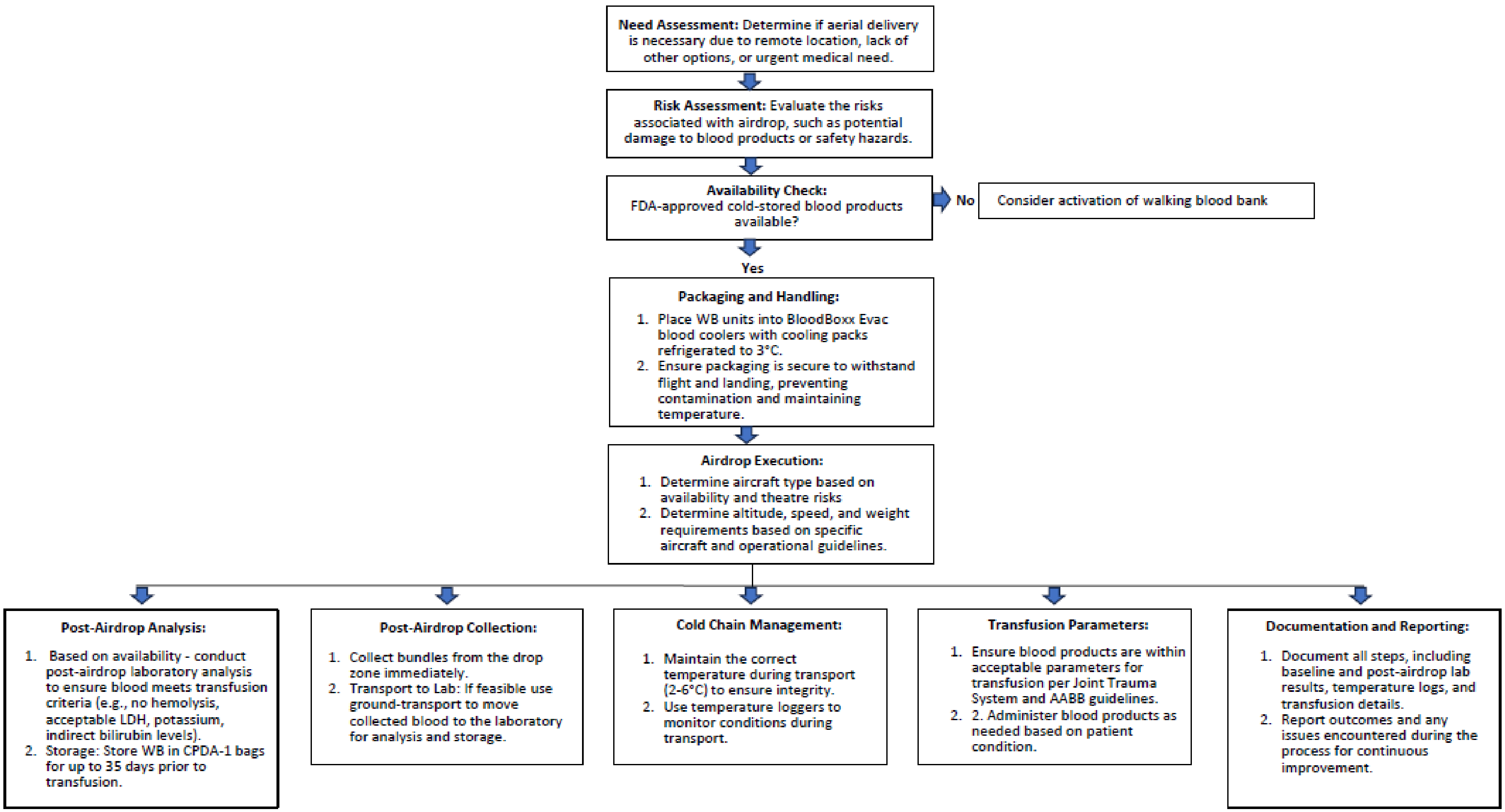
Conclusion & Recommendations

- **Standardization of airdrop procedures across DoD.**
    - Delivery programs need to alleviate end-user task requirements. The methods of assuring request initiation, mobilization, transport, delivery and use must have as much reduction in operational inertia as possible.
    - Development of expeditious after-action reporting with a clear pathway towards systems improvement following delivery operations is needed to sustain improvement and efficiency with each iteration.
- **Additional research into high-altitude and low-visibility drops.**
    - Further research in the use of high-speed, low-visibility drops by UAS platforms. Detection profiles, and impact to product.
- **Additional research and testing of point-of-care viability testing.**
    - Additional research in testing point-of-care viability needs to be performed for non-ideal delivery conditions.
    - Implementation of new drone technology at the operational level
    - Viability testing must be utilitarian for forward-deployed personnel. Point of care testing must be towards field-expedient testing.

- **Development of operational policies for blood airdrop integration into joint medical logistics.**
    - In non-SOF and SOF operations, part of the joint operational medical planning process. Joint publication needs to specify the responsibilities in each party and how to integrate for the UAS/delivery programs in JP 4-02 Joint Health Services.[16]
    - Division and Brigade level doctrine for WB management, storage, and capacity by unit.
- Enhance battlefield survivability and medical readiness.
    - Advocate for a streamlined FDA approval process for blood products and pharmaceuticals intended for military use. The urgent needs of combat care require faster access to life-saving treatments like freeze-dried plasma, freeze-dried platelets, and field-stable therapeutics at scale to meet today's threat environment.
    - Support continued collaboration between the Department of War, public and private entities along with the FDA to create adaptive, mission-focused regulatory pathways that ensure timely, safe, and effective solutions for warfighters.

Appendix A: Aerial Delivery of Blood Products: Protocol Flow Chart

Aerial Delivery of Blood Products: Protocol Flow Chart



Appendix B: Summary of Previous Studies on Aerial Blood Delivery

1. **Fixed-Wing Airdrop Studies**
    - Operation Blood Rain I & II (2021-2022)
    - UK C-130 Airdrop Study (2021)
    - Joint Medical Distance Support and Evacuation Study (2010-2011)
    - ILAR Event 8 (2005, C-23 Sherpa)
2. **Rotary-Wing**
    - Helicopter Transport Effects on RBCs (MD902, 2012)
3. **UAS**
    - Zipline Fixed-Wing UAS Study (2023)
    - Project Crimson (FVR-90 Hybrid VTOL UAS, 2021)
    - SnowGoose CQ-10A UAS Blood Airdrop Study (2005, USSOCOM)

There are a few pilot studies and initiatives that have demonstrated the viability of aerial delivery for blood transportation. A 2005 study completed by the U.S. Army Medical Research and Material Command performed airdrop via a fixed-wing light cargo aircraft – the C-23 Sherpa – to determine the ability to safely drop at 2K and 17.5K ft Mean Sea Level (MSL) altitudes.[7] Thirty pRBC units were placed in the Collins Box and the units were distributed into the center and corners of the load. The Collins Box was configured in the center of the pallet load. A Golden Hour Box with four units of pRBCs was shipped inside a separate box. Internal and external temperatures were recorded in both pRBC containers during shipment and the airdrop.

The Collins Box, the Golden Hour Container, and the contents, including the blood bags, survived the shipping and high altitude drops without observable physical damage. The laboratory analysis demonstrated that the levels of hemolysis, ATP, and other cellular parameter were like those observed in RBCs stored under standard blood bank conditions. The decrease in pH and increase in lactate production indicate normal metabolism. The observed drop in 2,3-DPG was consistent with a normal time-dependent process over the same period. This project supported the conclusion that delivery of these containers by a high-altitude pallet drop does not harm the containers or packed red blood cell viability. Additionally, the data indicates that the pRBC can withstand the low barometric pressure changes at altitude as well as the sudden forces associated with chute deployment and pallet landing.[7]

The 2010-2011 Joint Medical Distance Support and Evacuation Joint Capability Technology Demonstration included three successful viable blood drops via C-130.[6] The first drop utilized the Mosquito guided airdrop system with an 80 sqft ram air canopy. The drop occurred at 7,000 ft AGL via C-130. The drop system included a Collins Box filled with 6 units of red blood cells and 14lbs of ice. Post drop analysis showed no damage with acceptable temperature and humidity parameters in the box. Laboratory analysis deemed the blood viable for human use.[6]

The second test utilized six units of red blood cells along with a Thermal Angel device that was dropped using a Mosquito guided airdrop system with an 80 sq ft ram air parachute. The blood was packaged again inside a Collins Box with 14lbs of ice in the same fashion as the first test. The Collins box was sealed and placed inside a pelican case, then dropped from a C-130 aircraft at 21,000 ft MSL. Post drop analysis showed parameters met for temperate, humidity, and laboratory values for blood unit transfusion.

The third drop utilized two small Golden Hour Containers, three units of red blood cells per container. The two Golden Hour Containers were then placed within a pelican case and airdropped from 21,000 ft MSL utilizing the Mosquito guided airdrop system with an 80 sqft ram air parachute. There was no damage and post drop analysis showed parameters met for temperature, humidity, and laboratory values for blood unit transfusion.[6]

A 2021 UK study looked at the effect of parachute delivery via C-130 on red blood cell (RBC) and plasma quality measures of blood for transfusion.[5] Twenty-two units of leukodepleted RBCs in concentrates (RCC) in saline, adenine, glucose, mannitol (SAGM) and 22 units of WB were utilized for air transportation, parachute drop, and subsequent storage (parachute), or simply storage under identical conventional conditions (4 ± 2°C) (control). All blood products were 6–8 days post-donation. Twelve units of each product were allocated randomly to groups destined for parachute delivery (parachute) and 10 units of each product served as the control. Parachute units were packed into Credo Cubes, inside a PeliCase and rigged as parachute delivery packs. Packs underwent a 4-h tactical flight (C130 aircraft), then parachuted from 250 to 400 ft AGL before ground recovery. The units were sampled before and after airdrop at weekly intervals. A range of assays quantified the RBC storage lesion and coagulation parameters. Blood units were maintained at 2–6°C and recovered intact after recorded ground impacts of 341–1038 m s^{-2}. All units showed a classical RBC storage lesion and increased RBC microparticles during 42 days of storage, however, no unit showed hemolysis greater than 0.8% RBC mass the day after the drop. Fibrinogen and clotting factors decreased in WB during storage. Nevertheless, no significant difference was observed between control and parachute groups for hemolysis and RBC microparticles (CD235a+ MPs). Additionally, no statistical difference in potassium, sodium, pH, glucose, adenosine triphosphate (ATP), lactate and 2,3 diphosphoglycerate (2,3 DPG), Fibrinogen, factors V, VII VIII, prothrombin time (PT), activated partial thromboplastin time (aPTT), alpha2-antiplasmin and free protein S. Air transportation and parachute delivery onto land did not adversely affect, or shorten, the shelf life of fresh RBCs or WB.[5]

The 2021-2022 joint AFSOC and AFMC study on the effect of airdrop on fresh whole blood, affectionately tagged as Operation Blood Rain, included dropping 4 units of fresh whole blood from a fixed-wing aircraft (C-145) under a standard airdrop training bundle (SATB) parachute.[3] All 4 units had no evidence of hemolysis and met transfusion parameters per the Whole Blood Transfusion CPG of JTS.[6] The proof-of-concept pilot for Operation Blood Rain demonstrated the feasibility of airdropping fresh WB as a potential method of delivery for combat medics treating massively hemorrhaging patients in the austere pre-hospital setting; however, because of the small number of units, statistical significance was not obtained with that first study.[3]

The 2022 follow-on study sought to validate airdrop as a method of delivery for both fresh and stored WB for transfusion in the field.[4] This iteration included dropping 48 units of WB from C-145s and C-130s. It demonstrated that airdrop of fresh or stored WB in a blood cooler with a chute is a viable way of delivering blood products in the prehospital setting. All airdropped and control blood units met criteria for blood transfusion per WB transfusion guidelines as outlined by the Joint Trauma System (JTS) Whole Blood Transfusion Clinical Practice Guideline (CPG)[15] and the Association for the Advancement of Blood and Biotherapies (AABB) Circular of Information for the Use of Human Blood and Blood Components.[14] There were no signs of hemolysis on peripheral smear or on visual analysis of spun samples used for chemistry testing. Additionally, there was no evidence of hemolysis on ancillary assays to include LDH, potassium, or indirect bilirubin.[4] Current AABB guidelines on acceptable levels of hemolysis for stored pRBC units is <1%.[14,17]

The data from Operation Blood Rain II did show a mean decrease in blood pH and mean increase in blood glucose for both the airdrop and control groups, although this has been previously observed when mixing blood with the acidic anticoagulants of CPDA-1.[18] Additionally, the baseline values were within normal limits based on the timeframe in which the blood was stored. Potassium levels for all units used in the C-145 airdrops were within normal limits.[19] The capability of WB to coagulate was assessed with PT/PTT, which did not appear to be significantly affected in pre- and post-intervention analysis in the airdrop and control groups. The temperature of the units was 7.6°C and 6.8°C in the experimental and control groups, respectively, which is inside of the target temperature to transport WB 1°C to 10°C.

Blood storage is known to cause degradation of the structure and function of red blood cells over time. This process typically starts after 2 weeks of storage and can cause increased rates of hemolysis to the red blood cells.[20] WB in CPDA-1 bags can be stored for up to 35 days prior to transfusion. Studies and standard use have shown that even with these laboratory value changes over the duration of storage, stored WB is still safe for transfusion.[21] During the Operation Rain studies, all units of blood ideally would have been collected and airdropped with the same number of days spent in storage. However, this was a challenge due to the constraints of collecting high volumes of blood products and then coordinating airdrop missions. There was significant variance in the baseline values of the WB unit based on time of storage versus the use of fresh WB. This may have potential as a confounding factor; however, it may also be useful as a mimic of real-world conditions where airdrop would be used, which may include the use of either stored WB or fresh WB via either the Ranger O Low Titer (ROLO) protocol, the Air Force Special Operations Command (AFSOC) Special Operations Low Titer (SOLO) protocol, or the low-titer O WB protocol.[15]

During Operation Blood Rain II, accelerometer data showed an increase in G forces for the C-145 bundle, as compared to the C130 drop. An additional 10 lb weight was added to accommodate C-145 ramp requirements of 28 psf minimum. The increased weight correlates with an increase in force experienced by the blood product upon impact with the ground, however there were no signs of increased hemolysis upon laboratory evaluation. Additionally, the increased altitude of the C-130 drop of 500-feet AGL compared with the C-145 200- feet AGL did not show a significant effect on pre- and post-laboratory values between the two aircraft drops. Overall, this study shows that there is no major laboratory or physiological differences between FWB and stored blood once airdropped as compared to conventional delivery/storage methods. The other unique aspect of this study was the utilization of more than one type of military aircraft with slightly different drop profiles. This demonstrates the portability of this lifesaving procedure that will increase the operational flexibility to potentially use any aircraft of opportunity should the need arise.[4]

A 2012 study on the effects of helicopter transport on red blood cell components does not affect the quality and shelf-life of red blood cells.[22] 5 units of red blood cells were packed into an SS-BOX-110 container which can maintain the temperature inside the container between 2 °C and 6 °C with two frozen coolants. After the box had been transported in a helicopter for 4 hours, the red blood cells were stored again and their quality evaluated at day 7 (just after the flight), 14, 21 and 42 after donation. Red blood cell quality was evaluated by measuring adenosine triphosphate, 2,3-diphosphoglycerate, and supernatant potassium, as well as hematocrit, intracellular pH, glucose, supernatant hemoglobin, and hemolysis rate at the various time points. All data from the red blood cells that had undergone helicopter transportation were the same as those from a control group of red blood cell samples 7 (just after the flight), 14, 21, and 42 days after the donation.[23] Helicopters and rotary unmanned aircraft systems may also provide yet another way to deliver medical supplies, including WB to combat units using similar drop procedures.

While numerous studies have demonstrated the feasibility of delivering blood via parachute drop from a fixed-wing aircraft, future conflicts may not allow for the same level of air superiority that we have experienced in the past. As we prepare for near-peer military threats and the potential for prolonged field care scenarios, we must pivot to a more flexible style of aerial delivery using unmanned aircraft systems (UAS) or "drones."[23] UAS can bypass traffic and difficult terrain to deliver blood products quickly, which is critical in life-threatening situations. UAS can reach remote, austere environments that are otherwise difficult to access, ensuring patients in these locations receive the care they need. UAS could deliver packages discreetly into AORs that are too dangerous for manned-vehicle deployment and avoid putting additional service members at risk.[9]

A 2005 study completed by the U.S. Army Medical Research and Material Command performed airdrop utilized the SnowGoose (CQ-10A), an autonomously guided, powered parafoil system that can be ground launched from a High Mobility Multipurpose Wheeled Vehicle or air launched from a cargo aircraft.[24] In the study, the four Golden Hour Containers (GHC) each contained 4 units of blood. It was confirmed during packing that it is possible to fit 4 GHC's and parachute into a single SnowGoose cargo bay. Each GHC holds 4 units of blood making it possible to drop up to 16 units of blood per cargo bay. All four GHCs functioned according to specifications during the entire four-day period, ultimately maintaining a steady 3.5-3.7° C temperature. The GHCs were pre-conditioned to maintain their pRBC loads within the required temperature range in the face of warm ambient temperatures (i.e., above freezing). Each box contained four 250 ml pRBC units along with a two-channel temperature recorder. In each box, a temperature probe was inserted into the middle of the load, and one was attached to the outside of an end pRBC unit. Four pRBC units were drawn three days prior, four pRBC units were drawn 29 days earlier, and eight pRBC units were twelve days old. This provided for a range of red cell ages that could be tested for viability in the Yuma drop. A full range of in vitro red blood cell viability assays were carried out just before the units were sent to airdrop and immediately upon their return to lab. GHC 1 and 2 were each loaded with a mix of older and more recently drawn blood. This ensured that fresh and old red blood cells would experience identical stresses throughout the exercise. These are the units that were subjected to a static line drop from the Snowgoose. The rest of the blood was packed into GHC 3 and 4, which were subjected to a Snowgoose flight and air landing. The results of the in vitro assays were grouped and analyzed by age and origin, demonstrating normal storage trends. That is, there is no evidence that any of the groups of red cell units were adversely affected by the airdrop exercise. The analysis showed extremely low levels of hemolysis and high levels of ATP demonstrated suitability for transfusion, correlating with expected values for blood left in normal storage conditions for the same period. The decrease in pH and increase in lactate production indicate normal metabolism. The observed drop in 2,3-DPG, was consistent with a time-dependent process that is normally seen in red blood cells stored for a similar period. This study supports the conclusion that transfusable units of packed red blood cells can be delivered by the Snowgoose Unmanned Aerial System.[24]

A 2019 Research effort, sponsored by the U.S. Army Medical Research and Materiel Command and completed by Near Earth Autonomy, to design, develop, and demonstrate a comprehensive system to prove the utility of "just-in-time" delivery and recovery of whole blood via unmanned aerial systems (UAS).[25] The project proved the feasibility of an autonomous system to deliver whole blood to a point of injury in a dynamic environment. Deliverables included placing a Peregrine Autonomy System on a HQ-90 aircraft with successful proof-of-principle flight demonstration. There was also a preliminary design of blood transportation pods and an outlined concept of operations with mockup tablet interface for how field operators could interact with the aircraft.[25]

The U.S. Army Telemedicine and Advanced Technology Research Center (TATRC) led a test and demonstration of "Project Crimson - Long-range Autonomous Resupply of Critical CLVIII (Whole Blood) at the Tactical Edge" in 2021 of an Unmanned Aerial System (UAS).[8] The results supported the ability of UAS precision delivery of whole blood to remote and austere sites with no pre-existing infrastructure in remote landing zones via both autonomous vertical takeoff and landing or parachute drop when vertical landing is possible or not operationally required. 7 different mission profiles were successfully executed at 3 different drop/landing zones. Parachute drops consisted of two 5lbs payloads (inclusive of the cooling module) at a rate of eight meters per second within a three-meter radius dropping from 100 ft AGL. The system utilized modified L3Harris FVR-90 hybrid fixed-wing vertical takeoff and landing (VTOL) UAS with integrated Peregrine autonomy system and temperature-controlled blood transport containers. It could deliver up to 8 units of fresh whole blood in a 200+ kilometer operating radius, with cruise speeds of 45 knots.[8]

A 2023 study looking at the Impact of Delivery by a Fixed-Wing, Sling-Launched Unmanned Aerial Vehicle on the Hematologic Function of Whole Blood funded by the U.S. Army looked at the hematologic function of blood after transport on UAS.[9] This study collaborated with Zipline, a logistics company that provides hundreds of medical shipments per day globally (Ghana, Nigeria, Japan, US, etc). 30 units of non-leukoreduced, LTOWB were packaged and flown via Zipline on their fixed-wing UAS with autonomous flight on pre-programed paths for durations of 3 to 7 minutes. All flights were conducted on a single day with temperatures above 100°F. 2 units per box were placed into the UAS payload compartment. The UAS was launched from a high acceleration sling and the whole blood cargo was delivered via parachute drop prior to flight. Units taken on flights with longer flight paths (7 minutes) and delivered from 100 m altitude were labeled as "long," whereas units taken on flights with shorter flight paths (3 minutes) and delivered from 25 m altitude were labeled as "short." Finally, units that did not drop but were recovered from the UAS payload after the flight had completed (8–20 minutes) were labeled as "recovered" to investigate the impact of the rapid deceleration provided by the arresting wire. The maximum altitude during flight was 900 ft AGL, and maximum air speed was 61 mph. Each unit of whole blood was sampled for baseline control, then subsequently packed and flown on a Zipline UAS. Samples were either dropped via parachute deployment mid-flight (n = 22) or recovered with the UAS after being caught on with an arresting wire with a tailhook (n = 8). UAS flights were set on either a short (n = 18) or long path (n = 4). The viability of a sample was gauged through changes in free hemoglobin (HGB) as a measure of hemolysis, partial pressure of oxygen (pO2), and lactate levels. One-way ANOVA with repeated measures was performed to determine differences between the three groups: Control, Dropped, and Recovered. Paired t tests were performed to determine differences between flown samples and the controls. No significant differences in any metric were observed between the controls and the blood samples that were flown and parachute dropped or flown and recovered from the UAS.[9]

A 2023 literature review on UAS Delivery of Blood Products and Medical Logistics for Combat Zones examined 27 articles and discussed: Current limitations of prehospital blood transfusion in military settings (ROLO program, LTOWB, buddy transfusion, etc), current uses of UAS for medical logistics in regions of the world (ex. Africa) where the local infrastructure prohibits traditional delivery methods for medical supplies, pharmaceuticals, laboratory samples, and vaccines, and ongoing research surrounding UAS for blood product delivery that showed blood transported and dropped from UAS have minimal blood product degradation when thermoregulated and delivered in a manner that minimized trauma.[23]

There are a few unique considerations when deciding to utilize unmanned aerial methods for blood delivery. The first consideration is fixed vs rotary wing. Additionally, different airframes have unique drop profiles that need to be considered. Accuracy and risk of parachute failure are considerations as well. Fixed wing UAS typically use a catapulting launching platform, like the Zipline System, and would require parachute drop for blood products.[23] Rotary wing would enable vertical takeoff and landing and allow for materials to be sent back from the field. Typically, these models take off vertically, transition to horizontal flight, and then back to vertical for landing.[25] Rotary wing drones could allow for other materials to be returned to base but may be limited if the UAS is unable to determine a safe place to land (flat, level, dry, clear of objects and people).[25] The reliability of the drone technology used is critical. Drones need to have robust navigation and control systems to ensure they can fly accurately to their destination and return without incident. They should also be able to handle varied weather conditions. Compliance with aviation and healthcare regulations is necessary to ensure safety. This includes following flight rules, maintaining patient confidentiality, and adhering to guidelines for the handling and transport of medical supplies. Regarding limitations, like any aircraft, drones can crash or collide with other objects, posing a risk to people and property on the ground. Advanced collision-avoidance systems and careful planning of flight paths can mitigate these risks. As digital devices, drones are susceptible to hacking, which could interfere with their operation and compromise the safety of the delivery. Implementing strong cybersecurity measures is essential. Further areas of study include carrying capacity, battery life, range, climate control, post-delivery safety of blood products, and optimal delivery techniques.[23]

In summary, the results of multiple studies from the United States, United Kingdom, France, and Canada all demonstrated that various profiles and methods of aerial delivery did not result in clinically significant damage or hemolysis of the blood products for transfusion. Aerial delivery of blood products provides a promising solution to decrease time to transfusion at the point of injury, especially in a future conflict that may involve near-peer military threats where we do not have the luxury of air superiority. A great deal of research and testing has already been conducted that proves blood products can be delivered from a variety of aircraft and still meet transfusion safety parameters. For our military members to benefit from these advancements, we must develop official guidelines and protocols for implementation. It is important to note that the first line of care would continue to be to use FDA-approved cold-stored low-titer O WB and other FDA-approved cold-stored blood products. However, including hemorrhage adjuncts and other component therapies such as French FDP in addition to airdropped WB for a patient with massive trauma and hemorrhage in the pre-hospital setting could be employed in remote theater situations with no other expedient options available. Use of these adjuncts may reduce the need for additional RBCs, thus conserving resources for other casualties at low-cost. The risks and benefits of using airdropped WB will need to be considered by ground medics at the point of injury and combatant command surgeons.

Appendix C: Data Tables and Study Methodologies

Packing and Drop Procedures from specific studies:

Operation Blood rain (C-146, C-130 Airdrop)[3, 4]

In the 2021-2022 joint AFSOC and AFMC study "Operation Blood Rain," in compliance with standards set forth by the AABB and FDA, a total of 48 CPDA-1 blood collection sets (Haemonetics; NSN, 6505-01-599-8028) were used to collect 500mL WB. The units were stored at 3°C in a temperature-controlled refrigerator. For the C-145 drop, four units of WB were placed into each of the six BloodBoxx™ Evac blood coolers (Combat Medical; SKU, 39-401), each also containing four cooling packs refrigerated to 3°C.

A SATB parachute or 68-in pilot chute (NSN, 1670-00-216-7297) was packed and rigged to the airdrop blood cooler with 8/4 unwaxed cotton thread (Figures 1–5). The total weight of the chute, chute deployment bag, blood cooler, four cooling bags, four WB units, and an accelerometer was approximately 17.4 lb. C-145 ramp airdrops were required to meet a 28 lb per square foot (psf) minimum in accordance with Air Force Technical Order (TO) 13C7-1-11. Bundles were 8 pounds short; therefore, 10-lb weights were added to the front pocket. For the C-130 drops, paratroop door delivery was selected because of the lower 11 psf requirement for door bundles. No added weight was required. For each aircraft, an exception issued by the Fort Lee Aerial Delivery and Field Services Department lowered the minimum required weight for the chute from 30 lb to 13.5 lb.

The blood coolers were airdropped by the C-145 at an altitude of 200 feet above ground level (AGL) flying at approximately 100 nautical miles per hour. For the C-130, the blood coolers were airdropped from the paratroop door at an altitude of 500 feet AGL, flying at approximately 130 nautical miles per hour.

Figure 1. ***A. CPDA-1 bag configuration. B. Combat medical BloodBoxx™ evac blood cooler with attached chute. C. Delivery/pick up of control units via simulated vehicle of opportunity. D. Cooler loaded with four WB units, four cooling packs and one accelerometer. E. Close up of the loaded cooler for the C-145 drop showing 10lb weight. F. Post air drop bundle inspection***

Figure 2. ***A. C-130 profile, B. Floor loaded with bundles, C. The loadmaster drops a bundle from the paratroop door, D. Loading the C-130, E. Checking bundles prior to the drop, F. The C-130 airdrop, G. The bundle under the chute.***

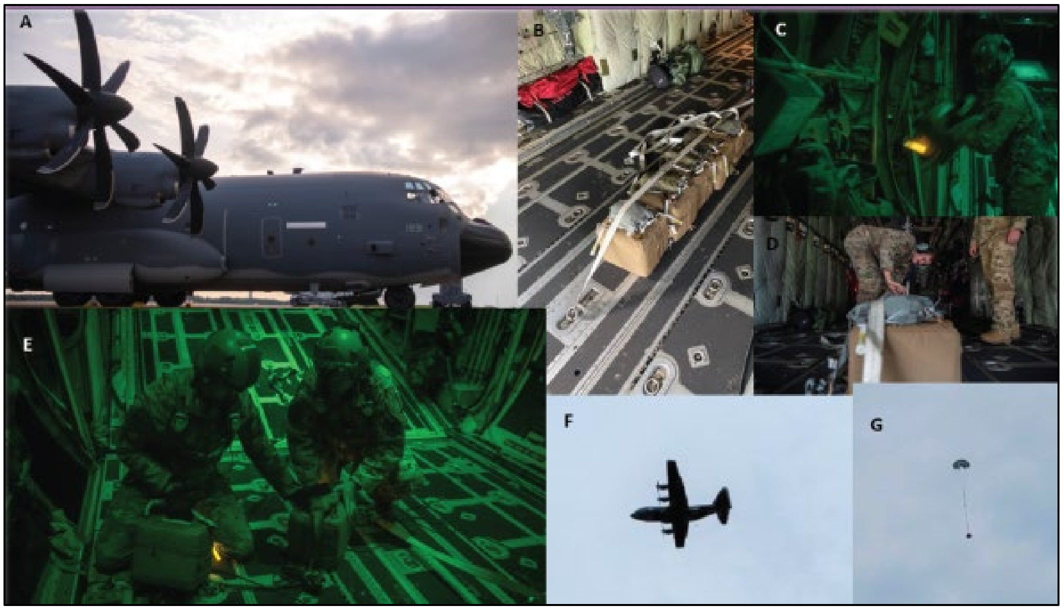
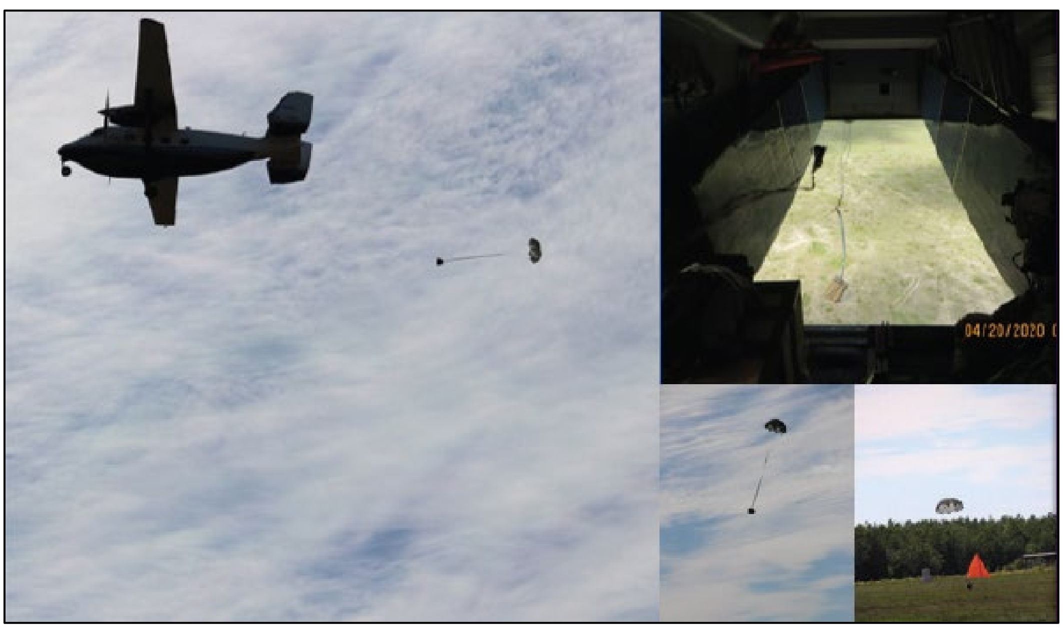


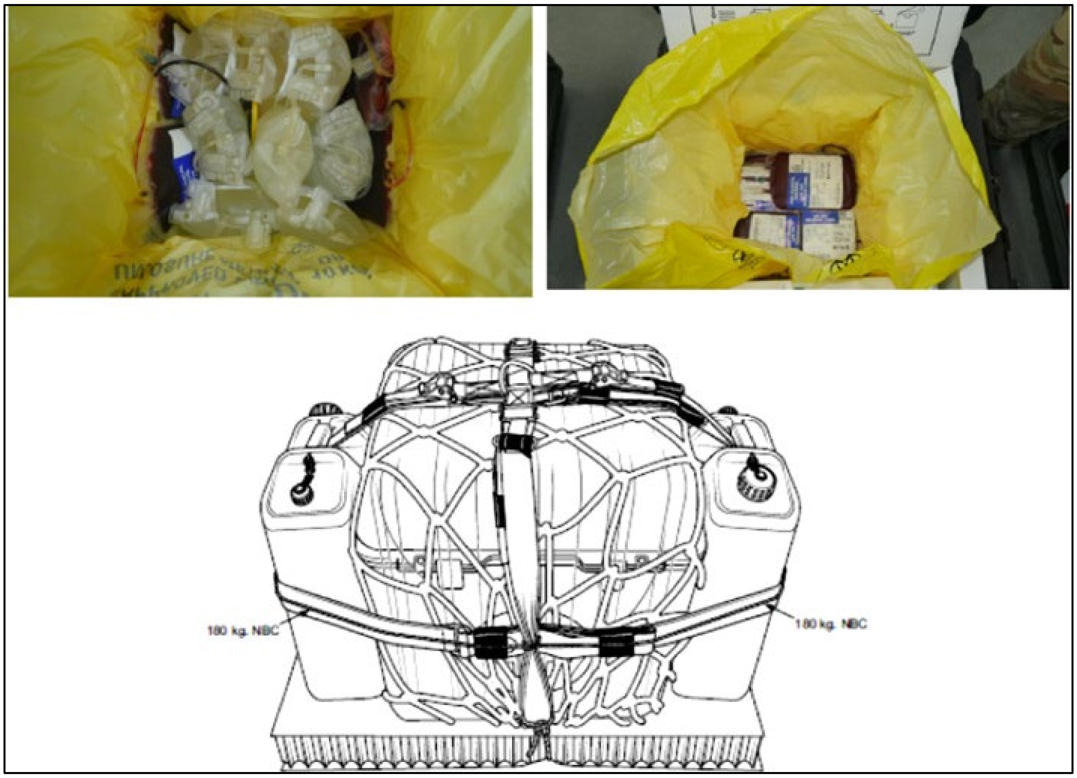
Figure 3. ***Clockwise from left. Airdropping a Golden Hour box from a C-145. Golden hour box exiting the C-145 ramp. Golden hour box landing at the drop zone.***



Effect of parachute delivery on red blood cell (RBC) and plasma quality measures of blood for transfusion (C-130 Airdrop)[5]

A 2021 UK study with C-130 used units of leuko-depleted RCC in saline, adenine, glucose, mannitol (SAGM) and units of nonclinical issue WB were randomly allocated for air transportation, parachute drop, and subsequent storage (parachute), or simply storage under identical conventional conditions (4 ± 2°C) (control). Parachute units were packed into Credo Cubes, (Series 4, 16 L) inside a PeliCase (Peli 0350) and rigged as parachute delivery packs. Packs underwent a 4-h tactical flight (C130 aircraft), then parachuted from 250 to 400 ft before ground recovery.

Figure 4. ***Packing layers for units of whole blood (WB, upper left) and RBC concentrate (RCC, upper right) in credo cubes.***



Note that units of clinical issue blood products are dark red while simulated units contain 0.9% saline and therefore appear light/clear. Bags of WB were placed vertically against the thermal isolation chamber, credo cube, while the Centre of the space was filled with bags of simulated WB. Bags of RRC (or SRRC) were placed horizontally flat within the cube in an overlapping brick pattern, repeated in concentric layers to fill the space with 22 bags. Each credo cube was placed singly in a Peli case and rigged as a blood harness pack (BHP) as shown in the lower panel (reproduced from 101A-1102-1B air transport operations manual: Construction procedures for aerial delivery loads, light stores dropping, 3rd edition 2020, Ministry of Defense)

Joint Medical Distance Support and Evacuation Joint Capability Technology Demonstration (C-130 Airdrop)[6]

The 2010-2011 Joint Medical Distance Support and Evacuation Joint Capability Technology Demonstration included three successful viable blood drops. The first drop utilized the Mosquito guided airdrop system with an 80 sqft ram air canopy. The drop occurred at 7,000 ft AGL via C-130. The drop system included a Collins Box filled with 6 units of red blood cells and 14lbs of ice.

The second test utilized six units of red blood cells along with a Thermal Angel device dropped using a Mosquito guided airdrop system with an 80 sqft ram air parachute. The blood was packaged again inside a Collins Box with 14lbs of ice in the same fashion as the first test. In addition, the Collins box was sealed and placed inside a pelican case, then dropped from a C-130 aircraft at 21,000 ft MSL.

The third drop utilized two small Golden Hour Containers, three units of red blood cells per container. The two Golden Hour Containers were then placed within a pelican case and airdropped from 21,000 ft MSL utilizing the Mosquito guided airdrop system with an 80 sq ft ram air parachute.

***Figure 5.* One Golden Hour container with 3 viable units of red blood cells**

***Figure 6.* Sherpa 700lb pallet with Collins Box**

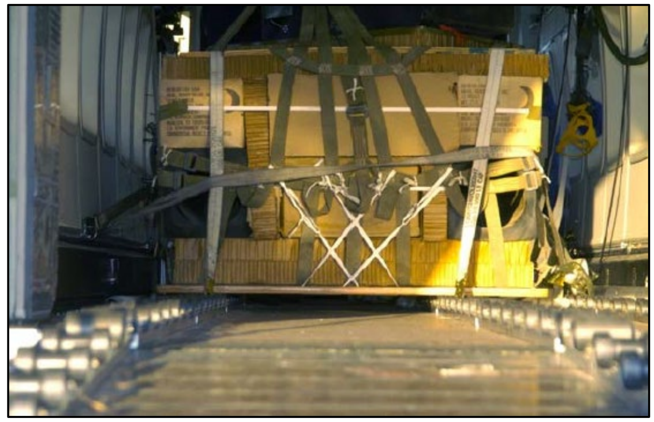
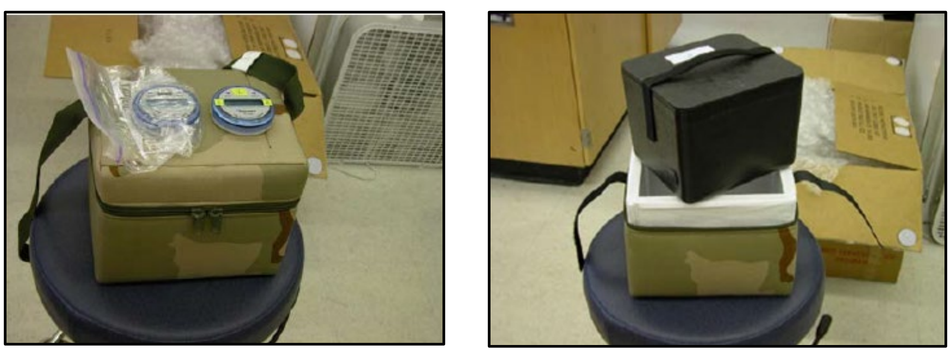


***Figure 7.* Sherpa JPADS guided parachute in flight**

***Figure 8.* GHC after drop and shipment back to WRAIR**



United States Army Research and Material Command (USARMC) Participation in Integrated Logistics Aerial Re-Supply (ILAR) Event 8 (C-23 Airdrop)[7]

A 2005 study completed by the U.S. Army Medical Research and Material Command performed airdrop via a fixed-wing light cargo aircraft – the C-23 Sherpa – to determine the ability to safely drop at 2K and 17.5K ft Mean Sea Level (MSL) altitudes. The process utilized pallet cargo loads ranging from 500lbs to 1300 lbs of rigged weight, using the G-12, 26 ft Ring Slot (RS) High Velocity, Low-Cost Airdrop System High Velocity (LCADS HV) and the Sherpa JPADS 1K parachute systems.

Thirty pRBC units were placed in the Collins Box and the units were distributed into the center and corners of the load. The Collins Box was configured in the center of the pallet load. A Golden Hour Box with four units of pRBCs was shipped inside a separate box. Internal and external temperatures were recorded in both pRBC containers during shipment and the airdrop.

Effects of helicopter transport on red blood cell components (MD902 Flight)[22]

A 2012 study on the effects of helicopter transport on red blood cell components does not affect the quality and shelf-life of red blood cells. 5 units of red blood cells were packed into an SS-BOX-110 container which can maintain the temperature inside the container between 2 °C and 6 °C with two frozen coolants.

Figure 9. ***The SS-BOX-110, equipped with an internal thermocouple probe to record the internal temperature and an outer probe to measure the ambient temperature during transport. The five units of red blood cell components and a dummy blood bag for recording the liquid temperature are also displayed.***

Figure 10. ***Five aliquots of red blood cells were put one by one in opposite directions after a bubble-sheet-wrapped frozen coolant had been placed on the bottom. Finally the other wrapped frozen coolant was put on the top of the red blood cell bags, and a foam plus was used as the ceiling to ensure a tight fit.***

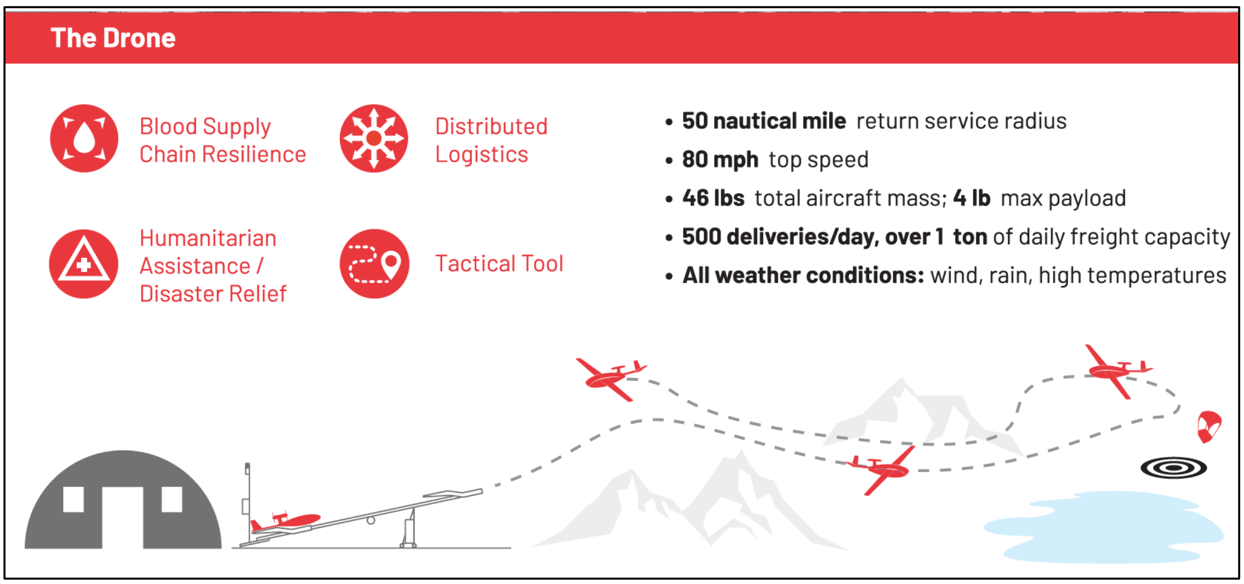
Figure 11. ***The container containing five bags of red blood cells, a dummy blood bag and two frozen coolants is shown. The outer temperature probe for measuring the ambient temperature and the data logger can be seen.***

Unmanned Aerial Systems Studies

The impact of delivery by a fixed-wing, sling-launched unmanned aerial vehicle on the hematologic function of whole blood (Zipline UAS)[9]

In this 2023 study, units of non-leukoreduced, LTOWB (n = 30) were packaged and flown via Zipline on their fixed-wing UAS with autonomous flight on pre-programed paths. Individual units were rolled in bubble wrap and packing paper before being loaded into the cargo container (2 units per box) which was placed into the UAS payload compartment. The UAS was launched from a high acceleration sling, and, under multiple flight paths, whole blood cargo was delivered via parachute drop prior to UAS recovery with an arresting wire. The maximum altitude during flight was 900 ft above ground level, and maximum air speed was 61 miles per hour.

***Figure 12.** Fixed-wing, sling-launched unmanned aerial vehicle on the hematologic function of whole blood (Zipline UAS)*



Project Crimson: Long-range Autonomous Resupply of Critical CLVIII at the Tactical Edge (L3Harris FVR-90 hybrid fixed-wing vertical takeoff and landing (VTOL) UAS Airdrop)[8]

There was a 2021 Test and evaluation event to confirm Technology Readiness Level 5 for the Project Crimson technology utilized modified L3Harris FVR-90 hybrid fixed-wing vertical takeoff and landing (VTOL) UAS with integrated Peregrine autonomy system and temperature-controlled blood transport containers. It could deliver up to 8 units of fresh whole blood in a 200+ kilometer operating radius, with cruise speeds of 45 knots. The current maximum weight of each cargo pod is limited to 10lbs each, for a combined cargo payload weight of 20lbs. Parachute drops consisted of two 5lbs payloads (inclusive of the cooling module) at a rate of eight meters per second within a three-meter radius dropping from 100 ft AGL.

Test 1: Landing zone identification with Vertical Takeoff and Landing for cooled blood pod delivery at Test Site 1. This test site was generally free of obstacles but had areas with significant slope with some mid-height grass and shrubs. Fully successful landing demonstration and delivery.

Test 2: Parachute Drop Delivery of Uncooled Medical Resupply at Test Site 1. Fully successful pods drop and delivery with both parachutes opening. After delivery, the aircraft returned to the base test site and demonstrated VTOL with avoidance of obstacles in the form of scatter obstacles (transport cases of various sizes).

Test 3: Landing zone identification with Vertical Takeoff and Landing for cooled blood pod delivery at Test Site 2. This test site was a relatively flat area with bare ground cover with several very large mulch piles and tree obstacles. Fully successful landing demonstration and delivery with avoidance of obstacles.

Test 4: Parachute Drop Delivery of Uncooled Medical Resupply at Test Site 2. Fully successful pods drop and delivery with both parachutes opening. After delivery, the aircraft returned to the base test site and demonstrated VTOL with avoidance of obstacles in the form of scatter boxes.

Test 5: Landing zone identification with Vertical Takeoff and Landing with maximum pod weight at site 3. This test site had a slightly sloped and uneven landing area with short ground cover and several Conex Box obstacles. Fully successful takeoff and landing demonstration with a total payload weight of approximately 18 pounds.

Test 6: Parachute Drop Delivery of cooled blood at Test Site 3. Fully successful pods drop and delivery with both parachutes opening.

Test 7: Landing site identification and hovering non-parachute pod delivery drop from 30 feet at site 3. This was a unique capability demonstration to show the ability to drop payload accurately and rapidly from a low height without needing to land. The pods suffered some damage, but the payload was undamaged. The test was successful.

There were two general cargo pod configurations, an insulated pod with active temperature control and monitoring for transporting whole blood and other temperature sensitive CLVIII, and an uninsulated CLVIII cargo container with larger internal volume. Each cargo pod configuration (temperature controlled and non-temperature controlled) came in a parachute drop variant after fitting with the parachute deployment mechanism. The temperature-controlled pods contained two units of surrogate blood each. Currently each pod is limited to 2 units of blood based on the ability of the active temperature control module to maintain temperature through max endurance of the FVR-90 aircraft.

Figure 13. Project Crimson System Overview: Long range hybrid VTOL UAS (L3 Harris FVR-90)

***Figure 14.** National design of the blood transport container. The design allows for 2 containers to be mounted under the wings of the HQ-90 aircraft and carry 8 units of whole blood.*

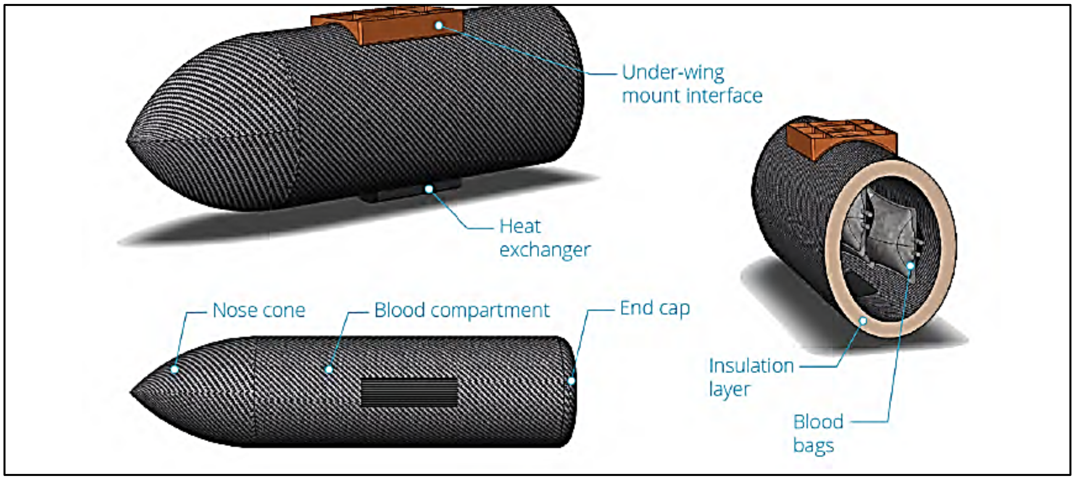


***Figure 15.** Air drop*

United States Army Research and Material Command Participation in Integrated Logistics Aerial Re-Supply (ILAR) Event 4 (CQ-10A UAS Airdrop)[24]

In this 2005 study, the SnowGoose (CQ-10A) is an autonomously guided, powered parafoil system that can be ground launched from a High Mobility Multipurpose Wheeled Vehicle or air launched from a cargo aircraft.

It has 6 bays that can hold up to 100 pounds of fuel or cargo in each bay. The cargo and parachute must fit within the bays that are 29.8” tall x 17.75” wide x 10.3” deep. The cargo bays have a gravity feed trap door on the bottom that releases the cargo at pre-determined coordinates.

Figure 16. GHC being released

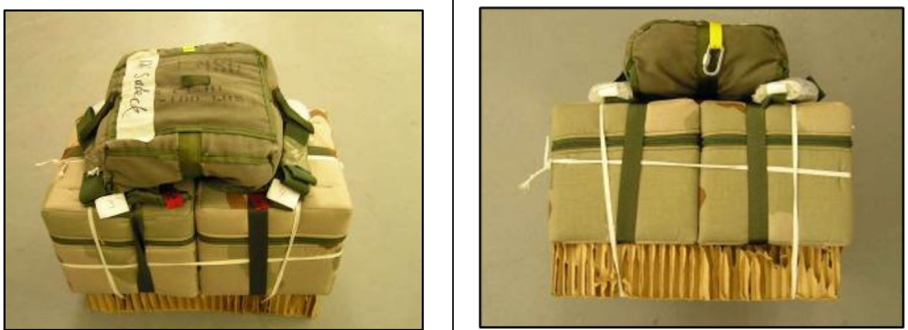
Figure 17. GHC landing

Figure 18. Initial inspection at drop zone

YUMA Golden Hour Containers & Blood:

The four Golden Hour Containers (GHC) each contained 4 units of blood. It was confirmed during packing that it is possible to fit 4 GHC's and parachute into a single SnowGoose cargo bay. Each GHC holds 4 units of blood making it possible to drop up to 16 units of blood per cargo bay.

***Figure 19.** The Golden Hour Containers (GHCs) and their contents (pRBC load) undamaged after the drop. GHC rigged for test.*



All four (GHCs) functioned according to specifications during the entire four-day period, ultimately maintaining a steady 3.5-3.7 Deg C temperature. The GHCs were pre-conditioned to maintain their pRBC loads within the required temperature range in the face of warm ambient temperatures (i.e., above freezing). Each box contained four 250 ml pRBC units along with a two-channel ESCORT iLog temperature recorder. In each box, a thermistor temperature probe was inserted into the middle of the load and one was attached to the outside of an end pRBC unit.

GHC 1, 2, 3, & 4 TICs & pRBC loads

***Figure 20.** 1 & 2 After Static Line Drop*

***Figure 21.** 3 & 4 After Air Landing*

Summary of Procedures

This is not an exclusive list of packaging recommendations and may need to be adjusted based on aircraft/drone availability, specific aircraft drop profiles, load weight limitations, medical situation necessity, and operational environment.

Table 1. Literature on aerial delivery of blood products.

Article	Aircraft	Drop Profile	Unit Type	Packaging	Findings
Clemente Fuentes, R. W., Shawler, E. K., Smith, W. D., Tong, R. L., Barnes, W. J., Moncada, M., Bohlke, C. W., & Mitchell, A. L. (2022). **Operation Blood Rain Phase 2: Evaluating the effect of airdrop on fresh and stored whole blood.** *Journal of Special Operations Medicine*, *22*(3), 9. https://doi.org/10.55460/a10n-ktmd Case Control Study	C-145/ C-130 (Fixed Wing Aircraft)	C-145: altitude of 200 ft AGL at 100 nautical mi/hr. For the C-130: from paratroop at altitude of 500 ft AGL at 130 nautical mi/hr 24 units C-145 drop/24 units C-130 drop/15 units control	Whole Blood (fresh), 4 units per container (48 total), CPD (citrate phosphate dextrose) collection bags (NSN: 6505-01-599-8028)	BloodBoxx™ Evac blood coolers (Combat Medical; SKU, 39-401), 4 cooling packs w SATB parachute/68-in pilot chute	Airdropped blood within transfusion parameters per the Joint Trauma System *Whole Blood Transfusion* Clinical Practice Guideline and the Association for the Advancement of Blood and Biotherapies (AABB) *Circular of Information for the Use of Human Blood and Blood Components*. No evidence of hemolysis on peripheral smear, LDH, potassium, or indirect bilirubin. PT/PTT/INR not affected. Mean pH decreases 2/2 mixing blood with the acidic anticoagulants of CPD. Baseline values are within normal limits based on the timeframe in which the blood was stored
Tong, R. L., Bohlke, C. W., Clemente Fuentes, R. W. C., Moncada, M., Schloe, A. D., & Ashley, R. L. (2021). **Operation Blood Rain: The effect of airdrop on fresh whole blood.** *Journal of Special Operations Medicine*, *21*(2), 29. https://doi.org/10.55460/6q4y-h71j Case Control Study	C-145 (Fixed Wing Aircraft)	C-145: altitude of 200 ft AGL at 100 nautical mi/hr 4 units Drop/4 units Control	Whole Blood (fresh/stored), 4 units per container, CPD (citrate phosphate dextrose) collection bags (NSN: 6505-01-599-8028)	BloodBoxx™ Evac blood coolers (Combat Medical; SKU, 39-401), 4 cooling packs w SATB parachute/68-in pilot chute (NSN, 1670-00-216-7297)	Airdropped blood within transfusion parameters per JTS and AABB guidelines. Analysis of covariance (ANCOVA) was used to compare the group differences, controlling for baseline. No evidence of hemolysis on peripheral smear, LDH, potassium, or indirect bilirubin. PT/PTT/INR not affected. Mean pH decreases 2/2 mixing blood with the acidic anticoagulants of CPD.
Bates, M., Watts, S., Doughty, H., Woolley, T., Miles, A., Barry, L., Jenner, D., Sedman, A., Purcell, R., & Kirkman, E. (2021). **Effect of parachute delivery on red blood cell (RBC) and plasma quality measures of blood for transfusion.** *Transfusion*, *61*(S1). https://doi.org/10.1111/trf.16501 Case Control Study	C-130 (Fixed Wing Aircraft)	C-130: altitude of 250-400 ft AGL 12 units WB Drop/10 units WB Control 12 units RCC/10 units Control	RBCs in concentrates (RCC) in saline, adenine, glucose, mannitol (SAGM), Whole Blood (WB), 12 units WB or RCC with 10 normal saline bags (simulated blood) interspersed	Credo Cubes, (Series 4, 16 L) inside a PeliCase (Peli 0350) and rigged as parachute delivery packs. Bags blood or saline (simulated blood) of were placed horizontally flat within cube in overlapping brick pattern, repeated in concentric layers to fill the space with 22 bags	Data analyzed by linear mixed model analysis of variance (ANOVA) with repeated measures over time, using baseline values as a covariate. Statistical analysis was performed using the NCSS Version 11 statistical package. All units remained within specification for blood issue 1 day after parachute delivery (<0.8% hemolysis) in both parachute and control groups. No statistical difference in hemolysis and RBC microparticles (CD235a+ MPs), potassium, sodium, pH, glucose, adenosine triphosphate (ATP), lactate, 2,3 diphosphoglycerate. (2,3 DPG), Fibrinogen, factors V, VII VIII, PT, PTT, alpha2-antiplasmin and free protein S. Evidence of storage lesions in both RCC and WB.
Lafond, K., Benney, R., Henry, M., et al. (2012). **Joint Medical Distance Support and Evacuation Joint Capability Technology Demonstration**. *American Institute of Aeronautics and Astronautics*. https://doi.org/10.2514/6.2011-2574 Case Control Study	C-130 (Fixed Wing Aircraft)	1st drop: C-130: altitude of 7000 ft AGL via mosquito guidance system 6 units RBCs 2nd drop: C-130: altitude of 21,000 ft MSL using Thermal Angel Device w mosquito guidance system.	RBCs	1st drop: Collins Box w Mosquito guided airdrop system with an 80 sqft ram air canopy, 6 units RBCs+14 lbs. ice. 2nd drop: Collins Box w Mosquito guided airdrop system with an 80 sqft ram air canopy, 6 units RBCs+14 lbs ice. Collins box was sealed	1st drop: Post drop analysis showed no damage with acceptable temperature and humidity parameters in the box. Laboratory analysis deemed the blood viable for human use. 2nd drop: Post drop analysis showed parameters met for temperate, humidity, and laboratory values for blood unit transfusion. 3rd drop:

Article	Aircraft	Drop Profile	Unit Type	Packaging	Findings
		6 units RBCs 3rd drop: C-130: altitude of 21,000 ft MSL using mosquito guidance system. 6 units RBCs		and placed inside a pelican case. 3rd drop: 2 Golden Hour Containers placed into pelican case w Mosquito guided airdrop system with an 80 sqft ram air canopy, 3 units of RBCs each.	There was no damage and post drop analysis showed parameters met for temperate, humidity, and laboratory values for blood unit transfusion.
U.S. Special Operations Command (USSOCOM), Yuma Air Delivery and Soldier Systems Division, 4th Psychological Operations Group (Airborne), Logistics Transformation Agency (Ft Belvoir), U.S. Army Soldier Systems Center (Natick), U.S. Army Medical Materiel Agency (USAMMA), & Army Medical Department. (2005). ***U.S. ARMY Medical Materiel Agency Participation in Integrated Logistics Aerial Resupply (ILAR) Event 8: After Action Report.*** Case Control Study	C-23 (Fixed Wing Aircraft)	C-23: 1st drop: altitude of 17.5K ft MSL w Collins Box 30 units pRBCS 2nd drop: altitude of 2K MSL w Golden Hour Box 4 units pRBCs	pRBCS	Collins Box w 30 units pRBCs w units distributed in center and corners of the load+14 lbs ice. Collins Box configured in the center of the pallet load. A Golden Hour Box with 4 units pRBCs was dropped separately. Utilized G-12, 26 ft Ring Slot (RS) High Velocity, Low-Cost Airdrop System High Velocity (LCADS HV) and the Sherpa JPADS 1K parachute systems	Laboratory analysis demonstrated that the levels of hemolysis, ATP, and other cellular parameter were like those observed in RBCs stored under standard blood bank conditions. The decrease in pH and increase in lactate production indicate normal metabolism. The observed drop in 2,3-DPG was consistent with a normal time-dependent process over the same period. The larger changes observed with the GHC units are consistent with previously observed temperature effects, with final values still close to normal storage ranges.
Otani T, Oki K, Akino M, et al. **Effects of helicopter transport on red blood cell components.** *Blood Transfus 2012; 10: 78-86* DOI 10.2450/2011.0029-11 Case Control Study	MD902 helicopter (Rotary Aircraft)	MD902 helicopter: Transported 4 hrs (no drop) 5 units RBCs	RBCs	SS-BOX-110 container, 5 units RBCs with 2 frozen coolants	Red blood cell quality was evaluated by measuring ATP, 2,3-DPG, potassium, hematocrit, pH, glucose, hemoglobin, and hemolysis rate at day 7 (just after the flight), 14, 21 and 42 after donation. All data from RBCs that had undergone helicopter transportation same as control
Peltier, G. C., & Meledeo, M. A. (2023). **The impact of delivery by a fixed-wing, sling-launched unmanned aerial vehicle on the hematologic function of whole blood.** *The Journal of Trauma and Acute Care Surgery*, *95*(2S), S152–S156. https://doi.org/10.1097/ta.0000000000004061 Case Control Study	Zipline (UAS)	Zipline UAS: Launched from high acceleration sling, multiple flight paths. Max altitude during flight 900 ft AGL and max air speed 61 mph 22 units dropped via parachute deployment mid-flight. 8 units in UAS caught on with an arresting wire with a tailhook. UAS flights were set on either a short (n = 18) from 25m AGL or long drops (n = 4) 100m AGL	non-leukoreduced, LTOWB	Individual units rolled in bubble wrap/packing paper before being loaded into the cargo container (2 units per box) then placed into the UAS payload compartment. Delivered via parachute drop prior to UAS recovery with arresting wire.	Viability of a sample was gauged through changes in free hemoglobin (HGB) as a measure of hemolysis, partial pressure of oxygen (pO2), and lactate levels. One-way ANOVA with repeated measures was performed to determine differences between the three groups: Control, Dropped, and Recovered. Paired t tests were performed to determine differences between flown samples and the controls. No significant differences in any metric were observed between the controls and the blood samples that were flown and parachute dropped or flown and recovered from the UAS.
Lammers D, Williams J. Conner J, Baird E, Rokayak O, McClellan J,	Multiple (UAS)	Various: See Table 2 from *Transfusion*	Whole Blood, Simulated Blood	Various: See Table 2 from *Transfusion*	Various: See Table 2 from *Transfusion*

Article	Aircraft	Drop Profile	Unit Type	Packaging	Findings
Bingham J. Betzold R, Eckert M. **Airborne! UAV delivery of blood products and medical logistics for combat zones.** *Transfusion*. 2023 Jan 27. 2023; 63: s96-S104. Systematic Review		UAS: Fixed Wing (zipline), Rotary Wing (M600pro, S900 DJ1, M10000, FAZER RG2), Hybrid Fixed/Rotary Wing (HQ-40) Fix wing plane (C-145, CASA-300, C-130) Other: Hypobaric chamber followed by climatic chamber	Products, RBCs, FFP, PLT, paired chemistry and hematology blood samples, FLYP, Fresh WB		Overall demonstrated feasibility of UAV deliver/airdrop with no or minimal evidence of hemolysis and meeting parameters for transfusion
Fisher, N. (2021). ***Project Crimson: Long-range Autonomous Resupply of Critical CLVIII at the Tactical Edge, MSSPIX 21 - After Action Summary.*** U.S. Army Telemedicine and Advanced Technology Research Center. Case Control Study	FVR-90 hybrid fixed-wing vertical takeoff and landing (UAS)	FVR-90 UAS: Parachute drops consisted of two 5lbs payloads at 8m per sec dropping from 100 ft AGL w cruise speeds of 45 knots.	Whole Blood	L3Harris FVR-90 hybrid fixed-wing vertical takeoff and landing (VTOL) UAS with integrated Peregrine autonomy system and temperature-controlled blood transport containers, 2 units per container	Lab values not noted in this After-Action Summary but all 7 mission threads were successfully executed across 3 remote and unprepared landing zones with varying obstacles and terrain, with autonomous VTOL and parachute drop successfully executed at each site.
U.S. Special Operations Command (USSOCOM), Yuma Air Delivery and Soldier Systems Division, 4th Psychological Operations Group (Airborne), Logistics Transformation Agency (Ft Belvoir), U.S. Army Soldier Systems Center (Natick), U.S. Army Medical Materiel Agency (USAMMA), & Army Medical Department. (2005). ***U.S. ARMY Medical Materiel Agency Participation in Integrated Logistics Aerial Resupply (ILAR) Event 4: After Action Report.*** Case Control Study	CQ-10A (UAS)	CQ-10A UAS: GHC 1 and 2 (8 units) Subjected to a static line drop. GHC 3 and 4 (8 units) subjected to flight and air landing	pRBCs	CQ-10A autonomously guided, powered parafoil system that can be ground launched from a HMMV or air launched from a cargo aircraft. 4 units per Golden Hour Container	No evidence that RBCs adversely affected by the airdrop exercise. Analysis showed extremely low levels of hemolysis and high levels of ATP demonstrated suitability for transfusion, correlating with expected values for blood left in normal storage conditions. The decrease in pH and increase in lactate production indicate normal metabolism. Observed drop in 2,3-DPG, consistent with a time-dependent process normally seen in RBCs stored for a similar period.

Table 2. Studies from Airborne! UAV delivery of blood products and medical logistics for combat zones. Transfusion.[21]

Authors	Year	Study design	Objective	Drone type	Cargo transported	Key findings	Limitations
Ackerman et al.[7]	2018	Nonresearch; Descriptive Article	Highlight Zipline's use of drones to deliver blood to remote regions of Rwanda	Fixed Wing	WB	Successful implementation of a drone-based blood delivery system	N/A
Homier et al.[8]	2021	Pilot/Proof of Concept	Compare drone versus ground transport time of simulated blood products in an urban environment	Rotary Wing; Modified M600pro	Simulated blood products	Drone-based delivery proved to be faster than ground transportation	Simulated blood products were used, short flight times and distances
Amukele et al.[9]	2016	Pilot/Proof of Concept	Examine the impact of drone transport on blood products	Rotary Wing; S900 DJI	RBC, FFP, PLT	No evidence of hemolysis, alteration in platelet count, changes in pH, or evidence of temperature changes following drone delivery	Short flight times, full range of physiologic testing was not performed on the samples
Yakushiji et al.[10]	2019	Pilot/Proof of Concept	Examine the effects of transport by drone on RBC	Rotary Wing; M10000	RBC	Transport by drone was feasible and did not significantly alter quality of RBC	Small number of trials, limited laboratory samples tested, short flight times and low altitude
Nakahara et al.[11]	2020	Pilot/Proof of Concept	Examine how drone transport of blood samples affects cross-matching tests for transfusion	Rotary Wing; M10000	RBC	RBCs transported by drone displayed mild hemolysis, but this did not affect cross-matching tests	Small number of trials, limited laboratory samples tested, short flight times, and low altitude
Yakushiji et al.[12]	2020	Pilot/Proof of Concept	Evaluate the quality of blood following airdrop from 10 meters	Rotary Wing; M10000	RBC	RBCs delivered via airdrop at 10 meters displayed evidence of damage. This was further affected by type of packaging RBC was delivered in.	Small number of trials, no parachute-based delivery system
Yakushiji et al.[13]	2021	Pilot/Proof of Concept	Demonstrate drone transport of blood can be performed over long distances	Rotary Wing; FAZER RG2	RBC	RBCs were successfully delivered via drone without evidence of hemolysis	Small number of trials, no adverse weather, vibration from flight not controlled for
Amukele et al.[14]	2017	Pilot/Proof of Concept	Examine the effect on samples during real-life drone flights greater than 3 hours in high ambient temperatures	Hybrid Fixed and Rotary Wing; HQ-40	Paired chemistry and hematology blood samples	Drone delivered samples had higher levels of potassium and glucose compared to controls	Small number of trials, samples were from healthy volunteers only, poor temperature control of samples

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Authors	Year	Study design	Objective	Drone type	Cargo transported	Key findings	Limitations
Tong et al.[15]	2021	Pilot/Proof of Concept	Examine the possibility of using airdrop techniques to deliver fresh WB to combat medics in prehospital military settings	N/A; Fixed-wing plane; C-145	Fresh WB	Parachute-based airdrop delivery of fresh WB did not result in hemolysis and met parameters for safe transfusion per the Joint Trauma System Whole Blood Transfusion Clinical Practice Guideline	Single trial, small number of samples, not drone-based delivery
Javaudin et al.[16]	2018	Pilot/Proof of Concept	Examine the possibility of using airdrop techniques to deliver component blood products	N/A; Fixed-wing plane; CASA-300	RBC, FLYP	Parachute-based airdrop did not significantly impact the quality of RBC or FLYP	Small number of samples, utilized expired RBC
Meli et al.[17]	2018	Pilot/Proof of Concept	Assess for differences in red blood cell composition following airdrop into the sea	N/A; Static airdrop	RBC	Static airdrop of RBC into maritime conditions did not display any differences compared to control samples at the cellular level. RBC quality was not affected following 35-day storage	Small number of samples, no parachute delivery, airdrop was from a static drop as opposed to an aircraft, air pressure was not accounted for, samples were all from different donors
Bates et al.[18]	2021	Pilot/Proof of Concept	Examine the effect of air transport, parachute drop, recovery, and ground transport on red blood cell and whole blood quality over a 35–42-day period.	N/A; Fixed-wing plane; C130	RBC, WB	No evidence of RBC or WB breakdown following parachute-based airdrop	Small number of samples, many whole blood samples displayed baseline hemolysis
Boscarino et al.[19]	2014	Pilot/Proof of Concept	Examine the effect of airdrop from high altitude low-opening (HALO) settings and high ambient temperatures on red blood cell integrity	N/A; Hypobaric chamber followed by climatic chamber	RBC	Biochemical and biomechanical markers of red blood cell damage remained within transfusion safety paraments following simulated military operation	Small number of samples, simulated scenarios with stable environmental conditions

Abbreviations: FFP, fresh frozen plasma; FLYP, French lyophilized plasma; PLT, apheresis platelets; RBC, red blood cells.

Appendix D: DOTMLPF-P Considerations

- **Doctrine:**
    - TM 8-227-12 / NAVMED P-6530 / AFH 44-152_IP TECHNICAL MANUAL ARMED SERVICES BLOOD PROGRAM JOINT BLOOD PROGRAM HANDBOOK 1 December 2011 – details for weight quantity and shipping considerations for blood products will need to be updated to address UAS capabilities for blood distribution and delivery.[10]
- **Organization:**
- **Training:**
    - Inclusion in pre-deployment medical and logistics training and validation for First Responders, Role 1 and Role 2 personnel Include validation of delivery from multiple delivery platforms.
    - Proper storage, transport and administration of blood and blood products is addressed in the following Joint Trauma System CPGs:
        - Damage Control Resuscitation[26]
        - Frozen and Deglycerolized Red Blood Cells[27]
        - Whole Blood Transfusions[15]
        - Prehospital Blood Transfusion[28]
- **Material:**
    - Procurement of standardized blood airdrop packaging, cooling, and temperature control monitoring systems.
- **Leadership & Education:**
    - Training commanders on aerial blood resupply capabilities.
    - Induct familiarization and content insertion into tactical courses and training with non-exclusive examples such as Tactical Combat Medical Care (TCMC), Special Operations Combat Medic (SOCM) Course, and others.
- **Personnel:** Appoint and train personnel in a joint environment
- **Facilities:** NA
- **Policy:** Consider the creation of a joint and dynamic entity that tracks and allocates blood across the battlefield. Empowered with joint capabilities for fast (under 30 min) response, coordination, and delivery of blood products and components, as well as authority to quickly cross-load banked blood across the large battlespace during LSCO environment.

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