COMPREHENSIVE REVIEW

Medical Support for Aircraft Disaster Search and Recovery Operations at Sea: the RSN Experience

Kok Ann Colin Teo, MAJ (DR);[1] Tse Feng Gabriel Chong, MAJ (DR);[2] Min Han Lincoln Liow, MAJ (DR);[1] Kong Choong Tang, COL (DR)[2]

1. Navy Medical Service, Republic of Singapore Navy, Singapore
2. Headquarters Medical Corps, Singapore Armed Forces, Singapore

Correspondence:
MAJ (DR) Teo, Kok Ann Colin
Navy Medical Service
Republic of Singapore Navy
AFPN 6060
126 Tanah Merah Coast Road
Singapore 498822
E-mail: colinkateo@gmail.com

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Abbreviations:
AO: area of operations
ATLS: Advanced Trauma Life Support
DMORT: Disaster Mortuary Operational Response Team
DVI: Disaster Victim Identification
HADR: humanitarian assistance and disaster relief
HIV: Human Immunodeficiency Virus
LST: Landing Ship Tank
PSO: peace support operations
RSN: Republic of Singapore Navy
SAL: search and locate
SAR: search and recovery
WOG: whole-of-government

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Abstract: The maritime environment presents a unique set of challenges to search and recovery (SAR) operations. There is a paucity of information available to guide provision of medical support for SAR operations for aircraft disasters at sea. The Republic of Singapore Navy (RSN) took part in two such SAR operations in 2014 which showcased the value of a military organization in these operations. Key considerations in medical support for similar operations include the resultant casualty profile and challenges specific to the maritime environment, such as large distances of area of operations from land, variable sea states, and space limitations. Medical support planning can be approached using well-established disaster management life cycle phases of preparedness, mitigation, response, and recovery, which all are described in detail. This includes key areas of dedicated training and exercises, force protection, availability of air assets and chamber support, psychological care, and the forensic handling of human remains. Relevant lessons learned by RSN from the Air Asia QZ8501 search operation are also included in the description of these key areas.

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Introduction

The maritime environment presents a unique set of challenges to search and recovery (SAR) operations. While there are established medical support plans on SAR operations for operations other than war, such as peace support operations (PSO) and humanitarian assistance and disaster relief (HADR) operations in a maritime environment, there is a paucity of information available to guide provision of medical support for SAR operations for aircraft disasters at sea.

Despite air travel volume increasing exponentially in Southeast Asia in the past five years,[1] air travel remains safe.[2] The absolute numbers of accidents and accident rates have not increased in the past five years. However, two major aircraft incidents at sea occurred in Southeast Asia in 2014. On December 28, 2014, the aircraft QZ8501 carrying 155 passengers and seven crew crashed in the Java Sea during bad weather en route from Surabaya, Indonesia to Singapore.[3] The QZ8501 search operation[4] showcased the value of a military organization in this scenario, responding rapidly to deploy SAR forces on site. For the purpose of this report, "SAR operations" comprises of either search and locate (SAL) or SAR type operations, or both, specifically for large-scale aircraft disasters at sea. Large-scale disasters are defined as those with a scale similar to the QZ8501 disaster.

The Republic of Singapore Navy (RSN) deployed an Endurance-class Landing Ship Tank (LST) with two embarked Super Puma helicopters, a Victory-class missile corvette, a Formidable-class frigate, a Submarine Support Rescue Vessel, and a Bedok-class mine countermeasure vessel to assist in the QZ8501 search operation.[4] The latter three vessels had underwater sonar search capability. Medical support planning was developed systematically, in conjunction with the evolving concept of operations during the mission, to ensure responsive and robust naval operational and underwater medical support for anticipated casualties, RSN servicemen, and foreign forces.

Several unique challenges surfaced during the planning and execution of medical support. This report will describe medical support considerations for SAR operations for aircraft disasters at sea and will recommend a systematic approach based on current evidence and the RSN experience in the QZ8501 search operation.

Key Considerations

Casualty Profile

The tri-modal distribution of death in the setting of trauma is well established.[5] Previous aircraft crash disaster data from different accident circumstances resulted in a similar distribution[6] with limited data on maritime aircraft disasters. In the setting of an aircraft crash at sea, only casualties in the "late deaths" group have a reasonable chance of survival. Casualties in the "early deaths" group may survive if they can be rescued and transferred from the crash site to the nearest Level 1[7] facility with Advanced Trauma Life Support (ATLS) within the golden hour.[8]

However, the unforgiving elements of the maritime environment inevitably would skew the graph to the left with increased peaks for the "immediate" and "early" deaths and with a diminished peak for "late" deaths. For the few who survive the crash, they are exposed to the immediate risks of drowning and dangerous marine animals, and eventually will succumb to hypothermia and dehydration if no rescue arrives.

This insight allowed planners to determine the recovery or rescue profile of the operation, providing crucial information which guided medical support formulation for the anticipated casualties, and more importantly, to cater resources for remains management. It is fair to state that SAR operations for aircraft disasters at sea will almost always take on a predominantly recovery profile.

Challenges Posed by Operating in a Maritime Environment

The area of operations (AO) in the QZ8501 search operation posed unique challenges to the provision of medical support. The further the distance of the AO away from shore, the longer it takes for ships to reach survivors, diminishing the casualties' chances for survival. The AO in a SAR operation is huge, and a considerable amount of time is required for the ships and aircraft to search the area meticulously. There is also the possibility of the initial AO being poorly defined during the initial phases of the SAR operation, causing further delays to reach survivors. The sea state of an AO also imposes considerable operational risks to ship crew and significant seasickness amongst seasoned sailors. In addition, operating conditions such as rain and poor underwater visibility also significantly hinders SAR operations.

Large Distance of AO from Land

The AO for SAR operations at sea is isolated from any land-based medical facility. The closest distance between the AO and an available Level III facility during the QZ8501 operation was an estimated 226 nautical miles. Dynamic maneuvers of afloat assets meant that medical support had to be individualized in real-time for RSN assets, ensuring pre-determined, expeditious evacuation times for any in-theatre casualty. This also required deployed ships to have self-sufficient medical supplies for prolonged periods of time. In addition, forward deployment of critical supplies on land would allow air-lift replenishment of essential resources.

Space Limitations

There is a finite space on board a ship. These spaces are often designed towards maximizing war fighting capabilities of the vessel and, although limited shipboard space may be suitably reconfigured to manage casualties or store medical equipment,[9] there may be overriding operational priorities which preclude this use. In addition, large number of casualties or remains may easily overwhelm this allocation.

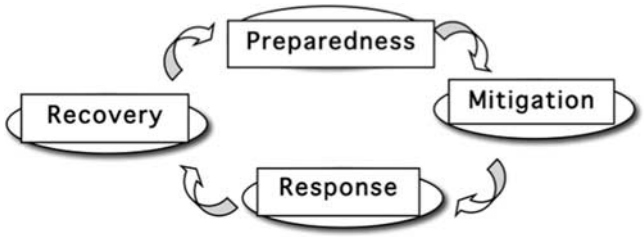

Figure 1. The Life Cycle of Disaster Management.

Life Cycle of Disaster Management

The life cycle of disaster management (Figure 1) consists of four phases: preparedness, mitigation, response, and recovery. These phases may occur in succession or simultaneously during the management cycle. This life cycle is the basis from which medical support for any disaster should be formulated upon.

Preparedness

Preparedness is defined as the continuous cycle of planning, organizing, training, equipping, exercising, evaluating, and taking corrective action in an effort to ensure effective coordination during incident response.[10] An emphasis on preparedness is key to success in subsequent phases of the disaster management life cycle.

Planning, Organizing, and Equipping—A dedicated medical support plan for large-scale SAR operations at sea enables a timely and systematic medical response to operational demands. A plan principled in flexibility and scalability enables any force to respond effectively. In the RSN, the principles of flexibility and scalability are central to RSN's medical support concept. This enables the RSN to adapt its peacetime medical support assets seamlessly into SAR operations.

Flexibility allows rescue workers to maximize logistical and manpower bandwidth to customize dedicated medical scale for large-scale SAR operations at sea at short notice. The RSN is able to leverage on the whole-of-government (WOG) approach[11] among government agencies to augment gaps in medical support not readily available in the military. In the search operation, Singapore deployed a Disaster Victim Identification (DVI) team consisting of forensic experts to Surabaya to assist in victim identification.[12] In Singapore, the DVI assets reside with the Ministry of Home Affairs. Without a WOG support for such operations, such niche capability areas would not have been readily available for deployment in the AO. This approach reflects the readiness by all government ministries to contribute key resources in order to fulfill specific needs of the operation.

It is also crucial to ensure medical assets deployed to support SAR operations conform to the tactical plan. Medical planners must be involved early in the operational planning process, and once the plan is established, it must be rehearsed with the forces it supports.[13]

The incidence of infectious diseases in a SAR operation has not been shown to be significantly higher than baseline incidence rates in a given area.[14] At the time of death, casualties are not more likely to be infected with epidemic-causing infections or chronic infections of concern (eg, Human Immunodeficiency Virus [HIV], Hepatitis B, or Hepatitis C) than baseline levels in the population where the victims were from. Most infectious

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organisms do not survive beyond 48 hours in a dead body, with the exception of HIV, which has been found six days post mortem. The RSN standards for the QZ8501 search operation is no different from baseline standards (ie, force protection against infectious disease includes vaccination, standard hygiene measures, basic personal protection equipment, and chemoprophylaxis, where necessary), in accordance to the levels of endemic diseases in the AO, and in accordance to latest World Health Organization (WHO; Geneva, Switzerland) guidelines. It is also crucial to educate deployed personnel on the adequacy of these measures and dispel any myths on infection control appropriately to avoid negative psychological impact on the ship crew.

Exercising, Evaluating, and Taking Corrective Action—Regular tabletop exercises will help refine the medical support plan through incorporating current medical advances, which occur quickly; will help evaluate the medical team's ability to co-ordinate with other response groups; and will test its readiness to response. Lessons learned from these exercises are invaluable in identifying gaps in the support plan. In the setting of increasing multilateral responses to any major disasters globally, HADR operations have been central to many multilateral exercises, especially in the Southeast Asia region. Co-operative efforts on HADR operations are a major working objective for the Association of Southeast Asian Nations (ASEAN; Jakarta, Indonesia)[15] in recent years. By positioning an aircraft disaster scenario in these exercises, stakeholder nations in the Southeast Asia region stand to benefit extensively by identifying inherent operational gaps and the potential for synergism in a collaborative multinational SAR effort in the region.

Mitigation

Mitigation is the effort to reduce loss of life and property by lessening the impact of disasters.[11] From an operational perspective, this is achieved by utilization of the appropriate number and types of assets for SAR operations at sea. From the medical support perspective, several conditions serve as effective mitigating forces to challenges posed by the maritime environment. These include: Availability of Air Assets, Availability of Chamber Support for Diving Operations, and Psychological Support.

Availability of Air Assets—Air assets are invaluable for casualty SAR at sea. They have been an essential feature in all major SAR operations at sea in recent memory. The air bridge that air assets provide, particularly helicopters, are crucial to potentially improving clinical outcome by expeditious evacuation of casualties to appropriate higher levels of care and forwarding forensic evidence quickly to avoid attrition of valuable identification and investigative information with time. Deployment of medical assets must leverage on this capability as a force multiplier.

The Super Puma is the workhorse for Singapore Armed Forces (SAF) SAR operations.[16] Embarked on the LST platform (Figure 2), it was used extensively in the QZ8501 search operation for SAL and for transfer of bodies and forensic evidence. It was also an invaluable asset in the evacuation chain for casualties to higher echelons of care.

The medical support for aircrew must also be catered for. Helicopters are organic to several naval platforms in the RSN that perform the abovementioned roles in SAR operations. The RSN also has deployed a dedicated naval aviation medical module to maximize the performance of embarked aircrew, especially in managing aircrew sea-sickness and work-rest cycles.

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Figure 2. Super Puma Operating on Board a Landing Ship Tank (LST) Platform.

Availability of Chamber Support for Diving Operations—The utilization of divers[17] for operations in support of Underwater Remotely Operated Vehicles and the recovery of remains and forensic evidence will necessitate recompression chamber support in the vicinity of the AO for diving-related illnesses. Dependent on the location of the AO, this might not be readily available. In the QZ8501 search operation, the RSN deployed the MV Swift Rescue in support of diving operations in the AO. With comprehensive organic recompression chamber facilities,[18] it is an ideal asset to satisfy all medical operational requirements for diving operations in an AO with no readily accessible chambers.

Psychological Support—Any resultant morbidity or mortality to any rescue worker in the SAR process due to inadequate mitigation of unaccounted risks is one too many. Apart from physical risks, stress-related psychological disorders are well-documented among untrained rescue workers, especially non-medical forensic handlers. Personnel not professionally trained in SAR operations often make up the majority of the SAR effort. There are many data available on psychological effects of a natural disaster, but data specifically on air crashes are limited. Taylor et al described stress reactions by personnel involved in recovery and identification of bodies after a plane crash in 1982.[19] He found that one-third of the subjects were experiencing post-traumatic stress immediately post-operation with one-fifth still having symptoms after three months. A more recent paper in 2004 by Fullerton et al, based on the 9/11 incident, described exposed disaster workers having significantly higher rates of acute stress disorder and posttraumatic stress disorder one-year post-incident and depression at seven months and 13 months post-incident. Individuals who were younger and single were also more likely to develop such disorders.

Pre-deployment psychological interventions are crucial in mitigating the incidence of these disorders[20] and were found to be effective during the QZ8501 search operation. Team-building

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activities that focused on effective communication and co-ordination, as well as preparation, in terms of education on what to expect in theatre, and provision of an institutional support system such as para-counsellors or psychologists in theatre, were key in alleviating high levels of anxiety that are masked by a professed sense of commitment to care for and protect all disaster victims during the SAR effort. The close-knit nature of the RSN shipboard communities also enables peer support during operations. Identification of persons with psychological concerns are also surfaced early by the open reporting and strong safety culture of shipboard units to facilitate early psychological intervention. This inherent protective factor may be absent in more heterogeneous units deployed in response to land-based disasters.

On the same note, post-operation intervention must not be neglected. Critical Incident Stress Debriefing is a well-researched and effective intervention.[21] It is a seven-step process that allows individuals to talk about their experiences, how it has affected them, brainstorm coping mechanisms, identify individuals at risk, and inform the individuals about avenues of help available to them. Appropriate clinical follow-up for at-risk individuals must be arranged as there may be a significant latent period before significant stress symptoms manifests. Adequate attention needs to be allocated to comprehensive psychological care for SAR workers to avoid under-detection and intervention that may result in significant morbidity to SAR workers.

Response

The United Nations Office for the Co-ordination of Humanitarian Affairs Disaster defines response as the provision of assistance or intervention, during or immediately after a disaster, to meet the life preservation and basic subsistence needs of those people affected.[22] The main domains for medical support during this phase are the management of surviving casualties and force medical protection.

Management of Surviving Casualties—Apart from considering the capability of deployed medical assets to deal with the likely spectrum of injuries, the capacity of these assets also is crucial. This is to pre-empt and avoid the need for over-triage in a situation where the needs of the casualties rescued exceeds the limited resources available out at sea. Planning norms for asset deployment may be based on the complexity and number of survivors expected as a result of any disaster.

It is essential for deployed assets to be capable of providing appropriate medical treatment to surviving casualties. Koeing et al described "complexity" of a patient[23] as the degree of difficulty in treating patient injuries. The survivor is expected to have multiple traumatic and maritime environment-related injuries as described previously. Each patient requires intensive medical attention, especially critical care resources. While the deployment of a Level II facility and above can provide such resources, it may require a considerable amount of preparation and time to arrive in AO that would significantly delay any survivors' access to immediate medical care. Hence, its value is likely to be limited to follow-up operations when the operation is expected to stretch over time and such facilities in the AO are extremely limited. A Level I facility ready for such incidents may prove to be of much higher value in optimizing any surviving casualties' chances of survivors.

In the QZ8501 search operation, the RSN deployed Level I medical teams and assets capable of ATLS on board most of her platforms, including a "first responder" ship, which arrived in the AO within one day of the incident. These teams are able to provide limited critical care to patients to optimize their chances for survival. This includes the use of ventilators, point-of-care testing,[24] and infusion pumps for the provision of inotropic support. Established critical care standards, such as the Fundamentals of Critical Care Society (FCCS) course,[25] and relevant medical simulation training and experience will enhance the ability and confidence of non-intensivists in the provision of critical care when intensivists are usually more meaningfully deployed with a Level 2 and above facility. All medical vocationalists' training in the RSN centers heavily on ATLS principles and the extensive use of medical simulation training as part of routine training during peacetime. Further critical care training is catered for PSOs in AOs distant from higher levels of care. The use of a similar medical support concept and assets during PSOs allows both ship and supporting medical crew to be familiar and comfortable with medical operations deployed on board, which translates into better care for casualties received on the ships. This level of care largely is appropriate and is justified for such operations in the absence of any surviving casualties rescued during the QZ8501 search operation. The decision on the number of medical teams and assets to be deployed will depend on the number of vessels deployed and expected number of survivors based on type of plane and number of passengers involved in the aircraft disaster.

In terms of capacity, an integrated approach is essential to share and co-ordinate resources within all ships operating in the SAR AO. This is an important consideration in view of the increasing multilateral nature of large-scale SAR operations and the likely similar profile of injuries sustained by surviving casualties. As a result of profile similarity, a few critical resources may be required repeatedly resulting in their severe shortage quickly.[23] A multilateral approach may help avoid the shift in individual-based care for low numbers of high-complexity patients to maximize each casualty's chances of survival, to population-based care due to limited resources, where care is mainly focused on casualties who are likely to have good clinical outcomes with the resources available. It will be tragic for casualties and families involved in the disaster if medical resources available in the AO are not utilized fully, forgoing the opportunity to enhance chances of survival for each and every surviving casualty rescued.

In the QZ8501 search operation, though no casualties were recovered, RSN remained in close co-ordination with the BADAN SAR NASIONAL (National Search and Rescue Agency Republic of Indonesia; BARSANAS), which allowed the expeditious evacuation of recovered human remains and debris for forensic examination.[26] During this operation, however, there was minimal direct co-ordination between medical teams, despite the presence of multiple ships with functional Level 1 facilities present in the AO, due to the absence of survivors. Medical support should leverage on such co-ordination linkages to ensure available medical assets in the AO are utilized fully when required.

Recovery

The recovery phase of a disaster is defined as the restoration of facilities, livelihoods, and living conditions of disaster-affected communities.[27] This is not applicable to an aircraft disaster at sea. This phase occurs after the rescue phase of a SAR response and is the predominant phase once the crash site has been located.

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A systematic approach to this phase is crucial to minimize the mismanagement of human remains located, which has a profound and long-lasting effect on the mental health of survivors, rescuers, and families. A thorough understanding of the decomposition process will allow recovery personnel to predict the location of bodies at any point of time in the AO and psychologically prepare themselves for this potentially daunting task to the untrained individual.

Appearance of Human Remains—The expected location of human remains is dependent on multiple environmental factors: prevailing weather conditions, water temperature, maritime organisms, and aircraft-related factors. The stage of decomposition of human remains is also a central factor in location. While the decomposition process on land is well established, there is little evidence available on the model for decomposition of bodies at sea. Decomposition rate of a body submerged in an aquatic environment is estimated to be one-half that of decomposition in air. The principle determinant of the rate of decomposition is water temperature. Submerged bodies in cold water may never resurface as there is no appreciable decomposition.[28]

The time required for the body to resurface primarily is dependent on the water temperature, which typically decreases with depth. With fairly warm water temperatures, a body can be expected to surface within a few days, whereas with cold or near-freezing water temperatures, resurfacing of the body can be delayed for several weeks to several months.[29] Other factors, which affect the rate of decomposition in water, include bacterial content, salinity, and the presence of aquatic animal life, and other incident factors such as obstruction by debris.

Body Retrieval—Based on the RSN experience and the decomposition model described above, the recovered body can weigh up to 200kg. The main contributor of weight to the body recovered is due to absorbed seawater and soaked artifacts worn on the body.

In the absence of specific equipment for such purposes, deployed RSN ships had to improvise organic ship equipment for the recovery process. The process was challenging due to the fragility and weight of remains, as well as the inclement weather that posed significant safety risks to the ship crew. Moving forward, it may be timely to explore the use of commercially available equipment, such as the SCOOPA system,[30] which are proven for small craft use and extensively utilized by the other coast guards and navies, to be adapted for use across various naval platforms based on considerations listed above.

Identification and tagging of bodies is done by matching information from the deceased with information from individuals who are missing or presumed dead. Standardized methods for identification and tagging, as recommended by International Federation of Red Cross and Red Crescent Societies (IFRCS; Geneva, Switzerland), are categorized into using unique references, labels, photographs, records, and securing of personal artifacts.[14] Many similar guidelines can be found in other established organizations such as Disaster Mortuary Operational Response Team (DMORT)[31] and Interpol. These guidelines reflect the importance of a standardized process for documentation, analysis, quality assurance, and respect for the dead. Follow-up definitive forensic procedures that require access to a forensic facility include autopsies, fingerprinting, dental examination, and Deoxyribonucleic Acid/DNA comparison.[32]

In the event where the immediate transfer of bodies to a facility for definitive forensic procedures is not possible, there are several options for the storage and disposal of bodies. Refrigeration between 2°C and 4°C is the best option.[14] In the absence of this storage option, other storage options such as dry ice (carbon dioxide frozen at 78.5°C) may be suitable for short-term storage.[14] Whichever storage option is used, each body or body part should be kept in a body bag or wrapped in a sheet before storage. Initial details gathered on the remains should also be transmitted to ashore DVI teams to allow preparation for the receipt of casualties. Where appropriate telecommunication means are available, a virtual autopsy also can be performed.

In the event where storage is not possible, or where storage capabilities have been exceeded, sea burial of bodies may be necessary. This is to avoid the hygiene and psychological impacts of active decomposition in an enclosed shipboard environment. Cultural sensitivities must be observed during the process of burial.

Deployment of an Afloat Forensics Capability—Mobilization of forensic resources may take several days and may not be available in the AO of SAR operations. In the QZ8501 search operation, the transfer of remains to a forensic facility ashore was hampered by adverse weather. Decomposition of bodies may translate into loss of forensic evidence with time. Hence, the early work of non-specialists in managing the dead in terms of proper recovery, documentation, and storage will determine much of the success of future identification by forensic specialists.

The availability of forensics capabilities in the vicinity of the AO confers many advantages. They include minimizing the loss of forensic evidence due to decomposition with time or attrition from the transfer process, early commencement of the DVI process, professional field guidance to non-forensic trained body handlers, and closer communication with SAR teams to facilitate positive outcomes during the forensic examination process.

Disaster Portable Morgue Units[33] by DMORT contain assets required for an on-site morgue during a large-scale disaster. These units are modular and have air and land mobility. A specific set of crew is trained to staff it operationally. These units may be deployed fully within 24 hours. Such a capability may be developed in response to large-scale disasters. This capability includes radiology, fingerprinting, pathology, forensic dentistry, anthropology, reconstruction, and embalming equipment.

However, developing such a capability may be manpower and logistically challenging. A fully equipped forensics team is extremely diverse in nature.[23] This may require a significant mobilization time. Many of these capabilities are also not routinely organically available to a military force; hence, personnel identified may not be suitable for deployment out at sea.

Hence, the deployment of an afloat forensics capability may be considered for future similar operations. The scale of each deployment must be deliberated on carefully to maximize its role in theatre.

Conclusion

Medical support of a SAR operation for a large-scale aircraft disaster at sea can be complex due to challenges posed by the maritime environment. The RSN leveraged on its organic medical support that is flexible and scalable which overcame many of these challenges posed by the QZ8501 search operation. The operation also emphasized the utility of a WOG approach to such

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operations, which may involve multiple domains of expertise such as forensics capabilities of a large scale at short notice. Specific areas, such as adequate preparedness through tabletop exercises specific to this scenario and aspects of forensics handling, remain to be desired. Additional capabilities, such as the deployment of an afloat forensics facility, have prominent benefits and should be considered in similar operations in the future. More research in this area is required to determine the optimal support model for such operations in the future.

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