The World in 90 Minutes or Less: Rocket Logistics and Future Military Operations

This research article was awarded second place in the 2022 CJCS National Defense and Military Strategy Essay Competition within the Strategic Research Paper category. While many students at JFSC achieve a high level of research, papers submitted to the competition represent some of the best research, writing, and thinking completed each academic year at Professional Military Education institutions. Manuscripts receiving recognition achieve an extraordinarily high bar. Other contest winners will be found at Joint Forces Quarterly.

Written by[1]
CDR Von P. H. Fernandes,
Maj Ashley Gunn,
MAJ Lucas Hoffmann, and
Lt Col Nita McQuitery

In 1959, Rear Admiral Henry Eccles described Logistics as "the bridge between the economy of the Nation and the tactical operations of its combat forces."[1] Rocket Logistics, the use of orbital-class rockets to carry cargo from one place on the earth to another, has the potential to shorten that bridge dramatically. In the seventy years since Eccles's statement, the competitive need for faster and more efficient Logistics operations changed how the Department of Defense (DoD) conducted Logistics and what Logistics contributed to global military operations. Efficient and streamlined Logistics not only provides commanders with freedom of action, but also extends operational reach. The DoD's ability to conduct efficient Logistics operations determines the extent and degree to which the U.S. can project power globally.

While air cargo became a feature of Logistics operations in World War II, cargo ships continue to transport the vast majority of supplies and military equipment for global military operations. Air cargo delivers speed to logistics efforts but at a fiscal cost and with restrictions on weight and volume. However, air cargo is still not fast enough for some logistical challenges in the USEUCOM, USAFRICOM, USSOUTHCOM, and USINDOPACOM theaters. The U.S. Space Force has a new cutting-edge research and development program, the Vanguard initiative, which is exploring the use of orbital-class rockets for point-to-point transportation. Rocket Logistics promises even faster speeds than air cargo on the battlefield but with higher costs and more restrictions on the cargo type, which, within the scope of this paper, is defined as both personnel and equipment.

Unlike civilian transportation missions, military missions do not have predictable destinations where investments in infrastructure development can be made to ensure a smooth landing. Thus, the Vanguard Program seeks solutions that have an all-terrain final descent system, with ruggedized exteriors to deal with foreign object debris (FOD) on landing and the use of new technologies like those currently being pioneered by NASA which will allow a descending rocket to create a landing pad during the final descent.[2]

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[1] The views expressed are those of the author(s) and do not reflect the official policy or position of Joint Forces Staff College, National Defense University, the Department of Defense, or the U.S. Government.

Assuming future commercially available rockets will meet all Vanguard program technical goals (the ability to transport 100 tons of personnel and equipment to an unimproved surface anywhere in the world), it becomes valuable to analyze the potential strategic and operational impacts of Rocket Logistics now.[3] The most judicious and pertinent questions to ask are: What are the benefits and limitations of Rocket logistics, and how do these characteristics apply to potential conventional force deployments, Special Operations Forces (SOF) missions, and Humanitarian Assistance/Disaster Response (HA/DR) activities?

Current & Near-Horizon Rocket Technology

The U.S. Air Force, U.S. Space Force, and U.S. Transportation Command are working together to develop and employ Rocket Logistics for worldwide solutions to deliver cargo from one terrestrial location to another.[4] The cargo will be loaded onto an autonomous rocket, which will take off, enter an altitude just above 100 kilometers (km), and travel to any location on Earth. The rocket can then conduct an autonomous, controlled descent to deliver its cargo. This method differs from air, sea, and land transport in several fundamental ways.

The most significant difference between Rocket Logistics and conventional methods is the speed of delivery; rockets are expected to transport tons of material across the planet in under ninety minutes by using an orbital trajectory to reduce transit time.[5] This presents a variety of logistical options to deliver valuable cargo within tactically relevant timelines, as opposed to hours or days (e.g. fourteen hours of flight time for a plane traveling from New York City to Nairobi, Kenya). The second advantage of Rocket Logistics is that movement above 100 kilometers in altitude is not governed by national airspace regulations. This means that the rocket would only need permission to access the nation's airspace from which it departed and the nation in which it will land. Along the rest of the journey, the rocket will be at an altitude that cannot be obstructed by overflight regulations, allowing the material to be delivered to regions otherwise difficult to access. This speed and flexibility come at an increased cost as the price per kilogram (kg) of cargo is higher for Rocket Logistics than conventional methods. Also, there are logistical concerns about refueling rockets at destinations and landing site requirements. For these reasons, Rocket Logistics is not expected to replace existing logistics capabilities, but function instead as an option for a high-speed, high-cost delivery method with long-range and potentially versatile landing capabilities.

The United States is undergoing a renaissance in the Commercial space industry that can be adapted to Rocket Logistics. Major competitors include SpaceX, United Launch Alliance (ULA), Rocket Lab, Virgin Orbit, and Blue Origin. The current market leader in cost, reliability, and capacity, SpaceX, has conducted cargo deliveries into orbit using its Falcon-9 and Falcon Heavy rocket systems, with 137 of 139 launches being successful as of February 3, 2022.[6] SpaceX delivers crews to the International Space Station using Dragon capsules and can deliver 63 tons into orbit with the Falcon Heavy. Moreover, SpaceX's next-generation system, Starship, currently in prototype testing, is designed to place over 100 tons of cargo into orbit.[7] While launch costs are dependent on numerous factors, current rates for Falcon-9 are around $1,500 per kilogram. This price is much less than the per kilogram average ($25,800) from 1980-2000. Industry observers expect continued price decreases as the technology matures and companies achieve economies of scale.[8] Following current trends, it is possible to project a time when

Rocket Logistics will be cost comparable to air cargo, especially when the costs of airfield construction are included. If such cost savings are realized, Rocket Logistics could replace aerial logistics for many routine military and commercial functions.

While an operational Rocket Logistics system could have various delivery mechanisms, the most versatile would be the separable capsule design, similar to that used by SpaceX's Dragon capsules or the Soyuz capsule. In this case, the booster(s) launches the vehicle into space and returns to a designated launch pad. A separate capsule containing the cargo parachutes to the delivery location with a hatch near ground level. This approach removes the need for specialized landing pads or offloading equipment, and the capsule's expendability would be mission dependent.

Limitations of Rocket Logistics

While rocket cargo provides numerous advantages in speed, current and near-horizon technologies have several limitations. The physical locations of the existing launch infrastructure limit where rockets can be launched from. Suborbital and orbital launches exert significant G-forces on payloads limiting the types of cargo that can be carried. While the advertised deployment speed of fewer than 90 minutes is accurate, these timelines do not include cargo and fuel loading times. Due to the strength of earth's gravity relative to current and near-future rocket technology, detachable boosters are used by all currently operational and prototype rocket systems. Since the booster does not proceed to the destination, Rocket Logistics missions to austere locations are unable to return cargo or the delivery capsule to the origin point.

When compared to cargo aircraft, rockets require significantly more specialized ground infrastructure. A military cargo aircraft can find aviation-grade fuel and a supporting runway at thousands of locations across the United States and around the world. In contrast, current commercial rockets typically require specialized launch platforms and fuel that are only available at a few locations. Figure 1 shows existing spaceports in the United States. Notably, only a few locations are currently capable of launching all rocket types. Operationally, the military units would have to fly, use rail transport, or drive personnel and equipment to the launch site(s). Other options would be to construct launch sites near supplies, equipment, and personnel designated for rocket cargo missions or to pre-stage personnel near launch sites. One caveat to this restriction is that a few companies like Virgin Orbit and Northrop Grumman (Orbital Sciences) have developed the capability of launching small orbital rockets from aircraft. Virgin Orbit uses a modified 747 to launch rockets capable of delivering 500 kg of cargo.[9]

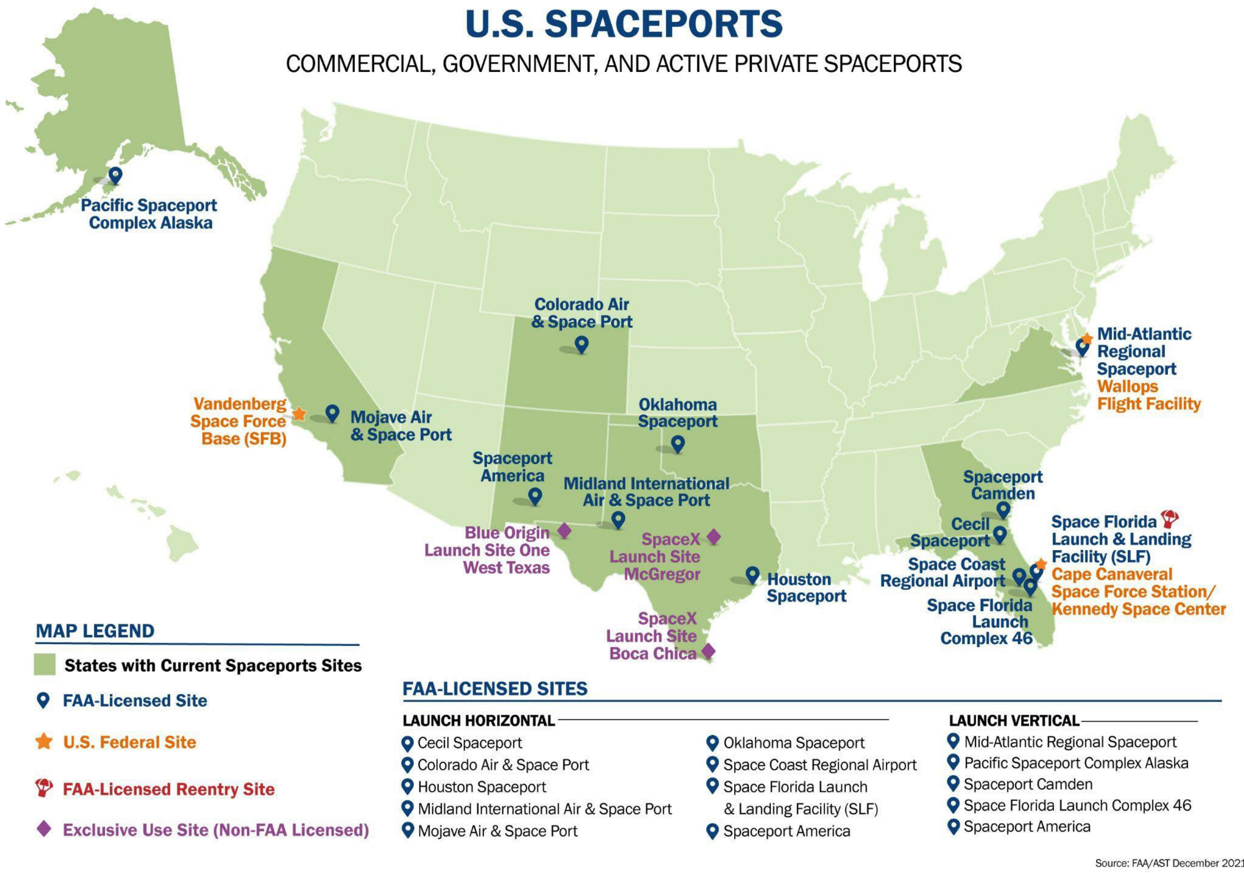

Figure 1: U.S. Spaceports: Commercial, Government, and Active Private Spaceports. Source: Federal Aviation Administration, "U.S. Spaceports Commercial, Government, and Active Private Spaceports," Accessed on April 18, 2022, https://www.faa.gov/space/additional_information/faq/

While cargo aircraft are relatively sedentary in their acceleration profiles, a rocket can produce more G-forces than fighter aircraft. NASA and civilian space companies recognize this and limit flight parameters for the protection of cargo. Despite acceleration limitations, G-forces must be considered when planning the operational usage of rocket cargo. While most military equipment is hardened, the 6 Gs of force experienced in some rocket launches are neither a typical design parameter for ground equipment, especially finely calibrated weapons and sensor systems, nor a typical screening criterion for ground personnel, and should be considered in operational planning for Rocket Logistics.

Figure 2 outlines the G-force limitations expected on the SpaceX Starship rocket, which is currently in the prototype testing phase of development, and outlines how a Starship cargo will likely experience up to 6 Gs of axial acceleration and 2 Gs of lateral acceleration with a maximum of 6.5 Gs of total acceleration.[10] This level of acceleration is similar to that experienced by Soyuz astronauts (~6 Gs) during landings, but is more than the 4-6 Gs that can cause untrained humans to lose consciousness.[11] Consequently, either additional training and medical standards would be required for Rocket Logistics capable units or the acceleration profile would need to be limited to reduce the risk of losing consciousness. Additionally, mission planning would need to consider G-force effects on cargo types to reduce damage to the payload.

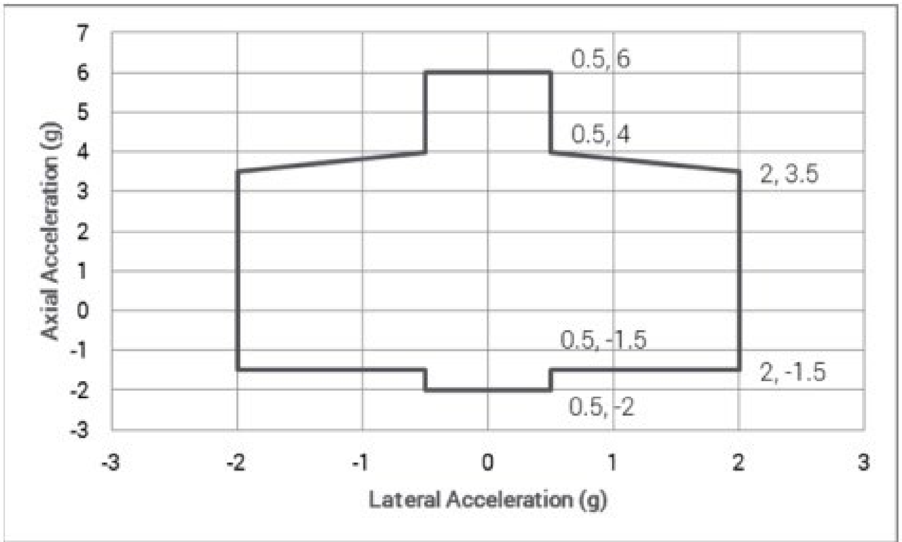

Figure 2: Payload Maximum Design Load Factors. Source: Space Exploration Technologies Corp, "Starship Users Guide," Modified on March 2020, https://www.spacex.com/media/starship_users_guide_v1.pdf

Rocket cargo is limited by both weight and volume, similar to aircraft, due to high costs and the engineering characteristics of rockets. Planners and procurement officials must factor these constraints into their strategic, operational. and procurement plans. A financial constraint is the cost of launch; for current operational rockets, the cheapest launch cost per kg to Low Earth Orbit (LEO) is $1,500 per kg offered by the Falcon Heavy.[12] Physical constraints are the dimensions of the cargo capsule; the Falcon Heavy is limited to carrying cargo that fits in its cylindrical fairing, 5.2m in diameter by 18.7m in height, with a tapered nose as shown in Figure 3. Operationally, these dimensions would allow the Falcon Heavy to carry a single M1A1 tank or a single MH-60R with rotor blades folded.[13] Future equipment procurement may need to consider rocket dimensions and procure foldable and collapsible systems, as all of the services currently do to fit vehicles, helicopters, and tactical aircraft on cargo aircraft and warships.

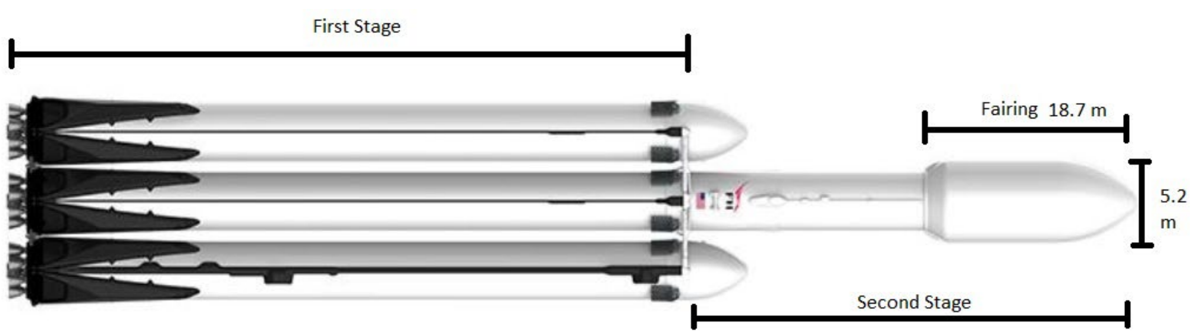

Figure 3: Falcon Heavy (With Fairing Dimensions). Source: Space Exploration Technologies Corp, "Falcon Users guide," Modified on September 2021, https://www.spacex.com/media/falcon-users-guide-2021-09.pdf

While SpaceX claims a 100-ton payload and the potential to reach a launch cost of $10 per kg with its next-generation rocket, the cost numbers require significant and rapid reusability which has yet to be operationally proven.[14] In other words, SpaceX purports pricing based on as-yet-unconfirmed capabilities. Thus, for shorter distances, close to existing American military bases, Rocket Logistics is unlikely to be cost-effective compared to air cargo. However, long-distance missions to Europe, Africa, the Pacific, southern South America, and Antarctica are more suitable missions for this approach.

While speed, practice, and anticipation can limit the ground time before the launch of a rocket cargo mission, ground time must still be considered for Rocket Logistics' operational utility. As with aircraft flight planning, mission planning should include orbital trajectory selection and landing location. Currently, a fully manufactured and certified rocket system typically needs at least 24 hours to go from storage to launch. For example, Space X's Falcon 9 cargo capsule is delivered to the launch pad and mated to the booster rocket in the 24 hours leading up to a scheduled launch.[15] NASA Astronauts currently board SpaceX's crew capsule 135 minutes prior to flight.[16] SpaceX can fuel its current rocket, the Falcon 9, just 35 minutes prior to launch.[17] As it has gained operational experience, SpaceX has progressively made these launch preparation timelines significantly more aggressive. Thus, a more expedited and streamlined ground experience for the launching of time-sensitive cargo is likely possible, making Rocket Logistics an even more appealing option for rapid global operations.

To achieve orbital or near-orbital velocities and altitudes, current and near-future rocket systems require the assistance of boosters, motherships, or other systems, which return to the launch site or are disposed of. While this process significantly improves the efficiency of the final stage of the rocket vehicle, it limits operations. Unlike a cargo aircraft or helicopter that can carry enough fuel or be refueled in flight, rockets for the foreseeable future will not be able to fly to an expeditionary location and return. The cargo and personnel that deploy via Rocket Logistics must find another way to exit the battlefield. This limitation is no different than traditional airborne infantry operations; however, the difference with rocket cargo is that the delivery mechanism costs significantly more than a parachute and may contain technology that the United States does not want adversaries to obtain. Additionally, Rocket Logistics' ability to deliver significantly further from friendly lines complicates extraction planning and resupply. Operational commanders will need to plan for the extraction of rocket-deployed personnel by air, land, or sea. Only resupply or reinforcement can be done with additional space flights.

Conventional Warfare and Rocket Logistics

The 2018 National Defense Strategy states that U.S. forces must be "strategically predictable, but operationally unpredictable.[18] This concept is useful for employment against strategic competitors but poses significant challenges for the logistics enterprise. In recent years, senior leaders have relied on conventional warfare principles such as Agile Combat Employment (ACE) and Dynamic Force Employment (DFE). The ACE methodology relies less on the large overseas base structure as hubs for projecting combat power and more on the U.S.'s ability to quickly launch, recover, and maintain aircraft from dispersed forward operating locations working closely alongside partners and allies.[19] Similarly, DFE's goal is to provide options for unpredictable and scalable employment of the Joint force while still maintaining control of the capacity and capability for major combat operations.[20] Both employment methods provide the means needed today to defeat long-term strategic competitors but are an incredible challenge to execute and maintain logistically. Our ability to integrate with allies and partners through DFE, military posture, and contingency operations will challenge adversaries, as long as the U.S. has the logistical capabilities required for these operations.[21]

If the U.S. were to transition from competition to conflict, Rocket Logistics would be a key addition to ACE and DFE capabilities and would complement USTRANSCOM's existing air, sea, and land operations. Unlike Operations *Desert Storm* and *Enduring Freedom*, strategic competitors are far less likely to allow prolonged force build-up. The logistics enterprise must develop innovative support and resupply concepts that do not depend on traditional distribution networks and processes.[22] A rapid-deploying, large-capacity solution is required, which Rocket Logistics would fill. Rocket Logistics mission applications can range from humanitarian aid to contingency response. In concert with other logistical modes, it can be the solution to not only deter an adversary from further aggression but also, in case of conflict, provide the operational endurance commanders need for freedom of action and operational reach in future conventional warfare. When the U.S. rapidly forward-deploys strategic assets in future crises, Rocket Logistics could expedite the coinciding maintenance packages and airbase assets such as Basic Expeditionary Airfield Resources (BEAR) or combat communications, ensuring that operational command and control and critical deployed capabilities are supported, maintained, and integrated into the broader effort.

Additionally, if able to transfer hazardous materials, Rocket Logistics would be an ideal transport mode for munitions movements or fuel resupply, especially in austere locations. Besides delivering supplies, personnel, and equipment to land forces in contingency operations, Rocket Logistics could deliver high-value, urgent supplies to deployed naval forces far from friendly ports, without the need for lengthy transit of supplies through foreign countries and foreign customs procedures. As warships do not carry spare parts for every eventuality, the failure of a critical component may significantly reduce its operational capacity. Rocket Logistics could deliver repair parts and personnel in less time than it takes to draft, route, and submit the required casualty report (CASREP) to request higher-level maintenance support.

Impacts of Rocket Logistics on Asymmetric and Irregular Warfare

U.S. Army Special Operations doctrine outlines the effectiveness of "surprise achieved through speed, stealth, audacity, deception, and new tactics or techniques."[23] Rocket Logistics has the potential to be an audacious new technique that quickly delivers SOF behind enemy lines and in unexpected locations, but it would sacrifice stealth to do so.

Currently, SOF teams deploy using aircraft, helicopters, and submarines. Air Force Special Operations Command employs specialized C-130s and V-22s to deliver SOF and supplies to the battlefield.[24] These cargo and tilt-rotor aircraft may require aerial refueling or a landing platform near the target area which may supply warning to potential target locations and enable an adversary to intercept the aircraft with air defense systems. In contrast, submarine deployed SOF teams have maximum stealth, but are limited to near coastal areas and require multi-day and multi-week trips to reach most target areas.[25]

Rocket Logistics provides an alternative for SOF delivery to the battlefield. With an under 90-minute transit time, a rocket can deliver a team from the United States faster than a C-130 from a friendly airfield or a tilt-rotor aircraft operating from an off-shore warship. Thus, Rocket Logistics will likely find a significant niche for time sensitive SOF targets like hostage rescue, terrorists, and mobile Weapons of Mass Destruction facilities. Rocket delivery from the Continental United States (CONUS) allows SOF forces to spend more time at home station training vice forward deployments on a ship, submarine, or austere location without access to high-quality training facilities.

As mentioned previously, Rocket Logistics missions will not require overflight clearances from countries along their route to the mission area. Removing this bureaucratic hurdle can dramatically accelerate the response time of SOF units, especially when unfriendly nations close the intervening airspace to U.S. aircraft, forcing significant detours. This characteristic means that Rocket Logistics has the potential to allow forces into areas that are otherwise politically difficult to access. Rocket Logistics will still require landing clearances. Landing clearances routinely require 14-30 days, but emergency requests may be granted in hours.

Despite the advantages of speed and operational flexibility, Rocket Logistics has some operational limitations uniquely applicable to SOF. Due to international treaties, the United States currently announces all rocket launches at least 24 hours prior to departure.[26] While adversaries will not know the final destination, they will know when a launch is scheduled. Once the rocket is in flight, sophisticated adversaries may engage with ballistic missile defense systems and identify the landing site rapidly after a team deploys on the ground. This vulnerability is significantly different from airborne delivered SOF teams flying below the radar horizon and submarine deployed teams. Most adversaries will likely have the capability of detecting the rocket in the descent phase either by sight, hearing, or radar and can easily observe the rocket's thermal signature as it reenters the atmosphere due to the heating effects of the air friction.

While submarine, tilt-rotor, and helicopter-delivered SOF can exfiltrate from the battlefield in the same manner they enter, parachute and rocket cargo delivered SOF must have an alternate extrication plan. Near-horizon rocket cargo technologies do not have the fuel to return to origin. The technology is a one-way ticket unless the DoD establishes intermediate staging bases (ISBs) stocked with spare boosters and fuel. ISBs in the Pacific and Sub-Saharan Africa could help facilitate the rapid movement of SOF teams and casualties between U.S. bases and these areas of operation with onward travel by other means.

More than just supporting traditional SOF missions, Rocket Logistics could facilitate new types of missions. The United States and its allies constantly compete with China and Russia but only rarely do so via direct military confrontations. Russia and China seek to change the status quo by changing the situation on the ground – delivering troops or fishing fleets to occupy territory. China's fishing fleet has also hindered the resupply of disputed islands.[27] During grey zone competition, when the U.S., Russia, and China are refraining from direct military confrontation, Rocket Logistics-delivered personnel could rapidly deploy. A rapid repositioning has the potential to rebalance a situation to America's benefit, giving the U.S. the ability to quickly occupy contested territory. China or Russia would then have the difficult task of dislodging American forces. If such units are isolated or blockaded, Rocket Logistics can provide resupply in an environment where an airfield might not be available.

Humanitarian Assistance and Disaster Response Missions

The unique aspects of Rocket Logistics provide critical capabilities in disaster response, either natural or anthropogenic. While it will not provide the cargo capacity needed to mitigate disasters for large populations, the immediacy of the response and the unique landing capabilities can provide necessary solutions that are otherwise unavailable. Historical analyses of previous earthquakes have shown that the greatest demand for emergency medical services occurs within 24 hours of disaster onset.[28] Immediate deployment of medical personnel and a mobile hospital could begin triage and treatment for those whose injuries cannot wait the 24-36 hours it could take for aid to arrive through commercial or military aircraft. Similarly, the deployment of an advanced assessment team could provide situational awareness and support for the major aid force that will follow. Such a unit could carry drones, water testing equipment, environmental sensors, and communication networks to provide international first responders, such as USAID (United States Agency for International Development), awareness of the extent of devastation and the availability of basic services. This team would assist subsequent response organizations in bringing the correct resources to the areas of highest need, easing and accelerating the disaster relief effort. A rocket-deployed advanced team would be most critical in disasters that destroy existing governance structures, as these institutions are unable to provide early data on humanitarian needs to aid organizations, delaying an effective response.

With the right training and expertise, a rapidly deploying team could mitigate the severity of a disaster by responding before the situation passes a critical point of escalation. For example, a quicker response might have mitigated the harm caused by the coolant failure at Fukushima, where the first hydrogen explosion occurred 24 hours after the tsunami damaged the reactor.[29] Rapid response teams would also be helpful in building levees before a dam collapse or delivering iodine pills after a nuclear disaster. In these cases, swift action reduces the impact of a disaster, potentially offsetting the additional cost of using Rocket Logistics. This dynamic adds just-in-time mitigation and prevention techniques to consequence management for the disaster response toolkit. With the rapid capabilities of Rocket Logistics, the Departments of State and Defense will need to spearhead new procedures and methods for expediting diplomatic permissions with international partners.

Rocket Logistics has the ability to expedite disaster response in isolated regions. There are many reasons that a disaster location or an affected population might be difficult to access by other means. As seen in the case of Tropical Cyclone Eloise's landfall in Mozambique in 2021, the tyranny of distance may inhibit a humanitarian response. On the continents of Africa and South America, and in the island nations of the Pacific, runways for large-fixed wing aircraft either do not exist or could be damaged by the disaster. Rotary-wing assets would be more versatile with respect to landing requirements, but their range is limited as shown in figure 4.[30] Rotary-wing ranges could be extended by using tilt-rotor aircraft, aerial refueling, and lily pad resupply. However, due to crew-day limitations, rotary-wing employment is difficult over longer distances; a constraint not observed with Rocket Logistics. Additionally, since the descent capsule would not have an air-breathing engine like other aircraft, it could enter places where volcanic ash, dust, or sand would preclude the use of other insertion techniques.

Figure 4: Range of UH-60 Blackhawk Helicopter, flying from Dakar, Djibouti, Nairobi, or Pretoria. Source: Google LLC, "Google Maps," Accessed on April 18, 2022, https://www.google.com/maps/.

In addition to how Rocket Logistics can help in the actual conduct of disaster response, they also provide clear and essential messaging. As the first international response on the ground, Rocket Logistics allows the U.S. to influence the narrative. An immediate presence within the affected area demonstrates U.S. commitment to its allies and its value as a Partner. Such messaging improves the perceived ability of the U.S. to respond to global security crises.

Weaknesses and Vulnerabilities of Rocket Logistics

Rocket Logistics exposes the U.S. military to vulnerabilities that our global competitors may attempt to exploit in a future conflict, putting military operations, personnel, and assets at risk. The most critical vulnerability is cyber, as Rocket Logistics craft will be heavily dependent on computer systems for navigation and control. Thus, adversaries will likely target space systems via cyber-attacks and intrusions. Malicious forces will likely attempt to infiltrate the supply chain and inject malware to disrupt or degrade critical spacecraft and launch systems. While the rocket will likely operate autonomously with internal navigation, these systems are vulnerable pre-launch and will probably be built on commercial systems that are not as secure as military platforms. Space systems must be protected from adversarial threats as we consider using Rocket Logistics to transport cargo and personnel for U.S. military operations. At the speeds being traveled (about 7.79 kilometers per second),[31] manual control would likely lead to the delivery being many miles off target and to mission failure as a single second of delay in initiation of the deorbit thruster burn could lead to a significant variance in landing location.

Conclusion

As an emerging capability, Rocket Logistics can provide more options to policymakers in Washington and more capabilities to deployed forces. In the initial phases of crises today, America's political leaders ask the locations of the nearest Carrier Battle Group, Special Forces Group, or Marine Expeditionary Unit and how quickly they can respond. In a future military with Rocket Logistics, the Chairman of the Joint Chiefs of Staff will be able to offer policymakers rocket-launched SOF and conventional units as additional options. Rocket-delivered forces will respond faster, potentially reducing the severity of future crises.

However, Rocket Logistics is still an emerging, niche capability. Like the early days of Air Mobility, Rocket Logistics is suitable for high-value, low-weight cargo – SOF team delivery, HA/DR advance teams, and critical resupply for conventional forces far from existing support infrastructure. Changes in equipment procurement, basing, personnel screening, diplomatic procedures, and training will ensure the DoD can take full advantage of this emerging logistical capability and mitigate some of its vulnerabilities. As we have seen with air cargo, over the past century, this capability will expand over time as its relative cost decreases and may absorb some missions from air cargo in the future. Rocket Logistics' key advantages – the speed and ability to evade airspace restrictions – deliver operational flexibility and additional operational security benefits that can deliver results on tomorrow's battlefield.

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