LEVERAGING VERTICAL TAKE-OFF & LANDING (VTOL) UNMANNED AERIAL VEHICLE (UAV) TECHNOLOGY FOR HUMANITARIAN AID & DISASTER RELIEF (HA/DR): THE "LAST TACTICAL MILE"

GRADUATE RESEARCH PAPER

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AFIT-ENS-MS-22-J-055

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY

AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT-ENS-MS-22-J-055

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Graduate Research Paper

Presented to the Faculty

Department of Operational Sciences

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Operations Management

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May 2022

AFIT-ENS-MS-22-J-055

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AFIT-ENS-MS-22-J-055

Abstract

Purpose – This paper examines the 2017 Hurricane Maria HA/DR VTOL delivery efforts in the mountainous northwest sector of Puerto Rico (P.R.) and utilizes near-term VTOL UAV technology in a fixed demand model to derive results for analysis. Additionally, the study covers a varying demand model for the VTOL assets to generate data for a scalable HA/DR response planning tool assisting decision-makers.

Design/Methodology/Approach – The goal of this study is to analyze qualitative inputs from subject matter experts in the Department of Defense (DoD) who served during the HA/DR efforts in Aguadilla, Puerto Rico to illustrate a list of assumptions to take into consideration in a realistic model for the selected VTOL UAV. The data derived from the HA/DR efforts were utilized to quantify the fixed demand model to highlight VTOL UAV applicability against traditional VTOL assets. Further, a model was built to assess varying demand while maximizing each VTOL asset's water and meals ready-to-eat (M.R.E.) transport capability to produce actionable data to feed into a HA/DR planning tool.

Findings – Analysis of both models produced by mixed methods research supports that there is a place for developing VTOL UAV technology resulting a lesser cost and higher utilization rate during sustained logistics for HA/DR. During the fixed demand scenario of Hurricane Maria HA/DR efforts in northwest P.R. for the 34 days in theater, the selected VTOL UAV utilized through the model accomplished the mission, set at a lower daily cost of $1,887.00 while requiring two operators with three assets. The models also demonstrated that the cost would be approximately 74% less than a single MV-22B with four operators, or 74% less than a single

HH-60W with eight operators modeled as if they were conducting the same mission set in separate scenarios. The UAV accomplished the daily requirement at a slower pace and with an increased number of dispatches from the hub. Results also supported the scalable utilization of VTOL UAV assets to sustainment logistics meaning that it allows a precise response with increased control of excess capacity if needed for multiuse. Findings also demonstrated that the varying demand model enabled the discovery of utilization space to be scaled for demands below the daily carrying capabilities of HH-60W and MV-22B for the selected VTOL UAV.

Originality/Value – This research addresses the applicability and cost-benefit analysis of VTOL UAV during HA/DR. This offers a perspective of an actual HA/DR effort performed by traditional VTOL assets compared to near-term technological advances in VTOL UAVs. This type of perspective provides a different method of conducting cargo deliveries to isolated residents, ultimately enabling an agile and lesser response cost. With the realization of the ease of scalability, the way forward in identifying the effects of implementing a cargo VTOL UAV delivery force becomes more easily defined. By running the varying demand model, qualified personnel is better able to establish the groundwork in setting the appropriately sized force to react to HA/DR efforts based on populous and distance of spokes from the operating hub.

Keywords Drone Delivery, Last Tactical Mile, Advanced Air Mobility (A.A.M.), Cargo Delivery, Vertical Takeoff and Landing (VTOL), Unmanned Aerial Vehicle (UAV), Humanitarian Aid and Disaster Relief (HA/DR)

Paper type Research paper

Acknowledgments

I would like to express my sincere thanks to my research advisor, Col Jason Anderson, for all the guidance and advice provided in this project. He helped me to think critically about all aspects of the endeavor and to communicate them effectively. I would also like to thank my research sponsor at Air Mobility Command, Brig Gen Darren Cole for his insight and forward-thinking help in shaping this study. A special thanks to the AFWERX Agility Prime team (government leads: Lt Col John Tekell and Ethan McKenna) for their analytical support provided by LinQuest Corporation staff: Caleb Notheis, Stephanie Boone, Jaclyn Nelson, Alan Seise, Dr. Parker Vascik, Nadir Ougazzaden, Dr. Ashish Bagai, Dr. Adam Ross, and Dr. Matt Fitzgerald. Finally, and most importantly, my wife and children deserve a heartfelt thanks for the amount of time they allowed me to devote my attention in pursuit of my passionate research.

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I. INTRODUCTION

Background

In September of 2017, Puerto Rico was struck by Hurricane Maria just two weeks after Hurricane Irma pounded its shores (Kishore et al., 2018, Talbot et al., 2020). Without question, this island territory was left in near-complete ruin (Talbot et al., 2020). By all accounts, the destruction caused by both hurricanes was more than the Puerto Rican authorities could handle on their own (Pasch et al., 2017).

Three days before landfall (84 hours), the second official forecast by the National Hurricane Center (NHC) posited Maria would become a major hurricane (see Figure 1) by the time it reached Puerto Rican soil (Pasch et al., 2017 with sustained winds blowing at 145 miles per hour (mph), peaking at 155 mph (Martinez et al., 2018). Heavy rainfall occurred in P.R in some places a total of nearly 38 inches (Pasch et al., 2017). To illustrate the level of destruction, the following timeline is posted below from Naor and Laor's Disaster Recovery after Hurricane Maria in Puerto Rico: Assessment using Endsley's three-level model of situational awareness (2020):

> "Communication networks failed, with 95 percent of the island's cell networks going down, leaving 48 of the island's 78 counties' networks completely cut off; at the same time, 85 percent of exposed phone and internet cables were knocked out. Only one radio station, WAPA 680 AM, remained on the air through the storm. The hurricane also destroyed the power grid, leaving approximately 95 percent of the island without power. Two weeks after the hurricane, 89 percent of the island still had no power, 44 percent had no water

and 58 percent had no cell service. One month after the hurricane, 88 percent of the island was without power (about 3 million people), 29 percent lacked tap water (about 1 million people), 40 percent had no cell service, and only 392 miles of Puerto Rico's 5,073 miles of road were open. The subsequent flooding that continued for weeks exacerbated the slow relief efforts. Puerto Rico lost about 80 percent of its agriculture, costing the island 780 million US dollars"

Hurricane Maria 2017: Puerto Rico and DoD Response

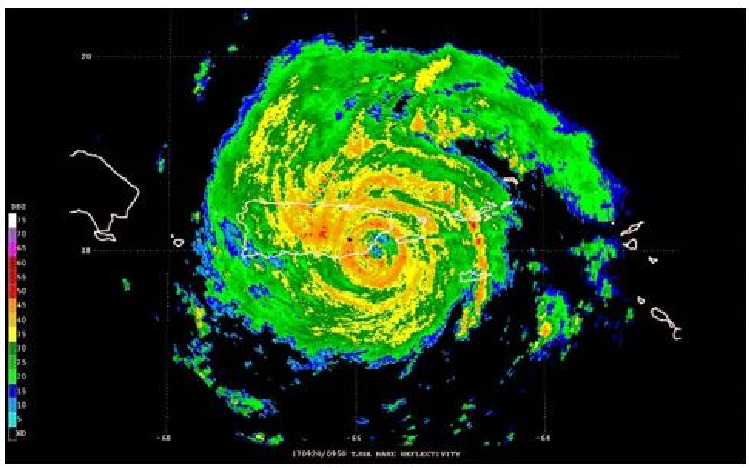


Figure 1. San Juan, PR Hurricane Maria Radar Image (0950 UTC 20 SEP 2017)

Perhaps there is no better example of the need for a rapid response for decisive aid than Puerto Rico and the effects of Irma and Maria. The death toll was uncertain. While initial official estimates indicated 64 casualties, various other sources purported that the number exceeded 1,000 (Martinez et al., 2018). Recovery efforts were slow but steadily made progress. By the end of 2017, just under half of Puerto Rico's residents were still without power, and a month, electricity had been restored to about 65% of the island. (Pasch et al., 2017).

Humanitarian Assistance and Disaster Relief (HA/DR) operations are supported by the Department of Defense (DoD) to enable the United States Agency for International Development

(USAID) or the Federal Emergency Management Agency (FEMA). Several military units participate in HA/DR and the United States Air Force (USAF) is no different. The 621st Contingency Response Wing (621 CRW) is a specialized unit tasked with setting up airfield operations at the beginning of a HA/DR effort, and offer continued assistance as the disaster aftermath progresses into recovery operations (AFDP, 2019). In the beginning stages of operations, one priority is the opening of the aerial ports where Contingency Response (CR) members are stationed to enable the movement of cargo through the port to those who need assistance (AFDP, 2019). However, due to the destructive nature of these events, communication lines are often damaged, and inaccessible, leading to isolated residents and resulting in significant delays before any sort of aid is delivered. This was especially evident after Hurricane Maria devastated P.R., leaving island-wide massive destruction.

During this time, the events that occurred posed significant challenges for HA/DR operations and military logisticians (Romano, 2011). For example, once cargo was delivered via aerial ports, the 621 CRW members on the scene provided firsthand accounts of cargo being backed up on an already crippled airfield. The shipments were centralized at these ports but relied on land-based assets and limited helicopter availability to disperse aid throughout the population. In addition to seeing the congestion on the ramps and storage areas, the Contingency Response Element (CRE) on the ground utilized standard metrics to scope their objective for cargo movement off the airfield. These metrics are based on how many 463L pallets can reasonably flow through the aerial port to be dispersed to residents in need. It is a common practice for that metric to be eight 463L pallets of cargo per hour in order to avoid excessive buildup at the aerial port (Sugalski, 2021). Once the outbound rate is reduced and storage is at capacity, the CRE stops inbound flights with deliveries and reroutes to other locations for storage. According to Romano, the primary reason for delayed airlift is a limitation to offload capability and throughput capacity (Romano, 2011).

HA/DR is dependent on route accessibility and is a major logistical concern after a natural disaster. Most HA/DR operations are characterized by rapidly changing circumstances and a lack of clear and accurate information; they are also distinguished by substantial pressure to quickly provide relief supplies and material (Romano, 2011). The traditional method of mass delivery to an aerial port leads to centralized cargo storage with a plan to disperse via roadways or other aerial means, which is often accomplished by the United States Army (USA) or the United States Navy (USN). Once the lines of communication are deemed not accessible, there is an extended period before essential cargo is delivered to the affected population. That delay, coupled with conditions and the ability to provide sustained logistical support during unfavorable roadway conditions, may be critical to those isolated individuals' survival. The traditional solution presented here is to utilize helicopters, also known as traditional VTOL assets, to overcome this problem.

Objective

The purpose of this study is to replicate the HA/DR efforts post-Hurricane Maria in Puerto Rico (PR) with the addition of overlaying the capabilities of a selected VTOL UAV performing the cargo deliveries that the historical traditional VTOL assets accomplished. By doing so, the model will highlight derived benefits and a trade space where VTOL UAVs could fit. Once the results indicate a benefit, a model or tool will be built for planners to utilize for scaling VTOL drone response to HA/DR events supplying water and MREs.

Research Questions

In pursuit of discovering the applicability of VTOL UAV technology for cargo delivering in the DoD, this paper addresses the following research questions:

Q1: What results could be derived if automated VTOL UAV technology was leveraged during Hurricane Maria HA/DR efforts in Puerto Rico's "Last Tactical Mile"?

Q2: What is the derived daily requirement of food and water deliveries accomplished during the post Hurricane Maria operations by DoD assets in the northwest sector of PR?

Q3: What VTOL UAV is soon to be available and suitable to conduct HA/DR mission set while reducing the complexity of implementation for DoD?

Q4: How can the data obtained from the models enhance future HA/DR operations?

This paper addresses the above research questions through a mixed methods research approach, consisting of qualitative and quantitative data collection in order to build an accurate model of the case study's environment. Additionally, this project develops a model to assist planners in the identification of DoD requirements for HA/DR efforts.

II. LITERATURE REVIEW

Overview

Recently, there has been a shift in ownership of disaster relief. The Federal Government is no longer solely responsible because the primary responsibility for disaster relief falls on state and local governments with their resources (Tulach & Foltin, 2019). In fact, no Federal action can be taken until the President issues a Major Disaster Declaration. However, if circumstances warrant it, a governor or tribal leader may request federal assistance from FEMA under the Robert T. Stafford Disaster Relief and Emergency Assistance Act of 1988 signaling that a disaster exceeds the state and local government's capacity to appropriately respond (US Government Publishing Office, 2018). The FEMA director then determines whether the disaster warrants a recommendation for the President (Cords, 2019). The Federal Government often takes a wait-and-see approach before determining the degree to which it will intervene following a disaster (Tulach & Foltin, 2019). Still, when authorization is given, FEMA takes charge and coordinates with supporting agencies like the DoD to assist the state's needs further.

Once the DoD was finally called upon, it operated in support of FEMA efforts (Larson et al., 2020). The DoD formed a Joint Task Force (JTF) for Puerto Rico (PR) Assistance and the newly formed JTF-PR was established with a mix of all DoD branches and total force. FEMA's aid response was prioritized with the following actions (Larson et al., 2020):

- Conduct immediate life-saving operations
- Conduct debris clearance operations
- Reopen air and seaports
- Re-establish utilities
- Conduct outreach

•Implement Puerto Rico commodities distribution plan

•Conduct comprehensive and inclusive public messaging

•Develop a concept for reentry operations

•Obtain visibility of private industry to reestablish normal commerce

To narrow the aerial port operation response, the USAF's 621 CRW retained the capability to operate a Joint Task Force-Port Opening (JTF-PO). In this case, a tailored Contingency Response Group (CRG) was tasked with aerial port opening (Larson et al., 2020). According to Joint guidance, the decision placed heavy emphasis on locating logistic bases as close as possible to the relief recipients while simultaneously considering supply sources. (CJCS, 2019). The CRG is exceptionally trained with the Army's Rapid Port Opening Element (RPOE) owned by US Transportation Command (USTRANSCOM) to facilitate the offload of air cargo and passengers and proceed with their operations onward movement up to 10 kilometers from the airfield. Once complete, the RPOE establishes an interface with the theater distribution system (AFDP, 2019). That interaction and distribution was a focus for a potential bottleneck due to the roadway network in disarray. The CR members are trained to deploy to forward locations with nonexistent or insufficient air mobility support, thus requiring them to retain core capabilities, including control functions, communications, aerial port, and aircraft maintenance (AFDP, 2019). Once operations are reopened, they directly influence the flow into the aerial port and out. However, if reducing throughput capacity in one subsystem affects the capacity for the entire system, the Theory of Constraints (TOC) is applied (Green, 2019). This was the circumstance in this case with supplies not being able to be dispersed away from the aerial port. That said, the TOC defines a system's goal, performance measures, and constraints to seek system optimization by leveraging those features (Goldratt & Cox, 2014).

The aerial port opening of San Juan Luis Munoz Marin International Airport enabled a significant portion of the total of 650 flights logged by mid-October 2017 in support of crucial humanitarian efforts in what has been titled FEMA's coordinated response in one of the longest sustained disaster air operations in US disaster relief history (FEMA, 2018). Due to the critical nature and isolated residents, aid was often flown via helicopter or airdropped. FEMA data indicated a total of 700 airdrops or landings by mid-October 2017 to stranded storm survivors in order to deliver food and water pallets (2018). Operations continued into the next year with even more DoD assets being brought into play. To evaluate the applicability of VTOL UAVs, the DoD efforts in the northwest sector of Puerto Rico will be utilized in order scope operations to the Regional Staging Area (RSA). The entire island of PR was divided into nine RSAs.

Manning Unmanned Systems

The capabilities of operating unmanned aircraft have inherent pros and cons compared to flying manned aircraft. With automation, the decision-making is often completed without human input. By increasing autonomy, the operator workload will theoretically reduce due to minimizing the tasks for the operator, ultimately shrinking the interaction even at the highest levels of control (Cummings et al., 2007). Further studies have identified the human interaction that higher levels of automation actually degraded performance when operators attempted to control up to four UAVs (Cummings et al., 2007). It is important to classify when the human interaction is a required input. A UAV command and control study accomplished the effective management of automation for UAVs across the various level of automation. An example from their study of these levels is the management-by-consent and management-by-exception. The first is where a human must approve an automated solution before execution, and the latter is where the automation gives the operator a period to reject the solution (Cummings et al., 2007).

The authors provide insight into the study that management-by-consent automation provided the best situation awareness ratings, the best performance scores, and the most trust for controlling up to four UAVs (Cummings et al., 2007). This is an exciting insight that could be utilized to identify the number of people required to operate swarms of drones. The OSD's Unmanned Systems Integrated Roadmap 2017-2042 also mentions the importance of identifying the ability of unmanned assets to free up personnel. By increasing the autonomy and removing the constant human interaction, it reduces the operator's cognitive load allowing operators to make command decisions and perform other high-level tasks (Fahey & Miller, 2018). The increased autonomy will enable the unmanned system to achieve a greater range of tasks, further contributing to operational capability (Fahey & Miller, 2018).

Drone Capabilities

Even though the Unmanned Aerial Vehicle (UAV) capabilities today are far more advanced than they were in 2017, the data can be used to evaluate the technology for another HA/DR event in the future. The recent small unmanned aerial systems (sUAS) and battery technology have been leveraged in the larger UAV space. In December 2016, Amazon demonstrated the advancements at the time in a cargo-carrying drone electrically powered carrying 5 lbs. for a location 13 minutes away (LaGrone,2017). In 2022, the company Elroy Air has a drone capable of carrying 300 and 500 lbs. and uses its hybrid power source to fly up to 300 miles (Crumley, 2022). There are also logistical drones carrying up to 50-pound payloads from ship to ship being tested for operational practicality at sea by the USN (LaGrone, 2022). Even before 2017, there were proven uses of drones in humanitarian events. There have been emergency mapping UAV applications with several organizations producing maps and providing high-resolution imagery as part of disaster response or disaster risk reduction programming to assess damage information and population count estimations (Boccardo et al., 2015). Geographic information system officers utilize a real-world example of this at the Port-au-Prince, Haiti, which organized geographical data for displaced people collected by UAVs flying over camps to map those areas and monitor the number of tents post-hurricane (Swanson, 2015). Another proven capability is long-range drone deliveries being conducted worldwide with small weights by Zipline, a company utilizing an airdrop method (2022). Austere locations have been a motivator in developing use cases. In order to try to improve the emergency response to sudden cardiac arrests in mountainous regions, there have been attempts to create defibrillator drones (Gutjahr et al., 2020).

VTOL UAV Selected: Freedom Lift Innovation (FLI): Turtleback

Freedom Lift Innovation (FLI) is one of many automated VTOL drone companies within the industry that offers specialized capabilities. This company developed a drone titled "Turtleback" that tailors to military operations with wide range of payloads. The capability for the drone payload vs range is shown in Figure 2. The "Turtleback" is capable of ISR, distributing power, and conducting cargo delivery via sling load or containerization (Langley, 2021). The ISR component satisfies the main interest in damage assessment information and in population count estimation (Boccardo et al., 2015). Addressing that problem in the aftermath of a disaster will enhance geographic situational awareness, which is a critical success factor for disaster response (Gutjahr et al., 2020). The drone has been modified for DoD integration. The "Turtleback" was designed to fit 18 models in a C-17 (Figure 9) and to be quickly deployed for immediate operation (Langley, 2021). This capability enhances "tactical last mile" delivery. The appealing capability of "Turtleback" for the HA/DR role is the 250 Nautical Mile (NM) range carrying a payload of 2,000 pounds designed for operating 3,000 hours a year with an initial coast of 1.3 million dollars and operating cost of $247 per hour. (Langley, 2021). The "Turtleback" drone has a specification sheet built for the flexible DoD mission set.

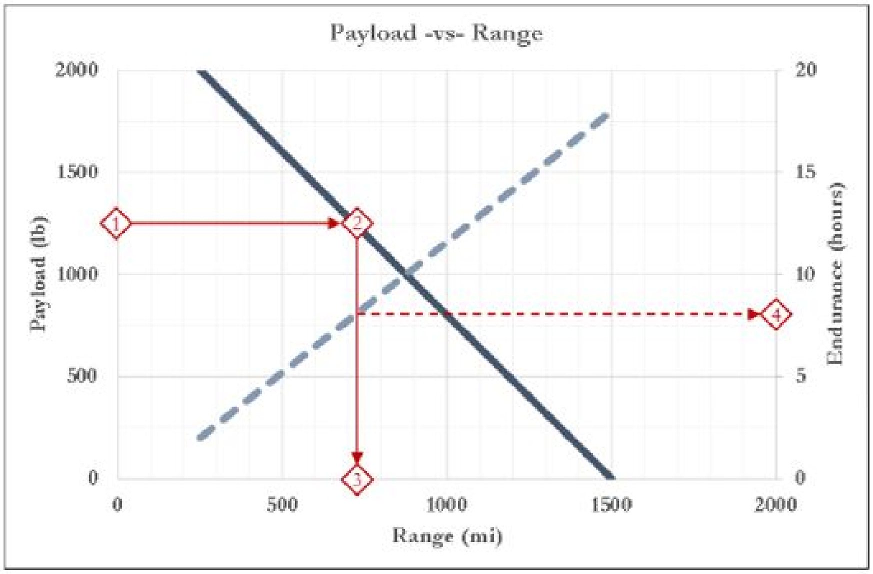


Figure 2. Freedom Lift Innovation's Turtleback Drone Payload vs Range (Langley, 2021)

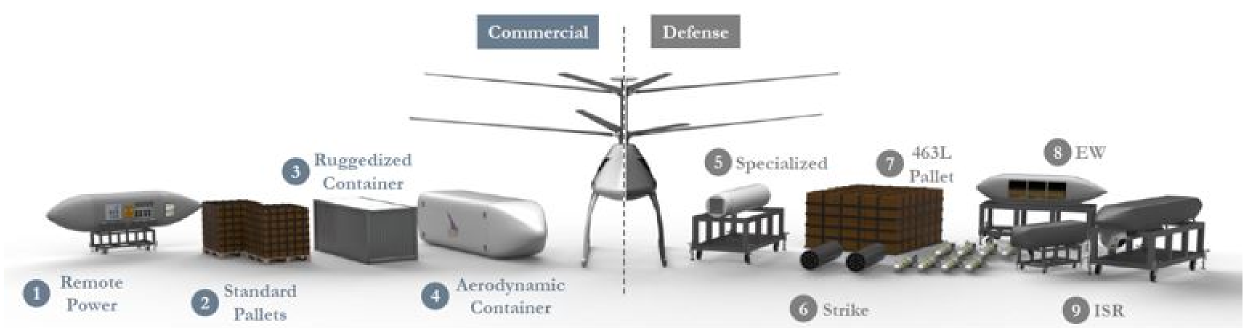
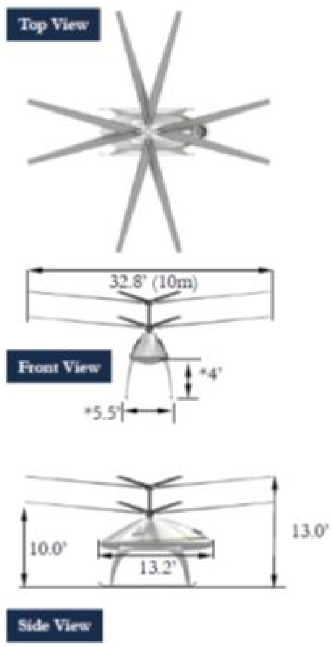


Figure 3. Turtleback Multiuse Roles

FLI's Turtleback Overview



Characteristic	Value
Certification	FAA Part 27 -or- MTC
Weights	MTOW 5,200 lbs; Empty 2,560 lbs
Usable Load	2,000 lbs (Payload) (100kVA Mission Power)
Range	250 mi (Payload) / 1400 mi (Ferry)
Cruise Speed	125 mph
Endurance	~3 – 18 hrs (Payload Dependent)
Altitude	20 kft Service Ceiling (12k HOGE)
Acoustics	~70 dB @ 100m
Powerplant	500 hp Heavy Fuel Hybrid Electric, 500 hp @ Rotor(s); 1,000 shaft hp available for 90 seconds
Fuel	Jet-A, JP, B20, SAF
Battery	5 min at full payload (~27kWh, 12C)
Operations	Level 4 Fully Autonomous Capability or Direct Control
Datalink	Low Latency BLOS (LEO Satellites) and WB LOS
Safety	Integrated weight and CG monitoring; 5 mins battery only flight + Autorotation Capability
Engine TBO	3,000 Hours
Vehicle Life	15,000 Hours

Figure 4. Freedom Lift Innovation's Turtleback Drone Design Overview (Langley, 2021)

Conclusion

HA/DR operations offer to be highly effective regarding utilization since it has a magnitude of applications due to its flexibility and reasonable costs. Several different mission sets can be rigged. Additionally, with the ability to utilize a single person to operate several UAVs, it gives the advantage of having a low footprint at an austere location.

Social acceptance of drone utilization needs to address the concerns of privacy and the access to airspace (Bravo et al., 2019). This study assumes that the environment is permissive due to the nature of the disaster and the need for assistance. Once all these issues are addressed, drones will certainly be much more secure, organized, and useful for humanitarian logistics (Bravo et al., 2019).

III. METHODOLOGY

Overall Research Design

This research utilizes a mixed-methods approach to analyze how HA/DR operations were conducted as a baseline for the integration of potential VTOL UAV operations. Inputs from subject matter experts (SMEs) provide an accurate perspective on the operational environment. The qualitative study of the historical event assists in understanding the operations and roles for military units. Additionally, the perspective of SMEs and company representatives regarding asset utilization enhanced understanding resulting in accurate model design. Information was derived from a previous research paper where interviews were conducted with several individuals from the Puerto Rican Port Authority, Federal Emergency Management Agency, Crowley Maritime, Tote Maritime, and Trailer Bridge shipping companies Guaynabo, Puerto Rico.

The fixed demand model (Model 1) was constructed to replicate the actual VTOL cargo movements conducted from the northwest sector of Puerto Rico, distributing inland to isolated residents. Model 1- Fixed Demand creates a replicated logistical sustainment environment based on case study data, which sets a fixed demand to the various sites for deliveries to be accomplished each day. The model then runs through three different aircraft for transport, two traditional VTOL assets and the VTOL UAV selected with their effective capabilities. The effective capability or capacity is not operating under ideal conditions; it has allowances taking into account downtime for maintenance or even weather in the realm of operating aircraft (Stevenson, 2018, p. 192). The results from Model 1 (Fixed Demand) displays what it will take to accomplish the required demand for each asset type with associated costs.

The next model is based on maximizing the design cargo carrying capabilities of the VTOL assets delivering with various numbers of each asset to ranging distances and population served, thus being a varying demand model. The design capacity operates under ideal conditions enabling maximum output for delivery (Stevenson, 2018, p. 192). Model 2 - Varying Demand will result in the total number of assets required to accomplish a HA/DR sustainment delivery of water and MREs with traditional and UAV VTOL aircraft based on USAID emergency minimum standards. This model ultimately provides a planner guidance on the minimum required amount of assets to accomplish water and food sustainment for a populous.

Research Execution

By matching the assumptions and limitations to the operating environment of the post-hurricane relief effort in the northwest RSA of PR, the model has a standardized environment for the modeled UAV to perform. First, Model 1- Fixed Demand was executed with the MV-22, HH-60W, and Turtleback UAV to see if the assets could accomplish the daily water and MRE sustainment for 34 days, just like the actual support recorded. Another model was created as a planning assistant because the Turtleback UAV displayed benefits when operating in the HA/DR environment compared to the other two traditional VTOL assets. Model 2- Vary Demand enables a planner to input the largest spoke distance from the planned hub and the supported population number to produce the minimum required number of MV-22s, HH-60Ws, or Turtlebacks to complete the derived daily demand. Model 2 can provide supporting data for decision-makers on whether to deploy traditional VTOL assets or the Turtleback.

IV. ANALYSIS AND RESULTS

Model 1: Fixed Demand – 2017 Hurricane Maria HA/DR Efforts from Aguadilla RSA, PR

The case study quantitative model was conducted through the AFWERX's Agility Prime analytical support team to highlight the capabilities of a VTOL UAV if the technology was available at the time of the DoD's response to the 2017 Hurricane Maria in Puerto Rico. The data and operating environment were specifically retrieved from the northwest sector of Puerto Rico. The models used were a hub and spoke evaluative model and point-to-point evaluative model conducted by LinQuest Corporation. The output displays the delivering capabilities, cost, and time associated with operations conducted by MV-22s, HH-60s, and the VTOL UAV selected, FLI: Turtleback. Furthermore, the modeling can compare the various assets to identify how many Turtlebacks would it take to equate to one MV-22 or HH-60 in the case study. The scenario is aimed to replicate the actual operations and discover if there are beneficial results derived from replacing the VTOL asset with FLI: Turtlebacks. The outputs of the number of assets, cost, and overall time required to meet the daily demand signal will enable a cross-comparison. This would allow insights if VTOL UAV technology were available at the time of the DoD's response to the 2017 Hurricane Maria in the northwest sector of Puerto Rico.

Model 1: Fixed Demand Data

Hurricane Maria's impact on Puerto Rico in 2017 and HA/DR efforts are well documented through federal reports and news articles. The review of these reports provided information regarding aerial deliveries conducted at the operational and tactical levels. The DoD was a supporting entity during the HA/DR efforts, and understanding their involvement with other governmental agencies assists with the whole government approach perspective. This data enables assumptions for the model in order to be authentic. It is vital to portray how HA/DR for

Puerto Rico post Hurricane Maria was conducted in order to cross-reference what it could be like with advanced technology implemented. Instead of focusing on the entire island of Puerto Rico, the study focused in the mountainous northwest region. Operations were established and conducted from the Rafael Hernandez International Airport (TJBQ), Aguadilla, PR. Multiple MV-22s were assigned to the region with a magnitude of mission sets, but one of the assigned missions included delivering humanitarian relief supplies to isolated residents. Members from the CRE deployed to that location were consulted for their subject matter expertise, and their viewpoints assisted with understanding the aerial port operations after the disaster. The data source used to emulate the cumulative delivery of water and food during the 34-day mission in the northwest Regional Staging Area (RSA) of PR resulted in 840 pallets of water and 892 pallets of food (DoD, 2017).

Model 1: Fixed Demand Assumptions/Limitations

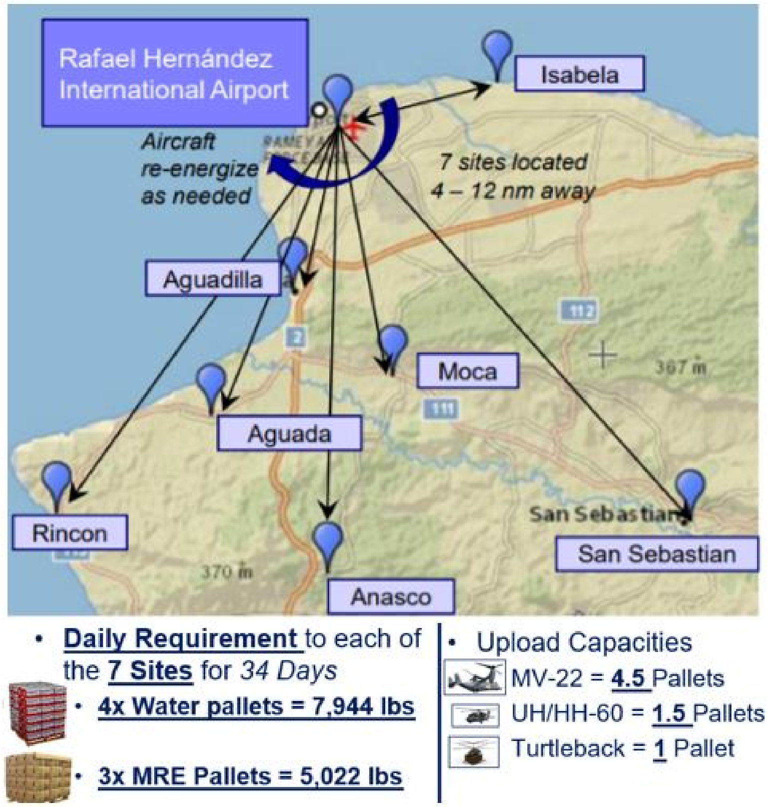


Figure 5. Seven Sites in Northwest Puerto Rico with Derived Demand & Carrying Capabilities

The fixed demand model has assumptions attempting to create a close resemblance to the operating conditions at the RSA hub established in Aguadilla, PR. Because the aerial operations lasted 34 days at RSA Aguadilla, the daily requirement was calculated and then equally distributed amongst the seven isolated sites, all of which were less than 15 nautical miles (NM) one-way from TJBQ. The data collected indicated a total of 1,693,440 .5 liter water bottles and 632,490 Meals Ready to Eat (MREs) were delivered to seven sites over a 34-day period from October 1, 2017 to November 4, 2017. This equates to a daily demand of 296 cases of 24 pack water bottles and 222 cases of 12-pack MREs to each site. In order to evaluate the use of the three VTOL assets, the cargo was standardized into a Water Pallet, and MRE Pallet load out. The Water Pallet consists of 74 cases of 24 packs weighing 1986 pounds (lbs.), and the MRE Pallet consists of 74 cases of 12 packs weighing at 1674 lbs. The pallet utilized is the Grocery

Manufacturers Association (GMA) wooden pallet measuring 40” x 48” x 4.5” and weighing 35 lbs. With the daily demand established, the daily requirement delivery to each site every 24 hours must be four Water Pallets and three MRE Pallets. That is a total of delivering 28 water pallets and 21 MRE pallets every 24 hours. The model will run the demand against the capabilities of each of the VTOL assets. If it is calculated to not to be possible by one asset, the model will continue to run with multiple similar assets to identify the minimum quantity needed to complete the daily demand.

During operations, it is assumed all preflight checks occur simultaneously with loading and/or refueling at the start of the day. Concurrent servicing operations are authorized allowing loading and refueling (when required) to occur simultaneously. Additionally, engine-running offloads are assumed at capable landing zones at each site and engine restart is included in the loading period. Additionally, each VTOL asset will run through the model with the following weather and aircraft maintenance assumptions.

The weather for TJBQ airport was analyzed with historical hourly Meteorological Aerodrome Report (METAR) information from October 1, 2017 to November 4, 2017. This study found for the manned assets, the weather minimum must be a visibility of greater than or equal to three statue miles and 3,000 feet of a cloud ceiling. For the unmanned asset, the weather minimums are one statue mile and 1,000 feet of a cloud ceiling. For both assets, they will not be in operation during thunderstorms. The total hours lost for manned assets average two-hour daily and unmanned assets lose .45 hours (27 mins) daily. Aircraft maintenance daily hourly deduction is based on the time it takes to complete preventive maintenance actions and inspections for flight for all three VTOL assets. Only light maintenance was performed during the modeled 34 days. It is assumed the MV-22 and the UH/HH-60 will consume two hours per day and the

Turtleback will be one hour per day. The effective availability of the manned assets are 20 hours a day, while the unmanned assets are 22.55 hours a day. It is assumed there will be sufficient staffing for all VTOL assets to conduct 24-hour operations with 12-hour shifts. In order to build an accurate model, there are further specific assumptions for each asset.

MV-22B

Figure 6. Humanitarian Aid Offload of MV-22 (Stelter, 2021)

-Total daily effective utility is 20 hours due to a loss of weather and aircraft maintenance assumptions

-Carry capacity limited due to volume: 4.5 Water or MRE pallets

-Crew requirement: 4 operators per aircraft for 12 hours

-Simultaneous load and refuel time: 15 mins

-Offload time: 10 mins

-Operational & Maintenance Reimbursement Cost per flight hour: $23,941

-Cost per asset: $92,918,269

-MV-22s have to be flown to the destination to support

For modeling purposes, the MV-22 is assumed to be in the conversion (CONV) mode while transiting to all locations based on the fact they are located less than 15 NM from the hub.

Because of the carrying capabilities of the MV-22, they take advantage of point-to-point delivery once they complete their daily requirement at a site.

HH-60W

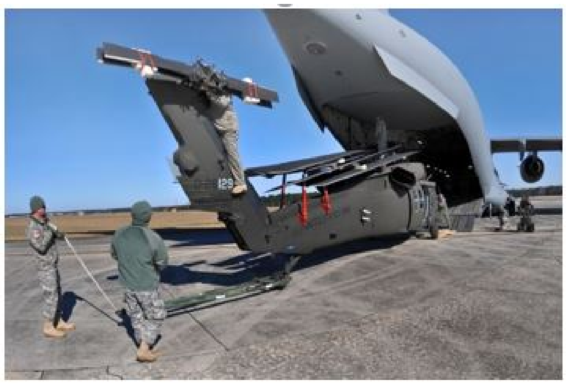


Figure 7. Upload of UH/HH-60 on C-17 Globemaster III (DoD, 2015)

-Total daily effective utility is 20 hours due to a loss of weather and aircraft maintenance assumptions

-Carry capacity limited due to volume and weight: 1.5 Water or MRE pallets

-Crew requirement: 4 operators per aircraft for 12 hours

-Simultaneous load and refuel time: 15 mins

-Offload time: 10 mins

-Operational & Maintenance Reimbursement Cost per flight hour: $10,514

-Cost per asset: $41,400,251

-Hub and spoke delivery unless capable of point to point once completing daily requirement at a site

-A C-17 can deliver 2x HH-60s

FLI: Turtleback

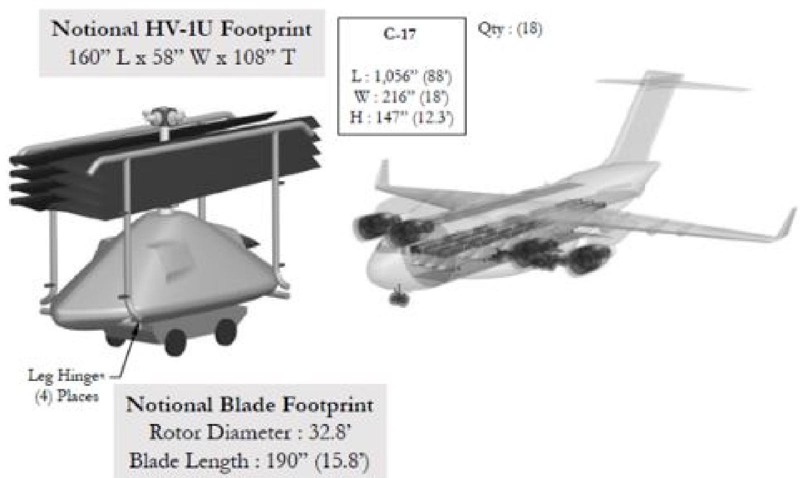


Figure 8. FLI Turtleback on C-17 Globemaster III (Miller, 2021)

Figure 9. FLI Turtleback with 463L Pallet (Miller, 2021)

-Total daily effective utility is 22.55 hours due to a loss of weather and aircraft maintenance assumptions

-Carry capacity limited due to weight: 1 Water or MRE pallet

-Crew requirement: 1 operator for every 4 Turtlebacks for 12 hours

-Simultaneous load and refuel time: 30 mins

-Offload time: 15 mins

-Cost per flight hour: $255

-Cost per asset: $1,300,000

-Hub and spoke delivery only

-A C-17 can deliver 18x Turtlebacks

In order to present the capabilities of automated VTOL UAV technology, the author reviewed 14 different UAVs within the advanced air mobility (AAM) industry with various propulsion sources to meet requirements. The FLI: Turtleback was selected to feature the best fit for the use case presented. Integration of the asset and mission effectiveness were the largest considerations in selecting the UAV for modeling. The Turtleback has features to include the ability to carry the military's standardized 463L pallets and Grocery Manufacturers Association (GMA) 40 by 48-inch pallets with a significant competitive payload and range capability. A significant assumption of this research is that the Turtleback UAV capabilities can perform the capabilities published and advertised from FLI.

Model 1: Fixed Demand Analysis

Model 1 was conducted with each asset type against the fixed daily demand, and the results indicated all of them could accomplish this mission set in their own scenarios. The results are charted in Table 1 for comparison. The results indicate the daily mission can be completed with the following number of each asset. It only takes one MV-22B to complete the daily mission, but it is noted it completes its point to point deliveries with a total daily mission time of 6.7 hours to include only 1.98 hours of flying, thus causing an idle time of no usage for 13.3 hours. It also only takes one HH-60W to complete the daily mission set, but it is being heavily utilized for 19.3 hours of the day. The Turtleback UAV is able to complete the mission set, but it requires three of them to operate. The three Turtlebacks accomplish the daily mission within 15.4 hours of the day flying an inclusive 7.4 total hours or roughly 2.5 hours each Turtleback. With an increase in the number of assets, it generally decreases the overall mission completion time for all VTOL assets. There are points in the data where the increased number of Turtlebacks does not decrease the daily mission time because they are simply not needed for the last delivery.

Table 1. Model 1 – Fixed Demand Results

	Number of Assets	Daily Flight Time for each Asset (Hrs)	Daily Dispatches	Daily Fuel Used (Gal)	Daily Operators Required	Delivery Complete?	Total Daily Msn Time (Hrs)	Daily Flight Times (Hrs)	Total Daily Loading Time (hrs)	Total Daily Unloading Time (hrs)	Daily Idle Time (Hrs)	Daily Mx & Wx Time	Daily Utilization %	O&M Cost Per Flight Hr	Daily Msn O&M Cost based on Flight Hrs	Total 34 Day Msn O&M Cost based on Flight Hrs	Total 34 Day Msn Time (Hrs)	Continous Operation for 34 day Req (Days to Completion)
MV22	**1**	**1.98**	**11**	**930**	**4**	**Yes**	**6.7**	**1.98**	**2.7**	**1.8**	**13.3**	**4**	**33.4**	**$23,941.00**	**$47,283.48**	**$1,607,638.15**	**227.1**	**11.4**
MV22	2	0.94	12	887	8	Yes	3.5	1.88	2.7	1.8	16.5	4	17.7	$23,941.00	$45,088.88	$1,533,022.03	120.2	6.0
HH60	**1**	**4.53**	**35**	**986**	**8**	**Yes**	**19.3**	**4.53**	**8.8**	**5.8**	**0.7**	**4**	**96.4**	**$10,514.00**	**$47,641.56**	**$1,619,813.13**	**655.6**	**32.8**
HH60	2	2.27	35	986	8	Yes	10.0	4.53	8.8	5.8	10.0	4	50.1	$10,514.00	$47,641.56	$1,619,813.13	340.4	17.0
TB	1	7.40	49	129	2	No	44.4	7.40	24.5	12.3	-21.9	1.45	197.2	$255.00	$1,887.00	$64,158.00	1508.5	66.9
TB	2	3.70	49	129	2	No	22.7	7.40	24.5	12.3	-0.2	1.45	101.0	$255.00	$1,887.00	$64,158.00	772.9	34.3
TB	**3**	**2.47**	**49**	**129**	**2**	**Yes**	**15.4**	**7.40**	**24.5**	**12.3**	**7.1**	**1.45**	**68.7**	**$255.00**	**$1,887.00**	**$64,158.00**	**525.3**	**23.3**
TB	4	1.85	49	129	1	Yes	11.9	7.40	24.5	12.3	10.6	1.45	53.0	$255.00	$1,887.00	$64,158.00	405.8	18.0
TB	5	1.48	49	129	2	Yes	9.3	7.40	24.5	12.3	13.2	1.45	41.3	$255.00	$1,887.00	$64,158.00	315.6	14.0
TB	6	1.23	49	129	2	Yes	8.3	7.40	24.5	12.3	14.2	1.45	36.8	$255.00	$1,887.00	$64,158.00	281.3	12.5
TB	7	1.06	49	129	2	Yes	6.5	7.40	24.5	12.3	16.0	1.45	28.8	$255.00	$1,887.00	$64,158.00	220.4	9.8
TB	8	0.93	49	129	2	Yes	6.5	7.40	24.5	12.3	16.0	1.45	28.8	$255.00	$1,887.00	$64,158.00	220.4	9.8
TB	9	0.82	49	129	3	Yes	5.6	7.40	24.5	12.3	16.9	1.45	25.0	$255.00	$1,887.00	$64,158.00	191.1	8.5
TB	10	0.74	49	129	3	Yes	4.8	7.40	24.5	12.3	17.7	1.45	21.3	$255.00	$1,887.00	$64,158.00	163.1	7.2
TB	11	0.67	49	129	3	Yes	4.7	7.40	24.5	12.3	17.8	1.45	20.7	$255.00	$1,887.00	$64,158.00	158.1	7.0
TB	12	0.62	49	129	3	Yes	4.7	7.40	24.5	12.3	17.8	1.45	20.7	$255.00	$1,887.00	$64,158.00	158.1	7.0
TB	13	0.57	49	129	4	Yes	3.8	7.40	24.5	12.3	18.7	1.45	17.0	$255.00	$1,887.00	$64,158.00	130.1	5.8
TB	14	0.53	49	129	4	Yes	3.8	7.40	24.5	12.3	18.7	1.45	16.8	$255.00	$1,887.00	$64,158.00	128.9	5.7
TB	15	0.49	49	129	4	Yes	3.8	7.40	24.5	12.3	18.7	1.45	16.8	$255.00	$1,887.00	$64,158.00	128.9	5.7
TB	16	0.46	49	129	4	Yes	3.8	7.40	24.5	12.3	18.7	1.45	16.8	$255.00	$1,887.00	$64,158.00	128.9	5.7

There are noticeable constant metrics within the results. The first to be explained is the constant flight hours. Because the daily mission set is fixed and the locations are fixed while operating a hub and spoke system, the flight hours do not change regardless of how many assets are participating. The seven sites at fixed flight distances result in constant flight hours, fuel used, and mission operational and maintenance (O&M) cost based on flight hours. The model calculated costs only during the operation of assets. No support, maintenance, or idle time costs were calculated in this study.

Additionally, the fixed number of hub and spoke dispatches results in constant loading & offloading time totals. The scenarios completing the demand provided the result of total dispatches or, in other words, aircraft launches from the hub. The single MV-22 would require 11 dispatches resulting in a takeoff every 37 minutes of their 6.7 hour mission. The single HH-60 resulted in 35 dispatches departing every 33 minutes of the 19.3 hour daily mission. The Three Turtlebacks accomplished 49 dispatches departing every 18.6 minutes of their 15.4 hours of operating. Even though the ground support personnel were not evaluated, the data can hint at the required workload for those at the hub need to consider the ground support element. With further filtering of data, several insights are revealed.

Filtering data to show a typical duty day of the assets displayed in Figure 11 highlights the true utilization of each asset during each run through the Model 1 - Fixed Demand. Generally, the MV-22s, whether it be one or two accomplishing the mission set, have a low utilization time operating, meaning they are the fastest. This is due to their ability to carry large amounts of cargo with longer ranges. The HH-60 can complete the daily deliveries with only one, but that is at the cost of being utilized 96% of the day based on the available operation window of 20 hours due to the weather and maintenance assumptions. The Turtlebacks were almost capable of completing the daily mission at 22.7 hours, but they did not make it within their 22.55 hour duty day. Three Turtlebacks were fully capable and completed the mission in 15.4 hours, resulting in a 69% utilization.

Another metric to quantify costs associated with the mission set is the total amount of operators required. The operators needed to accomplish the daily demand requirement per asset utilizes the specified personnel assumptions listed under each airframe. Figure 11 plots the variables of operators, assets, and hours required for the fixed daily demand operation. This figure presents the infeasible region with the mission being incomplete by one or two Turtlebacks. Figure 11 highlights the equivalency amongst the assets. This means the daily demand could be met by seven turtlebacks in similar time, 12 minutes faster, as one MV-22 performed with half the amount of operators. This of course translates to similar results with 14 Turtlebacks equating two MV-22s performance in daily mission time with again half the operator requirement. When comparing to the HH-60, five Turtlebacks with two operators complete the daily mission 45 minutes faster than two HH-60s with eight operators. Again, some of the Turtlebacks indicate the same performance with a larger amount of them. This is mainly due to the unneeded capability for the last delivery. The commonality in all of these comparisons is that the Turtleback completes the daily mission set under the demand's requirement at a significantly lower operating cost and personnel operating requirement.

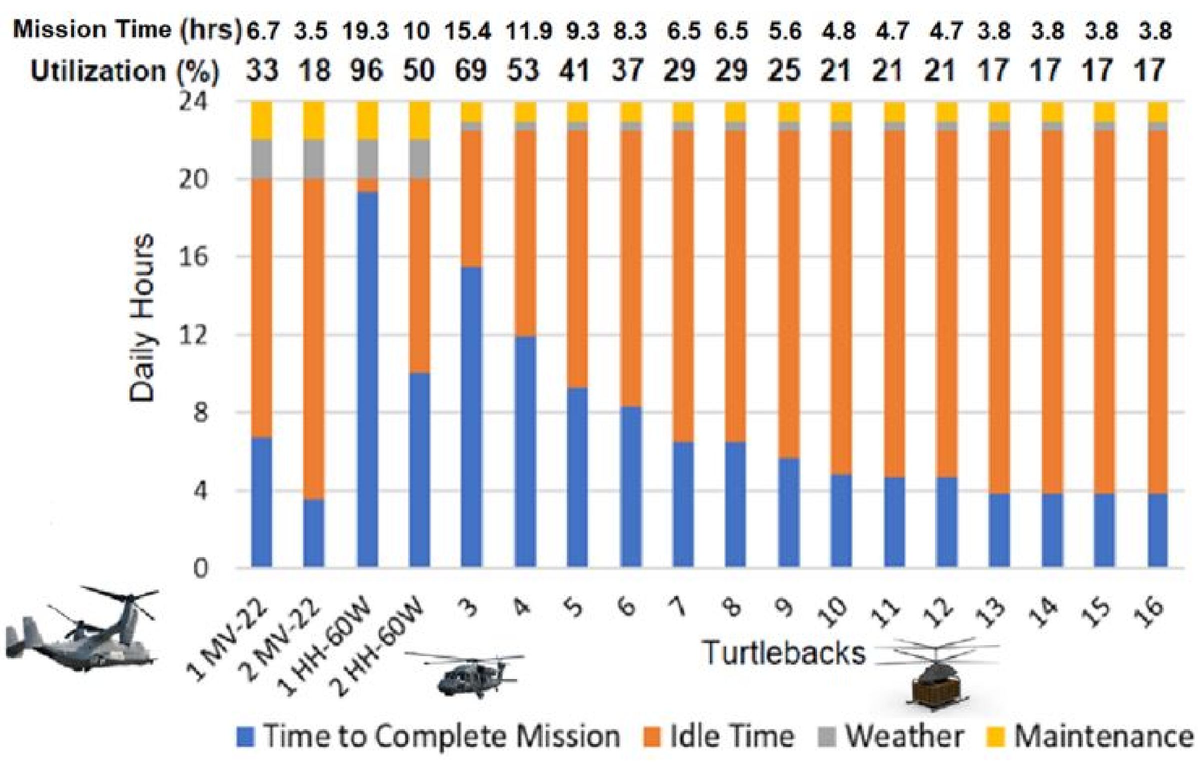


Figure 10. Daily Utilization of Assets

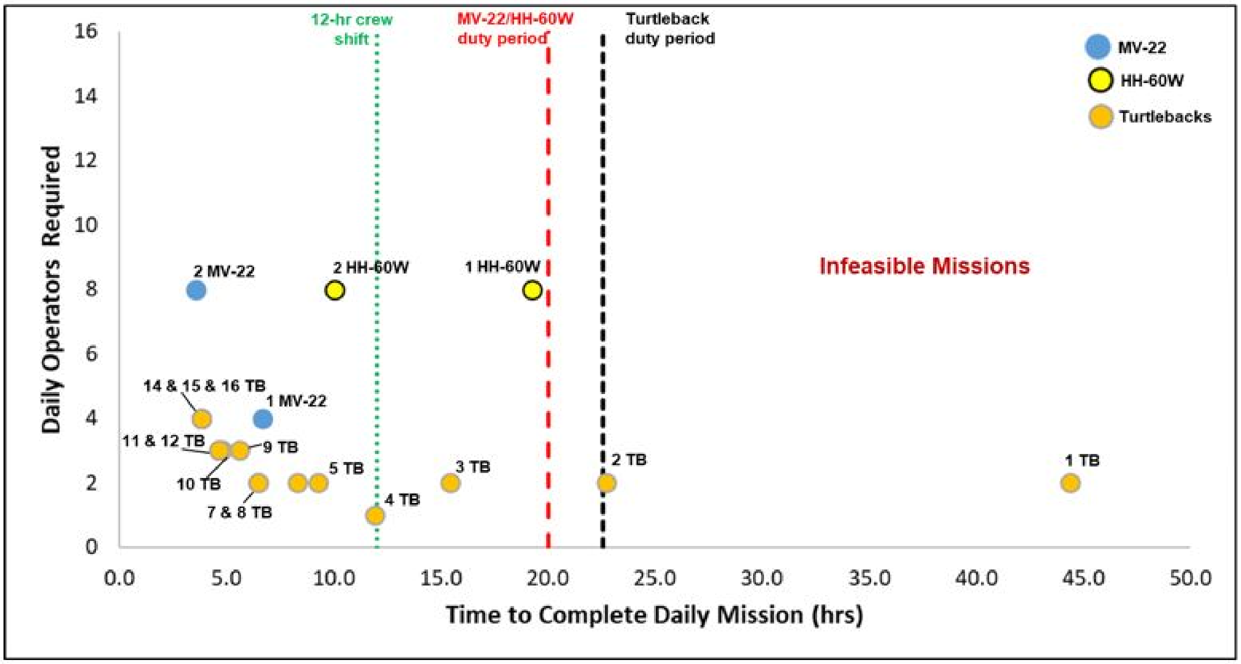


Figure 11. Number of Assets vs. Operators Required vs. Time to Complete Chart

The results in Figure 12, Figure 13, and Table 1 indicate an overall lower cost of 74%, operator requirement by 50%, and fuel expenditure by 86% to operate three Turtleback UAVs vs. traditional assets within the Model 1- Fixed Demand scenario. The three Turtlebacks complete the daily demand every day and have an excess capacity of 5.15 hours to perform other mission sets if needed. There is a high level of difficulty trying to anticipate the RSA's daily demand. Over-compensation often leads to a conservative decision to provide assets that can quickly perform the mission set with excess capacity. If the demand could be calculated and entered into a tool to provide an output of the total number of Turtlebacks needed, a planner could scale HA/DR efforts. Tailoring the response will lead to effective and efficient operations. In the case of Aguadilla RSA, there would have been an appropriate scalable response if the planner could identify three Turtlebacks for sustained logistics with time for multiuse roles. A C-

130, which can fit four Turtlebacks, could have been dispatched to TJBQ with three Turtlebacks and mission support personnel. Even in major maintenance issues, there would be little downtime because of the easy capability to add a Turtleback UAV on the cargo aircraft already inbound to replace it. Larger VTOL assets will likely need repairs on location, incurring significant delays and costs. In order to provide the planning calculations for this near-term VTOL UAV technology, Model 2 - Varying Demand was created to identify the operating space.

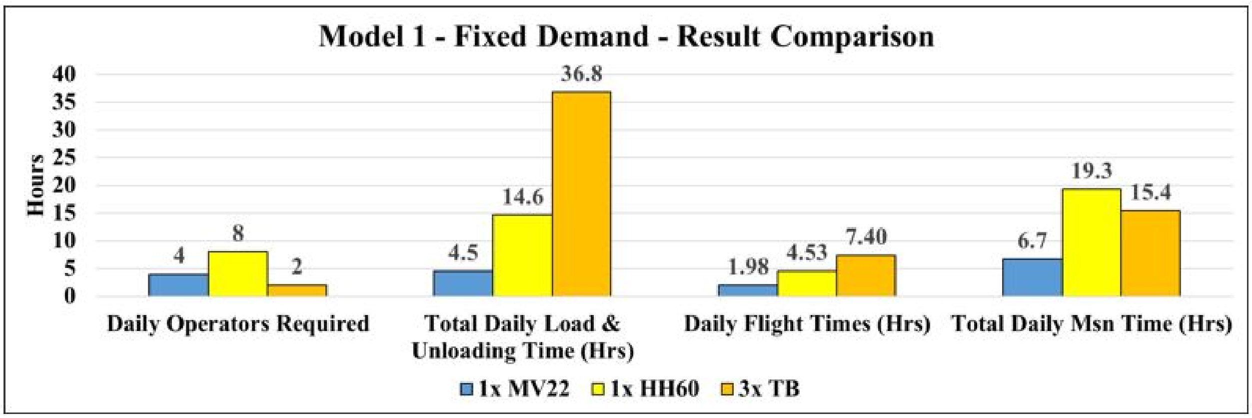


Figure 12. Fixed Demand Results

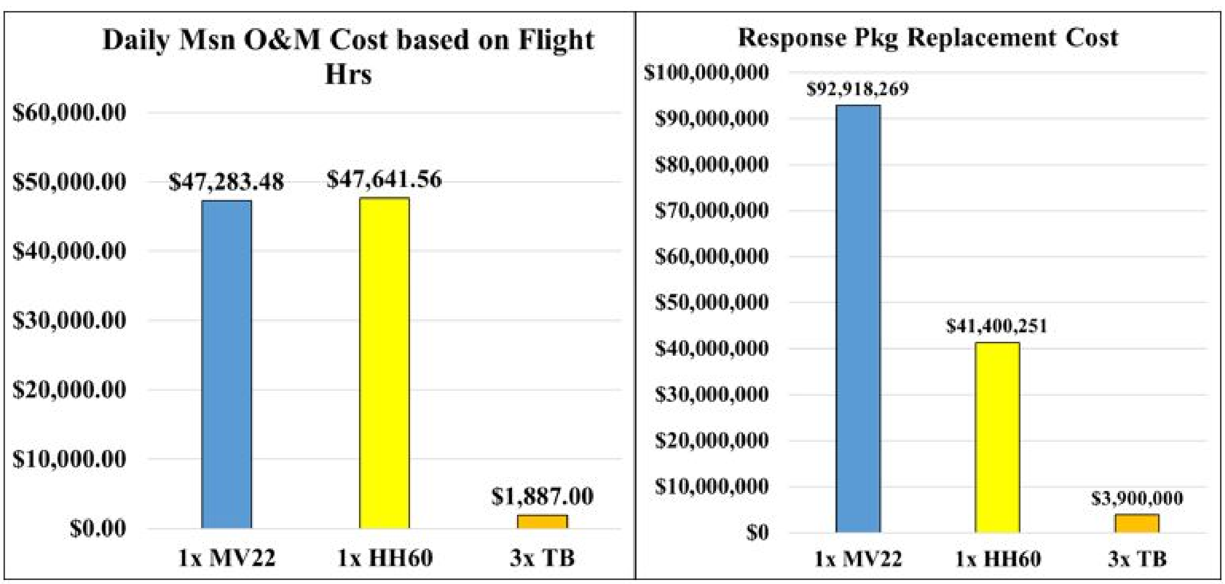


Figure 13. Cost Comparison

Model 2: Varying Demand "Planner's Tool"

Another quantitative model was constructed to utilize the maximum design capabilities of each VTOL asset within a 24-hour period. The output of the total number of trips based on varying distances is utilized for the varying demand model. The model places constraints on the carrying capacity of each VTOL asset. The user inputs the number of populous served and the maximum distance from the intended hub to the spoke. The output will present the total daily cost, number of assets needed to complete daily requirements, operators required, and cost of transporting each product to the isolated resident.

By running calculations highlighting the abilities of each VTOL asset in their maximum design capacity, it showed a clear comparison of the number of runs the asset could complete within a 24-hour period at varying distances and varying numbers of assets. The design capacity is operating under ideal conditions enabling maximum output for delivery (Stevenson, 2018, p. 192). The data identifies the maximum trips each asset type can make within a 24-hour period based on the number assets and distance from the hub varying from 25, 50, 75, 100, 150, and 200 NMs. The data enabled the generation of a reference table for the varying demand model. With the inputs of the total number of the population served and the furthest distance from the hub, an output is generated of cost and the minimum number of assets needed to fulfill the daily demand at the two specified variables. By changing either variable, it will change the required demand for the sites. Finally, the variables were run through a sensitivity analysis to derive further insights.

Model 2: Varying Demand Assumptions/Limitations

The assumptions listed previously are mostly applied besides the weather and aircraft maintenance assumptions. This model is limited in design to only represent hub and spoke operations. In order to calculate the number of trips, the model will utilize the same assumptions for uploading, refueling, and offloading as previously stated from the fixed demand model. With the MV-22, the aircraft is assumed to be flying in CONVERSION mode in the 25 and 50 NM runs, but in AIRPLANE mode for the rest. With the Turtleback, the only different assumption is that any one-way distance over 100 NMs will have the ability to refuel at the spoke to make it back to the hub. In order to identify the requirements based on each person, the USAID provides direction to provide 15 liters and 2100 calories a day (USAID, 2005, p. III-11 & 48). Every time the number of the population served was changed, the total cargo requirement changed. Additionally, any change in the distance from the hub to spoke changes the cargo's ability to transport. When the population is inputted with the distance, a total number of MREs and Water is calculated, which is broken out to how many load outs are required based on each asset's capability. The load outs are then added together and compared to the data table of the assets' run capability identified earlier. By finding the number of runs on the table, there will be an associated number of assets needed. The model has no cargo standardization amongst the three types of assets. All three assets have different load outs dependent on their carrying design capacities. The load outs are assumed for the weapon systems listed in Table 2.

Table 2. Carrying Capacity Assumptions

	MV-22	HH-60	TB
Capacity Limit	Volume 335 Cu Ft	Volume 111.7 Cu Ft	Weight 2000 lbs
Max MREs Capacity	4,824	1,608	1,056
Max Water Bottle Capacity	8,771	2,924	1,800

Model 2: Varying Demand Analysis

The varying demand model or "planner's tool" was produced in order to provide planners with a minimum baseline of assets required to support the "last tactical mile" of deliveries via VTOL assets. The sole basis of the water and food needs of the isolated residents is the determining factor of the cargo to be delivered. Based on the humanitarian requirements of 15 liters and consuming 2100 calories a day, this tool will output how many bottles of water and MREs are needed a day (USAID, 2005, p. III-11 & 48). In order to build a data set for the sensitivity analysis, a varying combination of population inputs and the maximum one-way distances were calculated. The number of sites is not a determining factor of demand since the total population number is considered. In combination, the limiting factor is the number of people and distance associated with the furthest site. If there are several sites with disparity from the maximum distance, then the planner may want to explore the option of separating the population and placing two runs into the tool for more accurate number of assets required. The following Model 2 – Varying Demand data was produced for comparison of MV-22, HH-60, and Turtleback capabilities.

In order to identify equal comparisons to the max capability of a single MV-22, Figures 14, 15, and 16 are presented. By viewing the data on Figure 14, it can be interpreted the single MV-22's maximum capability in delivering to 50 NMs is capable of supporting 4,900 people and at 200 NMs supporting 2,600 people. By taking the number of people being supported and cross-referencing Figure 16, it is clear it would take seven Turtlebacks for 50 NMs and ten Turtlebacks for 200 NMs. As for the HH-60, Figure 15 displays it would take three at 50 NMs and five at 200 NMs. This provides an interesting perspective to know how many assets it would take to reach the equivalent of a MV-2 performing the mission.

Figure 15 displays the minimum required amount of turtlebacks to operate to meet the demand based on the population served and the distance they are located from the hub. Additionally, the blue bars indicate the number of Turtlebacks that can fit inside the C-130 and C-17 cargo bays. Therefore, it can be inferred a single C-130 load of four Turtlebacks can support a 25 NM one-way distance serving 2200 people, additionally, at 100 NMs serving 1400 people and at 200 NMs about 800 isolated residents. The same can be done with the C-17 and other distances if included in the data table.

Another key point to the sensitivity analysis charts is the ability to identify the available range of capacity for the number of assets and one-way distance flown. Figure 17 displays a clear picture and an example of how it is identified that the addition of a Turtleback delivering to a spoke 50 NMs away is capable of increasing the service population by roughly 700 people each time. The deviations from the 700 population interval are due to a calculated rounding of required runs. This, of course, could be accomplished for the MV-22 and HH-60 as well.

Figure 14. Min MV-22s Required to Support Population at Varying One-way Distances

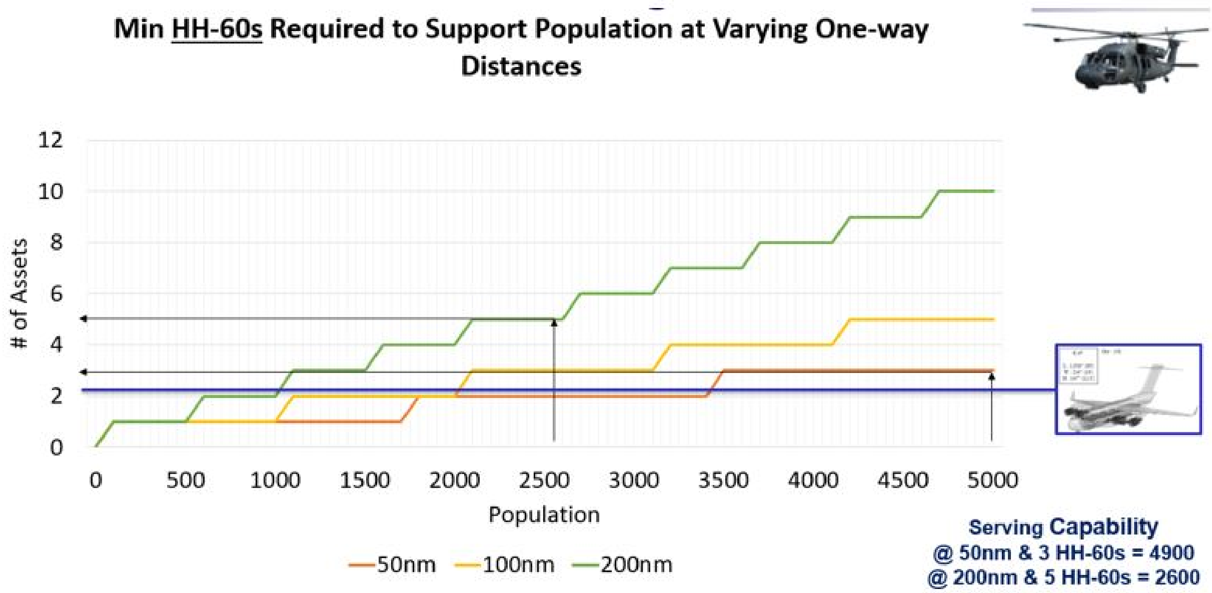


Figure 15. Min HH-60s Required to Support Population at Varying One-way Distances

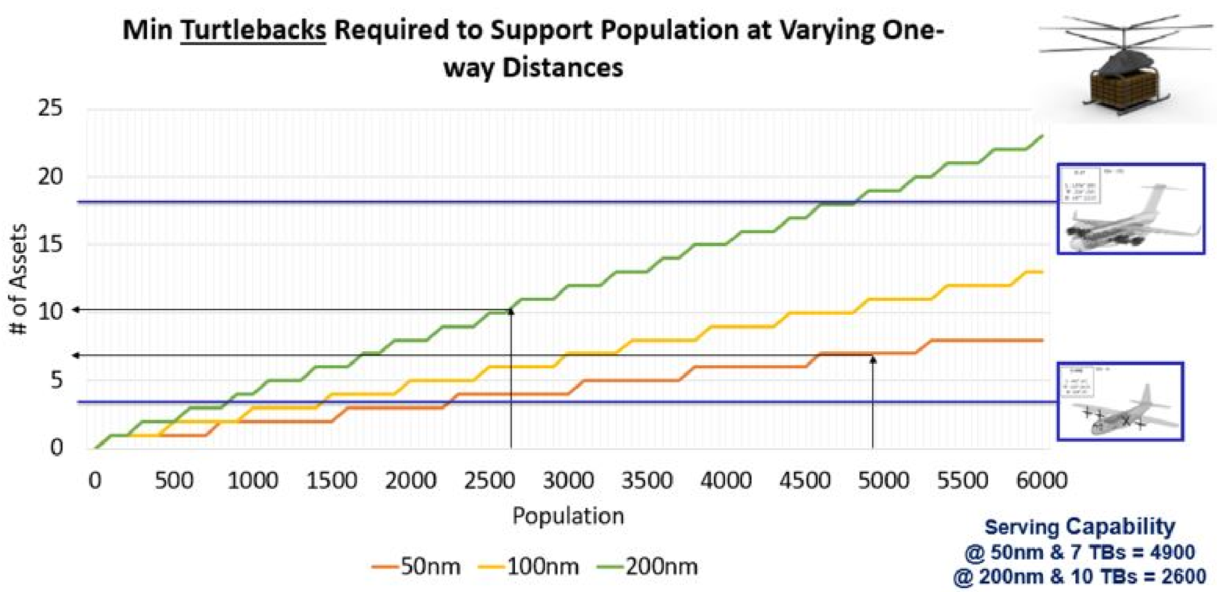


Figure 16. Min Turtlebacks Required to Support Population at Varying One-way Distances

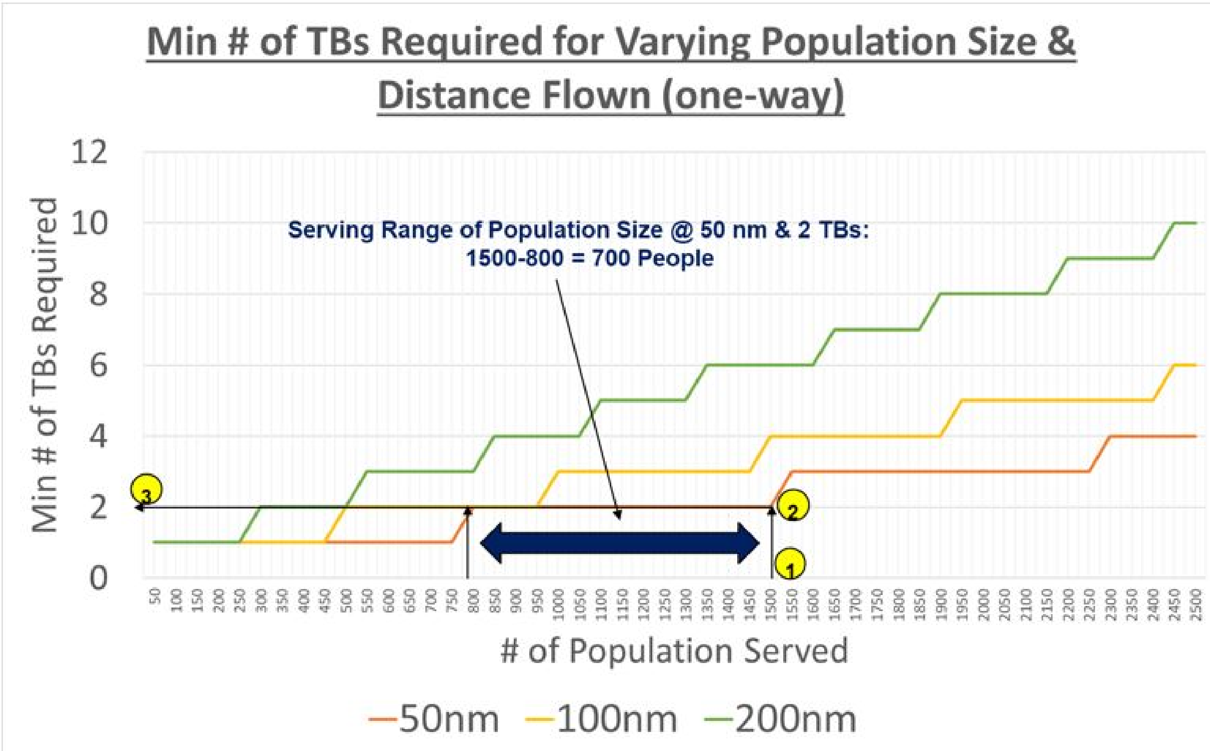


Figure 17. Turtleback Servicing Capability

Application

By overlaying the capabilities of emerging VTOL UAV technology into current HA/DR efforts, it presents the applicability to real-world events offering a different perspective on accomplishing the mission set. This concept can be continually applied until the UAV technology meets the DoD requirements and it is cost beneficial. On December 21, 2021, Tonga experienced the beginning of a volcano eruption, which progressed to cause destruction. To respond to the HA/DR requirement for Tonga, a planner can utilized the Model 2 – Varying Demand model in tailoring the DoD's response. For example purposes, the population served would be the population affected by the volcano on the island Eua. Eua's population is estimated to be 4,903 people and located 23 NMs away from the main island of Tonga. With that information, the planner can plug it into the model for the applicable outputs assisting in the decision for a response package. Figure 18 provides a graphical representation of the region and Table 3 presents the result comparison amongst MV-22, HH-60, and Turtleback.

Figure 18. Graphic of Tonga and Island of Eua

By utilizing Model 2, a planner can tailor the response package with the minimum number required of assets based on type. Because the Fua‘amotu International Airport (NFTF), location on Tonga can support C-130s or a C-17, Turtlebacks or a HH-60 package can be employed. However, by looking at the results, it is more cost-effective to employ five Turtlebacks with an operator requirement of three. Each day's total cost in operating hours would be $11,112.39, which is 78.5% cheaper than employing two HH-60s. One C-17 could fit the Turtleback employment, support elements, and humanitarian aid ready for delivery. This of course is a situation where VTOL UAVs would be very agile, efficient, responsive, and appropriately scaled. What type of situation would the Turtleback may not be scalable?

There are operating conditions that are beyond the feasible capabilities of the Turtleback because of its relatively short range and payload capacity compared to other VTOL assets. Table 4 provides a perspective of a larger scale HA/DR operation where the population is supported in 20,000 and the furthest distance is 200 NMs. Because of the efficient operation and lack of staffing needing to operate Turtlebacks, the cost is much lower while requiring a large employment force of 42 Turtlebacks and 21 operators. That type of employment would require three C-17 deliveries worth of equipment. Additionally, the ramp space required to base the assets would be based on the rotor diameter of nearly 33 feet for each Turtleback landing in a 40 by 40 foot area. The physical MOG will likely be met, and the working MOG of the support personnel would be substantial.

Table 3. Model 2 Results for Tonga Example

INPUTS				
Population Served	4903			
Max Dist from Hub	25	nm		
OUTPUTS				
Total Daily Humanitarian REQ:				
Req amt total MREs/per day	9806	MREs		
Req amt total water liters/per day	73545	Liters		
	TB	**HH60**	**MV22**	
# Required to meet daily demand	**5**	**2**	**1**	
# of Operators Required	**3**	**16**	**8**	
Total Loadouts (Rounded up)	92	57	19	Runs
Total Weight (lbs)	180712.7	177079.5	179711.9	lbs
Cost per day to operate TBs	$11,112.39	$238,207.81	$279,311.67	
Delivery Cost per MRE	$0.11	$2.60	$3.01	
Delivery Cost per .5L Water Bottle	$0.07	$1.43	$1.66	
Ute Rate per Orb (Hrs used a day)	0.96	0.98	0.97	%

Table 4. Model 2 Results for Large Scale Example

INPUTS				
Population Served	20000			
Max Dist from Hub	100	nm		
OUTPUTS				
Total Daily Humanitarian REQ:				
Req amt total MREs/per day	40000	MREs		
Req amt total water liters/per day	300000	Liters		
	TB	**HH60**	**MV22**	
# Required to meet daily demand	**42**	**20**	**5**	
# of Operators Required	**21**	**160**	**40**	
Total Loadouts (Rounded up)	372	231	77	Runs
Total Weight (lbs)	737151.5	722331.3	733069.3	lbs
Cost per day to operate TBs	$176,862.39	$3,942,750.00	$1,938,080.95	
Delivery Cost per MRE	$0.45	$10.61	$5.16	
Delivery Cost per .5L Water Bottle	$0.26	$5.84	$2.84	
Ute Rate per Orb (Hrs used a day)	0.97	0.99	0.97	%

V. CONCLUSION AND RECOMMENDATIONS

Overview

This research provides insight into how a VTOL UAV would perform within the 2017 Hurricane Maria relief efforts in the RSA of northwest PR compared to traditional assets. Basing the data off the case study for the Model 1- Fixed Demand provided a relatable operational environment for Turtleneck to perform. The model results implicated a significantly lower daily cost of $1,887.00 and operator requirement of two operators with three assets compared to traditional assets while completing the sustainment logistical daily demand of delivering 49 pallets of water and MREs to seven different sites. That cost is roughly 74% less than a single MV-22B with four operators or 74% less than a single HH-60W with eight operators as if they were conducting the daily demand in their individual scenarios. Model 1 identified that three Turtlebacks completed the same mission compared to MV-22s and HH-60s with time available to execute other mission sets if needed. It did reveal the increased requirement of dispatches, but that is due to the lower carrying capability and range of the Turtleback. The modeled Turtleback results reveal a potentially large element for upload and download support indicating a limiting factor in the case of large-scale movements. Because benefits were derived, Model 2 – Varying Demand was constructed to build a tool for planners to have another asset to consider when identifying scalable responses to HA/DR events.

Model 2 enabled insights on points of equalization amongst the MV-22 and HH-60 capabilities, along with the ability to identify the range of capability on one-way distances for supporting the populous with food and water. The capabilities spectrum on all three-weapon systems allows a quick comparison of what asset to employ. Depending on what capabilities are needed in the area of operation, the planner can adjust their decision based on the data. Are they looking for the most effective and fastest response? In that case, it may be the MV-22. If they are looking for assets to complete the sustainment logistics by the required time at a low cost, then Turtlebacks may be the answer.

Continual Contribution

With an automated VTOL UAV delivery force, the package can be customized to each event, making it highly scalable. This is beneficial to the point of maximization where the UAVs hit a level surpassing the support structures capabilities in place. That includes the ramp space, airspace availability, and working maximum on ground (MOG) capability. Using the Turtleback's capability for large-scale movements with heavy weights with a carrying capability of 2,000 lbs. to 250 NMs, will result in severe congestion amongst the support structure. As the capabilities increase over time with cargo UAVs, the model can be updated to explore its benefits. Furthermore, Model 2 can also be utilized to discover further insights if there were different cargo scenarios involving ammunition, base support items, or medical supplies.

Recommendations

Based on the complete results of the study, from both models there is a trade space for VTOL UAV operations within the DoD carrying cargo. The packages being easily deployable via C-130s and C-17s gives it an agile response to HA/DR events at a low cost. Running the VTOL UAV assumptions through the USAF traditional planning provides the perspective of what if they were available to use. This is especially true for supporting 621 CRW operations responding to the event. The Turtlebacks could deploy with members supporting their assessment in the beginning and then providing logistical sustainment deliveries until the lines of communication are cleared for traditional ground deliveries. Providing that much capability to the response team will enable rapid deliveries to those isolated residents in need after a natural disaster.

Use of Model 2 – "Planners' Tool"

This study established the reality of the growth of VTOL UAV technology and capabilities. Implementing planning practices including that growth could provide insights into what it could be like if the USAF had a drone delivery force. DoD entities monitoring the growth and considering it in their planning practices, will be ready for the moment of implementation.

Turtlebacks for Multirole Use

Because the Turtlebacks are already on location and will likely not be utilized for the entirety of the day, they could be utilized for other mission sets. The Turtleback has a flexible capability to be configured for different roles. If the initial team arriving at the HA/DR event is transported via a C-17, there is the capability to bring several Turtlebacks. The drones could be launched to support the initial reconnaissance mission set to identify the area's damage. Once that is established, the Turtleback could provide simultaneous security and relay for communications. Meanwhile, other Turtleneck are already starting rapid deliveries to those in need. The lower cost per asset is a scalable force multiplier with minimum manning requirements.

Future Research

With the ever-rapid development of the AAM industry, the capabilities available will likely meet the requirements of the DoD. What are those requirements, or when will the time be for investment by the DoD? Both are great topics for exploration. Updating research on the upcoming capabilities and developing models on how operations would perform will be vital in preparation for implementation. This study attempted to do just that and create a tool to adjust to the developments. Another means of looking at the DoD requirements may be researching several case studies based on the HA/DR event deriving demand. It can be taken further and done with combat operations with intra-theater DoD airlift. An aspect that is often overlooked and worth further studying is the military's social interactions with the VTOL UAVs delivering cargo during upload and download. With the several trips that are currently required by drone capabilities, a study in how swarms of automated UAVs would operate in the various airspace types and during their VTOL operations at austere vertiports.

Appendix A: Model 2 - Varying Demand Model

INPUTS		
Population Served	20000	
Max Dist from Hub	100	nm
Humanitarian REQ Guidance:		
Req amt per person/per day	2	MREs
Req amt per person/per day	15	Liters
Total Daily Humanitarian REQ:		
Req amt total MREs/per day	40000.00	MREs
Req amt total water liters/per day	300000.00	Liters

Turtleback (TB)										
MREs			TB	**MRE**			TB	**WATER**		
# of MRE Loadouts Needed/per day	37.88	Loads		1984	lbs			1986	lbs	
Total Daily Weight Moved/per day	75151.52	lbs		88	12 Pack cases			75	24 Pack cases	
				1056	Meals			1800	Water Bottles	
Water								900	Liters	
# of Water Loadouts Needed/per day	333.33	Loads								
Total Daily Weight Moved/per day	662000.00	lbs								
Total Loadouts (Rounded up)	372.00	Runs								
Total Weight	737,151.52	lbs								
TB Required to meet daily demand	**42**									
Cost per day to operate TBs	$176,862.39									
Ute Rate per Orb (Hrs used a day)	0.97									
Delivery Cost per MRE	$0.45									
Delivery Cost per .5L Water Bottle	$0.26									

UH60				**MRE**				**WATER**		
MREs			HH60	111.6666667	cu ft	Found 1.5 dimensions - found how many boxes	HH60	111.6666667	cu ft	Vol based on MRE cubing out
# of MRE Loadouts Needed/per day	24.88	Loads		134	cases			121.8181818	cases	
Total Daily Weight Moved/per day	73819.44	lbs		2967.541667	lbs			3160.021645	lbs	
				134	12 Pack cases			121.8181818	24 Pack cases	
Water				1608	Meals			2923.636364	Water Bottles	
# of Water Loadouts Needed/per day	205.22	Loads						1461.818182	Liters	
Total Daily Weight Moved/per day	648511.90	lbs								
Total Loadouts (Rounded up)	231.00	Runs								
Total Weight	722,331.35	lbs								
# HH-60 Required to meet daily demand	**20**									
Cost per day to operate	$3,942,750.00									
Ute Rate (Hrs used a day)	0.99									
Delivery Cost per MRE	$10.61									
Delivery Cost per .5L Water Bottle	$5.84									

MV-22				**MRE**				**WATER**		
MREs			MV22	335	cu ft	Found 4.5 dimensions - found how many boxes	MV22	335	cu ft	Vol based on MRE size
# of MRE Loadouts Needed/per day	8.29	Loads		402	12 pack cases			365.4545455	cases	
Total Daily Weight Moved/per day	74980.31	lbs		9042.625	lbs			9620.064935	lbs	
				402	12 Pack cases			365.4545455	24 Pack cases	
Water				4824	Meals			8770.909091	Water Bottles	
# of Water Loadouts Needed/per day	68.41	Loads						4385.454545	Liters	
Total Daily Weight Moved/per day	658089.02	lbs								
Total Loadouts (Rounded up)	77.00	Runs								
Total Weight	733,069.33	lbs								
# MV22 Required to meet daily demand	**5**									
Cost per day to operate	$1,938,080.95									
Ute Rate (Hrs used a day)	0.97									
Delivery Cost per MRE	$5.16									
Delivery Cost per .5L Water Bottle	$2.84									

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
03/06/2022

2. REPORT TYPE
Graduate Research Paper

3. DATES COVERED *(From - To)*
July 2021 - June 2022

4. TITLE AND SUBTITLE
Leveraging Vertical Take-off & Landing (VTOL) Unmanned Aerial Vehicle (UAV) Technology for Humanitarian Aid & Disaster Relief (HA/DR): The “Last Tactical Mile”

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Sugalski, Adam J, Maj

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology
Graduate School of Engineering and Management (AFIT/EN)
2950 Hobson Way
Wright-Patterson AFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT-ENS-MS-22-J-055

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
AMC/A4
Brig. Gen. Darren Cole (darren.cole@us.af.mil)
Building P-40 (A4, P, Q):
510 POW/MIA Dr
Scott AFB, IL 62225-5011

10. SPONSOR/MONITOR'S ACRONYM(S)
HQ AMC/A4

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A. APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED.

13. SUPPLEMENTARY NOTES

14. ABSTRACT
This paper examines the 2017 Hurricane Maria HA/DR VTOL delivery efforts in the mountainous northwest sector of Puerto Rico (PR) and utilizes near-term VTOL UAV technology in a fixed demand model to derived results to analyze. Additionally, the study covers a varying demand model for the VTOL assets to generate data for a scalable HA/DR response planning tool assisting decision makers.

15. SUBJECT TERMS
Drone Delivery, Last Tactical Mile, Advanced Air Mobility (AAM), Cargo Delivery, Vertical Takeoff and Landing (VTOL), Unmanned Aerial Vehicle (UAV), Humanitarian Aid and Disaster Relief (HA/DR)

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
					Col Jason R. Anderson, AFIT/ENY
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