Proceedings of the Annual General Donald R. Keith Memorial Conference
West Point, New York, USA
May 4, 2023
A Regional Conference of the Society for Industrial and Systems Engineering

Unmanned Aircraft System Swarm Decision Aid

Ami Kim, Thomas Martineau, Olivia Petty, Connor Rex, and Gary Lazzaro

Department of Mathematics
United States Naval Academy
Annapolis, Maryland 21402

Corresponding author's Email: lazzaro@usna.edu

Author Note: Most authors are undergraduate Operations Research students at USNA. CDR Gary Lazzaro, USN is the faculty advisor and the project sponsors are Andy Chapman, J.B. Baron, and Craig Doescher of MITRE Corporation. The students acknowledge the sponsorship of MITRE via the Office of Naval Research (ONR). The views expressed herein are those of the authors and do not reflect the position of the United States Naval Academy, the Department of the Navy, or the Department of Defense.

Abstract: This paper analyzes the use of small, low cost, Unmanned Aircraft System (UAS) swarms armed with Javelin warheads to engage land-based vehicle targets. Our project analysis shows that swarms of low-cost UAS can be as effective as more expensive weapons platforms. The use of small UAS swarms against enemy tanks equipped with defense systems can be evaluated and compared to current methods of tank destruction. Our Excel tool provides an analyst a decision tool that calculates numbers of kills for various scenarios. The tool considers which UAS are available to the user, the target type, size, and distance, and any present enemy defense systems. The tool also calculates the cost of each swarm and determines the optimal size and number of waves of UAS to employ. The goal of the tool is to inform decision makers in a challenging environment with limited time and resources.

Keywords: Swarm, Unmanned Aircraft System, Tanks

1. Introduction

ONR requires a decision aid that provides the most effective way for the United States Marine Corps to employ small UAS swarms against enemy targets. The decision aid evaluates three small UAS platforms against enemy targets that might include UAS counter-defense systems (confetti systems, shotgun nets, or both). The decision aid provides the probability that the UAS successfully damages or destroys a group of enemy tanks or vehicles. It is flexible enough to allow the user to include additional UAS platforms, assuming the appropriate parameters are known. The decision aid is a user-friendly Excel tool that delivers information necessary for enemy engagement decisions.

2. Context Analysis

2.1 Current Situation

The United States Marine Corps is capable of destroying enemy tanks and supply vehicles by launching Hellfire or SPEAR3 missiles from aerial platforms or by launching Javelin missiles from the ground. However, these approaches are costly and/or require close proximity to the enemy. In fall 2020, ONR created Project Overmatch, an initiative aimed at integrating more unmanned systems in all domains through data collection and management. One goal of Project Overmatch is to improve the capabilities of small UAS swarms to overwhelm and destroy enemy targets at low cost.

2.2 Objectives

The objective of this project is to develop an Excel-based decision aid that enables the user to input information about his or her specific mission. These inputs include but are not limited to: platform type, number of platforms available, target type, number of targets, distance to target, counter UAS systems, and budget. Based on these inputs, the tool determines the ideal swarm size, number of swarms, and platform type to accomplish the user's mission goal. The tool utilizes an editable database that includes information for each UAS platform available to the user. The tool's database holds data on three UAS, though additional platforms may be added.

3. Terminology and Resources

The three LOCUST platforms that are evaluated in the decision tool are the Notional UAS, the Hylio AG-110, and the Event 38 E-450. Figure 1 and Table 1 show the 3 UAS considered by our tool.

Table 1. Specs for Low-Cost UAS platforms considered in Excel decision tool

Platform	Cost	Launch Method	Maximum Speed	Endurance	Payload Capacity
Notional UAS	$4,995	Hand-launched	40 mph	150 minutes	8.7 pounds
Hylio AG-110	$22,462	VTOL	40 mph	50 minutes	30.4 pounds
Event 38 E-450	$35,000	VTOL	36 mph	90 minutes	15 pounds

Our tool considers two possible Counter-UAS systems that may be used by an enemy force. Confetti Systems are C-UAS systems used to disable one or more of a drone's propellers. A cloud of strong, streamer-like material spreads out in the air to catch in a propeller blade, making the drone unable to fly. Shotgun Nets are C-UAS systems that are employed via 40mm projectile launchers. Nets are shot out to ensnare drones, causing them to fall to the ground. Our tool assumes that an enemy force can only use each C-UAS system only once.

Small UAS swarm is the concept of multiple UAS working in conjunction to accomplish a collective goal using decentralized communication. Low-Cost UAS Swarming Technology (LOCUST) enables a swarm of UAS to work together to accomplish a specific mission. The UAS use machine-to-machine (M2M) communication and follow a swarming algorithm based on separation, alignment, and cohesion. The model's goal for a small UAS swarm is to overwhelm enemy defense systems and accomplish the same task of destroying a target with different, cheaper assets than what the U.S. Marine Corps currently uses, such as a Hellfire missile. For a land-based vehicle attack scenario, the cost of small UAS swarms to destroy an enemy target will be determined and compared to an arbitrarily chosen budget of $5 million. The UAS platforms can carry the weight of a Javelin HEAT warhead, which is included in the cost analysis of the drones.

The FGM-148 Javelin is a portable anti-tank missile manufactured by Raytheon Technologies Corporation and Lockheed Martin Corporation. It utilizes fire-and-forget technology, which enables the user to take cover immediately after launch because the missile uses automatic infrared guidance to reach its target. The FGM-148 Javelin is equipped with a high-explosive anti-tank (HEAT) warhead that is effective against modern tanks by top attack. Top attack ensures that the missile hits the tank where its armor is thinnest to have the greatest impact on the target. According to data provided by Naval Surface Warfare Center Crane, the HEAT warhead weighs 7.37 pounds, which is within the carrying capacity of the platforms featured in our model. This allows each UAS platform to carry a $178,000 HEAT warhead, raising the total cost to $182,995 per Notional UAS, $200,462 per AG-110, and $213,000 per E-450.

ISBN: 97819384964-4-8

Notional UAS AG-110 E450

Figure 1. Low-Cost UAS platforms considered in Excel decision tool

4. Model Data and Design

4.1 Assumptions

The model assumes that UAS are equipped with a Javelin HEAT warhead and follow a LOCUST swarming algorithm based on standardized rules of separation, alignment, and cohesion. The AG-110 and E-450 can be launched between 1 and 3 minutes via VTOL, and all may be launched simultaneously if desired. The Notional UAS is hand-launched and takes between 1 and 2 minutes to launch each UAS. The model assumes that UAS platforms experience mechanical failures approximately 20% of the time, similar to commercial drones. The model accounts for randomness in the failure rate through slight deviation from 20% each time it is run. The model assumes that enemy C-UAS systems are known and will be used any time a UAS is detected. Based on empirical testing data provided by Naval Surface Warfare Center Crane, Confetti Systems effectively disable UAS 90% of the time and Shotgun Nets effectively disable UAS 20% of the time. A single Javelin HEAT warhead is assumed to perform a total kill when engaging a soft target (i.e. support vehicle). When engaging a hard target (i.e. tank), the warhead assumption is 1 hit for a mobility kill, 2 hits for a firepower kill, and 3 hits for a total kill.

4.2 Model Design

4.2.1 Data Collection

The 'Data Collection' tab is a database for information about the UAS platforms. It includes: price, total number within the given budget, payload capacity, endurance, speed, launch method, wingspan, and weight. At any time, the user may add more platforms and corresponding information into the relevant columns shown in Figures 3a and 3b.

Platform	Price (USD)	Price with Javelin Warhead	# total (with given budget)	Payload capacity (lbs)	Endurance (min)	Cruise Speed (mph)
Notional UAS	4995	182995	27	8.7	150	40
Hylio AG-110	22,462	200462	25	21	50	22
E-450	35,000	213000	23	15	90	36

Figure 3a. Data Collection Tab User Inputs

Platform	Max Speed (mph)	Launch Method	Wingspan (ft)	Weight	Other
Notional UAS	50	hand-launched	6.42	5.3-14 lbs	
Hylio AG-110	40	Vertical Take-off	3	24.5 lbs (without battery)	1 mile transmission range; 5+ unobstructed
E-450	40	Vertical Take-off	14		

Figure 3b. Data Collection Tab User Inputs Continued

4.2.2 User Inputs

For each scenario, the user must use the Input tab to enter the mission goal and UAS specifics shown in Figure 2.

Platform	Number Available	Distance to Target [miles]	Target Type	Number in Column	Number Tanks	Number Support Vehicles	Counter UAV Systems	Budget
Notional UAS	27							
Hylio AG-110	25	25	Mixed Column	14	7	7	Confetti System	$ 5,000,000
E-450	23							

INPUT HERE:				
Set Total Budget:	5000000	USD	**Recommended Platform:**	**Notional UAS**
Set Distance to Target:	25	(miles)		
Set Target:	Mixed Column			
Set Number Tanks:	7	(tanks)		
Set Number Support Vehicles:	7	(support vehicles)		
Set Counter UAS Systems:	Confetti System			
Set Mission Goal:	**Maximize Individual Target Destruction**			
Mission Key:				
***Total Target Engagement** - prioritizing hitting every vehicle in the target column. This means not every vehicle may be a total kill, but every vehicle will be hit. Most effective against a majority of support vehicles.*				
***Individual Target Destruction** - prioritizing the destruction of an individual vehicle in the column before moving on. UAVs will ensure that each engaged vehicle will be destroyed, but not every vehicle may be engaged. Most effective against tanks.*				

Figure 2. User Input Tab

For each mission, the user must specify the budget, distance to target, type of C-UAS systems, number of targets, and the mission goal. If any of these inputs are unknown, it is up to the user to enter reasonable information based on his or her prior knowledge and specific situation. The tool will recommend a platform based on these inputs.

There are two options for the mission goal: Total Target Engagement and Individual Target Destruction. Total Target Engagement prioritizes hitting every vehicle in the target. This mission goal is most effective against a column of support vehicles. Individual Target Destruction prioritizes the complete destruction of an individual vehicle in the column. UAS will ensure that each engaged vehicle will be completely destroyed before moving on. This is more useful against tanks, which may require more than one hit to be destroyed.

5. Results

The decision tool enables the user to compare at least three different types of UAS. Based on inputs, the Excel tool returns results that can help the user determine the total number of UAS to employ, number of swarms to employ, number per swarm, total cost to employ, and the numbers of different types of kills. Figure 4a compares the overall probability that a UAS reaches the target when launch waves are not utilized vs when launch waves are utilized. Figure 4b shows the damage table and calculations used to determine the probability of different types of kills based on set conditions.

Section 1: Reaching the target. This section of the model compares using one wave vs multiple waves, and is dependant on the enemy's counter-UAS systems. The user starts by selecting one platform. This launches an analysis of the inputs section to determine the most successfull number of waves to use. Ultimately, this section chooses between one or mulitple waves, in order to maximize the probability of reaching the target.

			Percent Mech Fail:	**0.16165928**	**Percent Lost to Counter UAS Systems:**	**0.8468636662**		
	Without Using Waves:							
	Platform	Launched	*Mech Fail*	Remainder	*Defense Systems Fail*	**Reaching Target**	P_ReachingTarget	**Overall P_ReachingTarget:**
	Tiburon	27	*4*	23	*19*	**4**	0.146	**14.64%**
	Total Number	Wave 1	Wave 1 Size	Wave 2	Wave 2 Size	Wave 3	Wave 3 Size	
	27	Yes	9	Yes	9	Yes	9	
	Using Waves:							
Platform Selected:	Wave #	Launched	*Mech Fail*	Remainder	*Defense Systems Fail*	**Reaching Target**	P_ReachingTarget	**Overall P_ReachingTarget:**
Tiburon	1	9	*1*	8	*6*	1	0.110	**62.22%**
	2	9	*1*	8	*0*	8	0.878	
	3	9	*1*	8	*0*	8	0.878	
	Total	**27**	**4**	**23**	**6**	**17**		

Figure 4a. UAS swarm wave analysis in Excel tool

Damage Table			
Category	Description	Number UAVs Required (Tank)	Number UAVs Required (Support Vehicle)
Mobility Kill	Unable to move	1	1
Fire Power Kill	Unable to shoot	2	1
Total Kill	Inoperable completely	3	1
Damage Assessment:			
Mission Priority:	*Maximize Individual Target Destruction*		
Number UAVs Reaching Target:	17		
Number Allocated to Each Category of Vehicle:	10	7	
	Tanks	Support Vehicles	
Number in Target	7	7	
Number Mobility Kills	1	0	
Number Fire Power Kills	0	0	
Number Total Kills	3	7	

Figure 4b. Enemy damage calculations in Excel tool

In our scenario budget of $5 million, the model calculates the results shown in Table 2.

Table 2. Model Results

Recommended Platform	Mission Goal	Time Constraint	Number of Mobility Kills - Tank	Number of Fire Power Kills - Tank	Number of Total Kills - Tank	Number of Mobility Kills – Support Vehicle	Number of Fire Power Kills – Support Vehicle	Number of Total Kills – Support Vehicle
Notional UAS	Individual Target Destruction	No	1	0	3	0	0	7
Hylio AG-110	Individual Target Destruction	Yes	0	0	3	0	0	7
Notional UAS	Total Target Engagement	No	3	2	0	0	0	7
Hylio AG-110	Total Target Engagement	Yes	5	1	0	0	0	7

Each time the model is run, the results change slightly due to variance in mechanical failure and launch times. To model launch time variance, we ran a Monte-Carlo simulation of 4000 iterations of hand-launch times between 1 and 3 minutes per Notional UAS. For 27 Notional UAS, it produced a bimodal distribution with an average launch time of 30 minutes, with peaks at 23 and 35 minutes. We used this information to incorporate a condition in the model that determines whether the Notional UAS can be used in a time-constrained mission. The model's results are shown in the Outputs tab, and will aid the user in determining which platform is best for his or her mission before beginning the attack.

6. Future Work

In the future, the team is looking to refine the time consideration in the model. Currently, the Notional UAS cannot be used in a time-constrained mission due to its longer launch times. However, this could be improved by creating an input that allows the use to specify his or her time limit. That way, the Notional UAS may not always be ruled out. Additionally, it could rule out all UAS options if the time limit is extremely short. The team would also like to apply small UAS swarm analysis to maritime scenarios. This would include tactics, techniques, and procedures for the surface drone fleet engaged in a battle at sea against a target of small boats.

7. Conclusion

The decision tool helps an analyst to model low-cost UAS swarm attacks in a land-based scenario. A UAS swarm presents a successful, cheaper option than the current U.S. Marine Corps air assets such as an F-35B, which are equipped with SPEAR3 anti-tank missiles, or the AH-1Z and AH-1W, which employ Hellfire missiles. It is also cheaper and more covert than using current UAS platforms such as the MQ-9, which is much bigger in size. Moreover, utilizing small UAS lowers the risk to high value assets and U.S. personnel. This tool increases the user's ability to effectively employ small UAS swarms by providing accurate estimates of target destruction in accordance with the user's mission goal.

8. References

Brown, Jennings (2019). The US Army is Developing a Grenade That Nabs Drones with a Net. https://gizmodo.com/the-u-s-army-is-developing-a-grenade-that-nabs-drones-1832430881

Dual RC. (n.d.). Elanus Duo - Ready to Fly. https://www.dualrc.com/elanus-duo/rtf

Hylio Inc. (2020). *Hylio Ag-110 UAS Spec Sheet.* https://static1.squarespace.com/static/5fda5e32e32eb9353e52a7cc/t/623230dd3840d71ce523c699/1647456478711/AG-110+Spec+Sheet+Imperial.pdf

Event 38. (n.d.). Introducing the E450. https://event38.com/fixed-wing/e450-vtol-drone/

Liszewski, A. (2021). DARPA's Latest Defense Weapons Knocks Drones Out of the Sky Using Advanced…Confetti Streamers? https://gizmodo.com/darpas-latest-defense-weapon-knocks-drones-out-of-the-s-1847080837

Richardson, J. (2017). The Coming Drone Swarm. https://www.defenceprocurementinternational.com/features/air/drone-swarms

ISBN: 97819384964-4-8