AIR COMMAND AND STAFF COLLEGE
AIR UNIVERSITY

STUNNING SWARMS:
AN AIRPOWER ALTERNATIVE TO COLLATERAL DAMAGE

By
Alan E. Blanchard, PhD, Major, USAF

A Research Report Submitted to the Faculty
In Partial Fulfillment of Graduation Requirements

Advisor: Lt. Col. Terry L. Bullard

Maxwell Air Force Base, Alabama

April 2010

Disclaimer

Table of Contents

Figures

Abstract

This paper proposes and advocates the concept of Micro-Air Vehicle Incapacitating Swarms (MAVIS) as an effective non-lethal capability for irregular warfare as well as other spectrum-of-warfare applications. The intent of MAVIS is to provide an alternative to the conventional USAF arsenal that typically produces unacceptable collateral damage in the COIN/IW (counter-insurgency/irregular warfare) fight. Collateral damage has proven counterproductive to winning the hearts and minds of the populace afflicted with the cancer of insurgency/terrorism. Due to the difficulty in determining the exact targets in a dynamic urban environment or in any situation with imperfect intelligence, MAVIS will be used in an "area attack" fashion to administer metered doses of medication to subdue combatants as well as nearby civilians. Rendered unconscious from the fast-acting and long-lasting medication, the insurgents/terrorists will be removed from the populace while sedated, processed to gather intelligence, and permanently separated from the people. MAVIS will deny insurgents/terrorists their cherished martyrdom, allowing the threatened government to process them as it sees fit.

"Air power contains the seeds of our own destruction."[1]

-- General Stanley McChrystal, Oct 2009

I. Introduction

To this author, the quote above reflects an absolute frustration with the singularly destructive options presently available in the airpower arsenal. For the first time in its history, the awesome offensive firepower of the USAF has been rendered combat ineffective (in many situations in Afghanistan). The enemy did not have to enter the skies to silence our guns or neuter our bombs; they simply hugged the beltline of the population. The USAF typically presents ground commanders a binary option to stop combatants for the full spectrum of combat operations: kill all within a given radius (typically large in terms of the human damage potential), or do nothing. It's clear that, in the vast majority of instances, General McChrystal would have the USAF do nothing. This is unacceptable to any airwarrior and should be a call to acquisition arms – we must acquire new, relevant capabilities and get back into the fight! In its present form, US airpower, the unparalleled master of the conventional, lethal air fight as demonstrated in Desert Storm and Allied Force, is desperately in need of non-lethal capabilities well-suited for the "fog and friction" (especially imperfect intelligence) and the zero-defect mentality of the COIN/IW (counterinsurgency/irregular warfare) fight. This paper proposes one such possible answer, MAVIS (Micro-Air Vehicle Incapacitating Swarms), that would provide a desired airpower capability for future General McChrystals and would enhance airpower's ability to provide war-winning capabilities in COIN/IW fights. Much like a disappointed school teacher, this author believes airpower advocates and purse string-pullers have not been applying themselves to their COIN/IW non-lethal work. They are avoiding their responsibilities to effectively support the COIN/IW mission in the same way their forefathers avoided their responsibilities to effectively support the CAS (close air support) mission after WWII. Despite

budgetary constraints, the USAF can and must do better. It took two major conflicts, Korea and Vietnam, before the USAF got serious about CAS and fielded the A-10 Warthog, an aircraft with legendary military effectiveness. By the same token, how many more COIN/IW conflicts will the US be involved in before the USAF gets serious about developing *dedicated* (non-ISR) COIN/IW capabilities? This does not have to be a zero-sum game with conventional force acquisition. Using cheaper, "right-tech" solutions for COIN/IW will preserve expensive, high-tech platforms for the conventional fight with a peer or near-peer adversary. At the very least, it is hoped that this paper provides airwarriors food for thought on potential non-lethal capabilities and helps break the paradigm that airpower is only relevant to the USAF when wingspan measures in feet.

A. Airpower and Collateral Damage

You can't beat physics. The USAF flies with bombs that range from hundreds to thousands to tens of thousands of pounds, not to mention the nuclear arsenal. The USAF is the premier purveyor of potential large-scale global destruction. And the fragile bags of rosy liquid we call humans don't do well when confronted with blast, crush, and high-velocity shrapnel forces produced by USAF armament. Collateral damage inevitably ensues when conventional USAF firepower is called into action, especially in an urban environment.

a. Conventional Warfare

In a conventional fight, too much, in this author's opinion, is going on to be primarily concerned with collateral damage. Yes, there is usually a standard edict to minimize collateral damage whenever possible, but the primary emphasis is on defeating the conventional enemy. This is as it must be. Avoiding collateral damage is a luxury afforded states not in a fight for their survival. Consequently, for the US, conventional warfare typically does not focus

exclusively on minimizing collateral damage. It's a concern, but it's not the be-all, end-all. If we're fighting for the survival of our constitution and our way of life, all bets are off.

b. COIN/IW

On the other hand, everything changes when we go into COIN/IW conflicts. Although the US is regularly targeted for terrorist attacks, COIN/IW fights and their struggles for government legitimacy don't affect our sovereign soil: we're typically helping out some other state in crisis. It's their fight and we must never forget it; Vietnam is a tragic example of what happens when we did forget it. The United States is presently fighting two irregular wars, in Iraq and Afghanistan, and the relevance of the US Air Force's conventional capabilities is in question: do these unequalled, awesome USAF conventional capabilities help or hurt the irregular war effort? We are fighting insurgents/terrorists (I/Ts) who hide among the population,[2] using innocents as shields, daring us to use our might to capture or kill them. Following the laws of war and carefully crafted rules of engagement, the USAF finds, fixes, and finishes I/Ts using unmatched precision and restraint. I/Ts die, but unfortunately we also cause "collateral damage," a euphemism for dead civilians and destroyed housing/infrastructure. Following an air strike, the images of tiny, dismembered, crimson-stained bodies appear like clockwork in the media, television, internet, DVDs, and print, as propaganda against America. These emotional images can then inspire the generation of more I/Ts, creating a perpetual irregular war. The USAF has taken significant steps to limit collateral damage; for instance, the development and fielding of the small diameter bomb.[3] At 250 pounds, it promises precision and a smaller radius of destruction.

But collateral damage, no matter how well-controlled the bombing, continues, along with its negative impact in the hearts and minds of the locals we are trying to protect. It is not

surprising that General Stanley McChrystal, commander of US forces in Afghanistan, has severely restricted aerial bombing to limit Afghan collateral damage. Moreover, these COIN/IW fights are not an aberration: they are representative of what General Rupert Smith calls "the reality of our new form of war"[4] characterized by conflicts that endure for years or decades where "we fight among the people."[5] Given this, it may be concluded that the USAF needs new capabilities relevant and tailored to the thick of the irregular fight. MAVIS is one promising non-lethal capability worthy of consideration.

B. Overview of Research Question and Thesis

This research began with the question of "the feasibility of incapacitating swarms to subdue combatants and limit collateral damage" and was motivated by the increased sensitivity that our liberal (from an international relations perspective), globalized world has developed with respect to the unintended killing of civilians during military operations; i.e., collateral damage. Since the fall of the Soviet Union, the US has gained hegemonic status in the world while communications technology has allowed for rapid distribution of images and video of any military actions. As a result, US military actions are of global interest and are immediately broadcast around the world. Unfortunately for airwarriors, their engagement options are generally limited to observing enemy activity through an exceptional array of ISR systems in air, space, and cyberspace, and then responding with munitions or not responding at all. Their main decision: kill or not kill. This deadly binary decision, especially in a TIC (troops in contact) scenario, must often be made with less than complete intelligence in a matter of seconds; e.g., "Who else is in that house?" In this author's view, a dearth of options seems available for airwarriors —we certainly need a viable, humane option between doing nothing and killing everyone. From these concerns and the research question stated previously came the thesis for

this paper: *"Swarms of micro-UAVs (unmanned air vehicles) administering chemical incapacitants are a feasible and value-added COIN/IW capability to subdue combatants and limit collateral damage."*

C. MAVIS Vignettes

The following vignettes are provided to flesh out the MAVIS concept and show the utility of MAVIS (or similar airborne non-lethal capabilities) in military operations. They also show how the MAVIS systems will expand from initial ground use in the Army to use with USAF fixed-wing delivery systems, like the MQ-9 Reaper or the Joint Strike Fighter.

a. Urban Patrol

SrA Hetfield couldn't believe he was back in the Middle East. It took him a year to be officially deemed a conscientious objector -- and less than a week to be reassigned as an operator of some brand-new MAVIS system to finish out his six-year commitment. This was not what he had planned. But after six months of joint training as a "Guardian" (the MAVIS operators were given this nickname because their mission was to guard the citizens in military operations against kinetic responses) at Ft. Sam Houston and Lackland AFB in Texas, he developed a seemingly bizarre mix of infantry, medical, intelligence, and technical skills needed to effectively employ the MAVIS system: infantry skills, because he was to be embedded into grunt units, either Army or Marine; medical skills, because MAVIS "knocked out" the civilians as well as the insurgents for hours, and he had to recognize the signs of distress brought about by the incapacitant to properly respond with antidotes (Hetfield had himself been "knocked out" as part of his training); intelligence skills, because he would often be the first one on the scene to search combatants for maps, documents, electronic gadgets, or media. And, of course, he

needed technical skills to operate and maintain this swarm of six Frisbee-sized UAVs--the standard set- up for the MAVIS system.

This was the day of his first mission, an urban patrol, with the US Army grunts and their Iraqi counterparts. They had humped this route numerous times and knew many locals by name. A level of trust had built up, just as the senior military leaders had predicted. The citizens were turning to the better peace that the Iraqi government, with American support, was offering. The insurgents wouldn't stand for this – they needed to have some civilians killed at the hands of the Americans and had carefully planned their operation. It would all be recorded and posted on the web.

Going through his pre-mission checks was always fun and tended to gather a crowd. Hetfield would first check the battery life and expiration dates on the "black Frisbees" – the UAVs were pre-packaged with the incapacitants when he initially picked them up from the Med Group. He just needed to check the date to ensure the incapacitants were still good and make sure the batteries were charged. Then the fun began. To check the operation of the system, he loaded the six UAVs into what looked like a tube-shaped rucksack. They were laid on top of one another like a stack of pancakes into the spring-loaded tube. He strapped on the ruck, bent slightly forward at the waist, and pulled the ripcord by his side. Immediately, all six disks were thrust into the air, their motors started automatically, and they established a hover roughly three feet above and behind him. To an outsider, the erratic hovering motions of each individual disk made it seem something was wrong, but this was designed to ensure snipers wouldn't have an easy time picking off MAVIS UAVs. Using his "light stick," which bore an uncanny resemblance to a policeman's baton (including the wrist strap), Hetfield used laser light to direct the swarm from the top of one temper tent to another. He looked like a wizard waving his staff –

the grunts called him Merlin. While MAVIS was in training mode, he gave the swarm commands to "attack," "hover in place," "return," and "shut down." The swarm dutifully sent back responses that caused the light stick to vibrate, confirming that the system was operating as designed. After a minute or so of flight ops, Hetfield rechecked the battery levels and reloaded the MAVIS UAVs into his ruck. Everything was good to go.

After an hour of marching in the middle of the platoon column with LT Burton, Hetfield was over his initial nervousness and started to relax. But as they turned a corner, shots rang out from atop the building at the end of the street 300 meters away. Three insurgents were taking harassing pot shots at the soldiers (and Hetfield!). What the platoon couldn't see was that there were over a dozen civilians cowering around the periphery of the rooftop; naturally, they were women and children. The only doorway off the roof was locked from the inside. Other insurgents had set up shop on nearby rooftops to record the deaths of these civilians on video when the inevitable US bombs were dropped on the building. With some careful editing, they would have a precision US airstrike on defenseless civilians for the whole world to see. LT Burton was considering an air strike when he turned to SrA Hetfield and told him to "take 'em out." Hetfield instinctively pulled the rip cord, sending the MAVIS swarm bouncing off the concrete wall—he was a bit too close to the building, but fortunately the system was designed for this type of abuse. Staring down the light stick and using the sight (simply pointing the stick wasn't going to be accurate enough), Hetfield switched off the safety and sent his entire UAV swarm flying toward the rooftop using the "attack" command. Although it seemed to take forever (it was only a minute), the UAVs made their way to the rooftop, released their drone swarms, and began to incapacitate everyone moving, giving priority to those it sensed were holding abnormally hot items (rifles recently fired). With the insurgents' guns silenced, the

platoon moved into the building, isolated the "knocked out" insurgents, and waited while SrA Hetfield and the medic assigned to them monitored the civilians and recovered his swarm. The platoon left once the Red Crescent arrived to take over. There would be no propaganda film today. And Hetfield was very happy the IFF (identify friend or foe) tags stuck to everyone's Kevlar worked or he would have had to deal with a platoon of groggy, angry grunts.

b. Mountain Sentinel

TSgt Ulrich went through the same training SrA Hetfield did, but Ulrich was no conscientious objector (not that there's anything wrong with that). His "light stick" to control the MAVIS system was mounted on his M-4 right under the barrel, just like an M-203 grenade launcher could be mounted underneath an M-16 in the Vietnam era. When he zeroed his M-4, he also zeroed his MAVIS laser. He was a dual threat and a true combat multiplier: primarily a non-lethal MAVIS operator but also a standard, lethal ground pounder when needed.

One thing MAVIS brought to the fight was an exceptional range that far exceeded anything organic – if you could get the laser light on the target, MAVIS would get there, even if it was two clicks away. Sure, MAVIS was non-lethal and it took a while to get to its target area (definitely not faster than a speeding bullet), but it could effectively shut down harassing gunfire and snipers at critical times. Heck, MAVIS was often faster than waiting for an airstrike – that could take more than half an hour. And the effect of MAVIS <u>now</u> versus an airstrike <u>later</u> meant that the grunts were relying more and more on TSgt Ulrich and his bag of tricks. On several occasions, Ulrich was attributed with saving civilian lives, as houses that would have been leveled using the old kinetic approach were now cleared without damage using MAVIS. The civilians sure didn't like getting stung, but it beat the heck out of dying. And, as is the case in every conflict, TSgt Ulrich was finding new ways to use MAVIS.

The engineers who developed MAVIS designed it for direct action against an immediate threat. One night Ulrich found another use. He was attached to a squad going on a supply run. After picking up their supplies and getting within 20 clicks of their base, one of the overloaded vehicles broke hard and couldn't be fixed. They really couldn't leave it out there and higher told them to stay with the vehicle and supplies until they could get the recovery vehicle. It would be 0800L before that would happen and it was 0100L now. They would have to set up a security perimeter and wait it out with just two pair of night vision goggles.

Ulrich started thinking about MAVIS. What he did next was to position each of the six MAVIS UAVs at key avenues of approach and set them in an "armed overwatch" type of position on the ground. If anyone (without the IFF tag) tried to sneak up on the squad, MAVIS would automatically go airborne and "knock out" the threat sending a message back to Ulrich on his wrist-mounted multi-function receiver. In this mode, the system was using GPS coordinates so that Ulrich could maintain situational awareness. There was only one hit the entire night – a goat. But this did prove the concept that MAVIS could be used to enhance force protection. In fact, from this day forward when the MAVIS system was not being used on patrols, Ulrich was setting up MAVIS as a networked system of unattended ground sensors on the high ground around his mountainous forward operating base.

c. Enhanced Reaper

Noting the success of MAVIS in these grunt applications, the USAF wondered about the possibility of putting these MAVIS UAVs into CBUs (cluster bomb munitions with the cluster bombs removed) with WCMD (wind-corrected munitions dispenser) tail kits. These could then be used on an airborne platform for deployment to "remote locations" in either direct action mode (e.g., attacking a house) or as unattended ground sensors with teeth (e.g., a non-lethal

ambush for high-value targets). And after shellacking the USAF for using cluster bombs in Afghanistan, Human Rights Watch was thrilled to see anything non-lethal replacing the cluster bombs in the CBUs. In their minds, MAVIS wouldn't be anywhere near as bad for the population as cluster bombs or landmines. War was still unacceptable, but MAVIS was less unacceptable than the kinetic alternatives.

After many years of flying with lethal and sensor payloads, the MQ-9 Reaper was finally loaded with an MD-2020 (a "MAVIS Dispenser" modified from an old cluster bomb design from "2020" filled with 36 MAVIS UAVs stacked like pancakes) in September of 2035. Many years of development and testing had passed since MAVIS had been fielded for ground-control use. These new MAVIS UAVs were specifically modified for "remote control/remote location" use (RC/RL or "Rick Roll" missions). They had nuclear batteries[6] as well as solar cells for redundant power. The chemistry had been tweaked on the incapacitant to get the LD_{50} (the dose that kills half the population) as high as possible without losing effectiveness; i.e., to make it safer. Communication with the MQ-9 was now done through laser beams.

Capt Hammett was handed off an MQ-9 with the first MD-2020 round. He had extensive training with this round in the simulator and was eager to try it out. Like they had done many times before, the insurgents stole a fuel truck earlier in the day and were headed back toward their sanctuary. MSgt Newsted had been tracking the truck using the MQ-9 sensors and saw it get stuck in a river crossing. In an hour there were about 30 folks, who all looked to be insurgents, draining the truck's fuel into five-gallon jugs. It was really difficult to tell who those people were down there. Some were definitely insurgents. But how many were just innocent civilians looking for a good deal on gas? Impossible to tell from 20,000 feet. In years past, this would have been a Hellfire mission, but now there was another option and Hammett took it.

After coordinating to ensure a ground team could get there within three hours for MAVIS recovery operations, Hammett released the MD-2020 with coordinates set for the fuel truck. Roughly 500 feet above the ground, the 36 MAVIS UAVs were released and formed a hovering perimeter around the truck about 25 feet above ground level. One by one, the UAVs began releasing their micro-UAV drones to incapacitate all those around the truck, as Hammett had commanded from thousands of miles away. The folks tried to get away, but the swarms were too persistent. Within five minutes, all human activity was still and Hammett directed the swarms to stand down; i.e., drones rally to their motherships and motherships land to conserve power.

As they rolled up to the scene, the Guardians (MAVIS operators) embedded with the grunts took control of the biggest MAVIS swarm they had ever seen at one time – 36 UAVs! Capt Hammett transferred control to the Guardians seamlessly. By this time, all the drones had returned to their respective MAVIS motherships and were held in place by simple magnets. Technically, this mission was a great success for the MAVIS family of systems. The four thieves who stole the truck were indeed insurgents and were processed. Thirty-five men and children from the nearby village had came to get fuel and were just in the wrong place at the wrong time. A Hellfire attack would have been an unjustifiable slaughter of the innocents, not to mention an information operations nightmare for us and a propaganda coup for the insurgents. MAVIS was definitely the right way to go in this instance.

Not unsurprisingly, MAVIS was mostly a curiosity for the conventional "big" USAF when it was fielded for ground use; however, after the MD-2020 persistent intelligence collection capability and non-lethal "strike" capability were fully integrated into the AOC (Air Operations Center) Weapon System, the utility of MAVIS was never again in question. In fact, folks started talking about loading MAVIS swarms into hypersonic platforms (with designs

driven by hypersonic boundary layer effects[7]*) for rapid, non-lethal global "strikes" and intelligence gathering in areas of suspected human rights abuses. The United Nations had little problem approving such uses.*

D. General MAVIS System Requirements

In this section, the general MAVIS system requirements will be stated to ensure MAVIS can be a useful system. These requirements should only be thought of as draft requirements that would need refinement prior to any thought of system acquisition.

a. Platform

As can be seen in the vignettes, the MAVIS system actually depends on two platforms: a mothership for large-scale movements, and a drone colony, released from the mothership, for the final close-in "attack." These two platforms have different requirements.

The mothership must be rugged enough to bounce off interior and exterior walls while protecting its drone cargo. It must also be able to fly in the extremes of weather (temperature, humidity, precipitation, dust, etc.) and in winds up to 20 knots. It must be able to fly up to 20 knots and must be able to hover at altitudes of 25,000 feet mean sea level. Each mothership must weigh less than five pounds so that a MAVIS-specific rucksack with six MAVIS motherships would weigh no more than 40 pounds total. While heavy, this is not an unacceptable load for an infantryman on patrol. Power should be sufficient to allow flight or hovering for at least 30 minutes and the batteries must be easily replaced to facilitate extended operations. Each mothership must have the capability for interchangeable payloads so that a variety of sensors (e.g., electro-optical, infrared, acoustic, seismic, etc.) and communications (e.g., wireless, SATCOM, laser com) can be tailored to the mission at hand. The communication capability must allow for two-way communication with the man-in-the-loop MAVIS controller and with

the drones. The mothership must also have its own mechanism for injecting incapacitants in the event the drones fail—this must be a more energetic approach than the drones use in the sense that the injection mechanism must be able to apply more force and use a longer needle to defeat a target with no exposed skin and wearing thick clothing. And, of course, the mothership must have provisions to carry and protect its colony of drones, such as storage cells along its outer edge with retractable doors.

The requirements for the drones are much simpler. These must be able to carry a combat-effective incapacitant payload and an injection system. They must also have a sufficiently compact "stowed" configuration when in transit via the mothership. Power should allow for a flight time of 10 minutes, as it is envisioned that drones will be released only when near their targets. For any long-distance or long-duration flying, the drones would return to the mothership, so a way must be found to quickly attach/detach drones to/from the mothership. Drones will need a simple communication system to receive commands from the mothership and to relay their incapacitant status (whether the dose was delivered or not).

b. Command and Control

For the ground-controlled system described in the "Urban Patrol" and "Mountain Sentinel" vignettes, the C2 system must be capable of rapidly delivering commands in a line-of-sight fashion suitable for a complex 3-D environment, with a wireless non-line-of-sight backup system. Status updates from MAVIS must be relayed back to the operator and displayed on a system that does not detract from the operator's mobility but does enhance his or her situational awareness. The C2 system will only need to issue simple commands as MAVIS must have sufficient artificial intelligence for obstacle avoidance and efficient and effective navigation.

For the air-controlled system described in the "Enhanced Reaper" vignette, the C2 system must be capable of being integrated with a satellite communication system to ensure the MAVIS UAVs can be located and controlled no matter their location.

c. Incapacitant Characterization & Self Destruction

Most incapacitant approaches rely on airborne delivery systems usually involving explosions to disperse chemicals for inhalation. A variety of incapacitating effects are possible, from instant unconsciousness to delayed grogginess to uncontrolled euphoria. The incapacitating effect MAVIS requires is nearly instant unconsciousness without contaminating the battlefield with an aerosol cloud.

The non-lethal capabilities the USAF requires in 2035 must be able to separate innocent civilians from I/Ts while preserving infrastructure; e.g., housing, places of worship, and government facilities. Certainly the ideal *lethal* solution would be a munition that targets only I/Ts, but this assumes perfect intelligence; i.e., we know with absolute certainty who the I/Ts are, can identify and target I/Ts in a crowd, and can eliminate I/Ts with absolute precision. Typically, the fog and friction of war suggest less than perfect intelligence and hence the potential for collateral damage—we can, with absolute precision, get the wrong guy. To limit collateral damage and its propaganda value, a new capability should be inherently non-kinetic to eliminate destruction and/or dismemberment. Note that it is possible to imagine a kinetic, non-lethal weapon that could produce irreversible incapacitating injuries, but this type of capability would be counterproductive in the quest for hearts and minds. Thus, to be effective while benign in the world media, the non-lethal capability must be completely reversible. This leads to discussions of directed energy and chemical incapacitants. The problem with directed energy is its abruptly temporal nature – it incapacitates only as long as the beam is on the target (and

longer-term application of directed energy for the purpose of sustained incapacitation might be considered torture). The targeted I/Ts will return to fighting as soon as they escape the beam. Any non-lethal, reversible capability must have a reasonably long period of effectiveness on the order of hours, not seconds as with directed energy, to be an effective incapacitant on the battlefield. This gives our warfighters time to recover incapacitated I/Ts at the time of their choosing. But like directed energy, any effect must be immediate to ensure that armed, fanatical I/Ts can cause no harm to the civilians in their midst. This leads to the solution of a medicinal/chemical capability that produces a fast-acting, long-lasting, incapacitating, but reversible effect. This chemical compound must also be able to withstand the extremes of a military environment (temperature variations, vibration, etc.).

In addition to the requirements that the chemical compound produce an incapacitating effect within seconds in humans that lasts for no less than four hours, there is a clear requirement that the chemical compound also be designed to "self destruct" when needed. Presently, many countries are littered with landmines (e.g., Vietnam[8]) and cluster bombs (e.g., Afghanistan[9]) that continue to cause collateral damage long after the conflict ends. In the case of Vietnam, "over 40,000 Vietnamese have been killed by landmines and unexploded ordnance (explosives) left behind from that conflict."[10] MAVIS must not have this legacy collateral damage issue with any component of the system; i.e., children playing with errant drones and stinging themselves or I/Ts capturing drones for use in nefarious activities against our forces. Thus, a means must be developed to render the incapacitating compounds harmless if control of either the mothership or the drones is lost.

It must be acknowledged that an ideal chemical compound having completely reversible effects and a non-lethal effect in every application probably will never exist. Every compound,

even water, has an LD_{50} that will produce death in humans. The best that can be done is to develop a compound that has an acceptably high LD_{50} for the majority of the population while retaining a useful effect. Remember that the MAVIS approach should always be compared against a kinetic battlefield alternative and not necessarily evaluated in isolation. Even if people die or suffer long-lasting effects due to a MAVIS attack (a slight but definite possibility), their numbers would be a small fraction of those lost if bombs were dropped. And, although somewhat macabre, the data surrounding those deaths would feed back into the research of incapacitating compounds to reduce the toxicity of future compounds.

d. Sensors

Numerous sensors must be integrated into the MAVIS systems. The ground operator must have, at a minimum, a receiver to track MAVIS UAV location and status. The motherships must have laser spot trackers and GPS receivers to receive commands directing MAVIS flight and actions. The motherships should also have a range of plug-and-play sensors, including electro-optic cameras, infrared cameras, proximity sensors, acoustic sensors, seismic sensors, motion sensors, and other CBRNE (chemical, biological, radiological, nuclear, and explosive) sensors. The drones need proximity sensors to judge distance from the target (and from each other while flying in a swarm formation) and infrared sensors to find warm areas to attack.

e. Logistics

In any modern acquisition program, the entire cradle-to-grave life of the system must be considered. For MAVIS, many of the components, such as sensors, motors, and batteries, will be COTS (commercial-off-the-shelf) items. Due to the small size of the MAVIS components and the built-in "self-destruction" capability of the chemical compounds, the drones will be considered disposable. The motherships that go astray (e.g., due to a malfunction) will be

recovered during operations if doing so can be accomplished without undue risk. The hardware, not including the incapacitants, will be considered unclassified devices when empty, but classified and under strict control when "loaded" with incapacitants. The incapacitants will be kept under tight control in the local medical clinic along with other strictly controlled medications. Loading the drones and mothership payloads with incapacitants will be restricted to medical technicians. MAVIS operators will sign out "new" MAVIS motherships (loaded with drones in their stowed configuration), and return MAVIS motherships with their collection of spent drones for refueling following each mission.

II. Current Status

A. Review of USAF UAS Roadmap

The DoD *FY2009-2034 Unmanned Systems Integrated Roadmap*[11] references flapping wing drones ("nano-flapping air vehicles") but does not have a suitable mothership for the MAVIS concept that must be able to fly indoors. In fact, based on the *Roadmap*, it appears that DoD is not focused on the indoor UAV problem at all. This is particularly troubling for the USAF, as our adversaries in Vietnam and Afghanistan have used caves and tunnels to effectively escape the effects of airpower. Bombing cave openings is no guarantee of permanently sealing off an extensive and ancient cave complex—you'd need every single opening 100% blocked and that, of course, requires perfect intelligence of every possible opening, which is not likely. An alternative approach would be to fly MAVIS motherships through these complexes and "attack" anyone inside. This would reduce the risk for follow-on forces that would clear the caves seeking enemy intelligence. For the cave complex mission and for other indoor missions, the USAF should develop the capabilities necessary to effectively execute these low Reynolds number[12] types of missions. To dominate the air, the USAF must dominate in all scales, and the

"indoor air force problem" is ripe for future development. The USAF must not ignore or downplay this mission area as the Army ignored and downplayed aerial bombing when the airplane was first applied to military operations in WWI—microUAVs are in a similar stage of development and their potential is similarly incalculable.

B. Micro Air Vehicle Platforms

Many possible airborne platforms at the micro-scale (typically bird-size) or nano-scale (typically insect-size) exist that range from scaled-down fixed-wing airplanes to tiny helicopters[13] to insect-inspired flapping wing vehicles.[14] Despite the challenges of micro-air vehicles development,[15] this author is confident little risk exists in assuming the availability of suitable air vehicles for MAVIS.

a. Fixed Wing

The state of fixed wing micro-UAVs is mature, as it is essentially a scaled-down version of the planes that have been flying for a century now. As an example, the Lockheed/DARPA MicroStar, with its six-inch wingspan and three-ounce gross weight, was flying in 1999 with a 15-minute flight time.[16] That was eleven years ago and things have only improved since then. The author was directly involved with flight testing the Special Operations Command's BATCAM UAV. In 2005, this UAV had flexible, folding wings made of carbon fiber, full-motion video, and laptop control. The concern with a fixed-wing approach for MAVIS is that the platform would need to be in constant motion to stay aloft and this may not be practical or even possible in an enclosed area.

b. Flapping Wing

The state of flapping wing micro-UAVs is not fully mature, and these UAVs are still in development. These aircraft are inspired by the motion of actual biological models, i.e., birds and insects. One particularly interesting project the USAF could leverage is the Nano Air Vehicle (NAV) program conducted by AeroVironment with sponsorship from DARPA (Defense Advanced Research Projects Agency).[17] In December 2008, the flapping-wing nano-UAV demonstrated an ability to climb/descend and fly sideways, as well as forward and backward.[18] The DARPA objective of the project is to "develop and demonstrate an extremely small (<15 cm), ultra-lightweight (less than 20 grams) air vehicle system with the potential to perform indoor and outdoor military missions."[19] This is the present state of the flapping wing art. If it were smaller, the NAV would be an ideal platform for the MAVIS drones. It will probably take three years to get the present NAV flying in an ideal fashion, five years to get a group of them flying in militarily useful swarms, and another 10 years to get this system miniaturized to the insect scale desired of a MAVIS drone. Some of this work could be done concurrently to shorten the development timeline.

c. Rotary Wing

The state of rotary wing micro-UAVs is mature for the same reason fixed-wing is mature: these are just scaled-down versions of mature aircraft. From a MAVIS "mothership" perspective, what makes rotary wing appealing is that the platform can hover, and the rotors can be ducted to provide protection from inevitable contact with interior and exterior walls. One particularly promising rotary wing approach is the quad rotor approach, which has "extremely favorable flight characteristics. Each pair of rotor blades spin in opposite directions, thereby canceling out any torque (rotation caused by the spinning rotor blades momentum), keeping the

helicopter flying straight and true. Not only does this make the helicopter easier to fly, counter rotating propellers increase efficiency and flight times."[20] This description aptly describes the physical advantages of the quad rotor approach.

A number of COTS quad rotor systems are presently available. The Draganflyer X4 has been configured for a variety of payloads and has a gross take-off weight of 33 oz, but has a rather large diameter (for MAVIS purposes) of 31 inches and the rotors are not protected.[21] With a diameter of 40 inches, the AirRobot AR 100-b is even larger, but it has a protective ring around the rotors desirable for MAVIS applications.[22] This particular system has been designed to work with "video goggles"[23] so that an operator (especially a MAVIS operator) could more easily identify targets. Another quad-rotor system with even more protection for the rotors is the CyberQuad (Fig. 1) that uses ducted fans instead of exposed rotor blades—it has a "top speed…around 40 mph with a mission time of 35 minutes"—and has already been used to conduct "an extended survey of an offshore drilling platform and an oil rig damaged by fire."[24] Using the MAVIS requirements for the mothership, readily available COTS systems may be adapted for the MAVIS mission.

Figure 1 CyberQuad with storage box
(reprinted from http://www.wired.com/dangerroom/2009/12/australian-drone-perches-stares/)

C. MAV Command and Control

A laser beam should be used in a dynamic 3-D environment and a laptop solution used for remote operations. Either mode could be used by a ground operator or an airborne platform. To issue commands, the laser beam would be "chopped" at different frequencies that would trigger fixed swarm behavioral algorithms such as subdue, harass, recon, standby, and return. When line-of-sight is lost (and for remote operations), these same commands would be issued using a redundant wireless command and control system.

a. Hardware

Hardware to support MAVIS C2 is mature and readily available. The ubiquity of lasers for military applications, such as rangefinders and target designators, and for commercial applications, such as laser levels and pointers, suggests that adapting laser system for MAVIS command and control will not be a daunting task. The prevalence of wireless C2 for military and commercial UAVs suggests that modifying a COTS or GOTS (government off-the-shelf) system for MAVIS use will be possible. For the MAVIS operator to maintain situational awareness for remote operations, either a PDA-like device may be strapped to the forearm of the ground operator, or a standard, ruggedized laptop could be used for remote operators.

b. Software: Swarming algorithms and AI

Of greater concern is the software that controls MAVIS motherships and the swarming behavior of the drones. While work has been done covering intelligent coordinated UAV flight[25] and swarming,[26] MIT recently decided to rethink 50 years of artificial intelligence (AI) research.[27] This will impact the development of MAVIS and its modes of behavior; however, it should result in superior AI for a fielded MAVIS in 2035. While AI will necessarily impact the

programming of the MAVIS motherships, the swarming behavior of the MAVIS drones will probably be relatively simple. P.J. Singer states that the "beauty of the swarm, and why it is so appealing to military thinkers for unmanned war, is how it can perform incredibly complex tasks by each part's following incredibly simple rules."[28] In order to create complex swarming behavior from simple programming rules (as would apply to the MAVIS drones), Singer claims that the "AI would be less than the systems on the market today."[29] Thus, for MAVIS, the software for drone swarming behavior can be thought of as mature, but the AI that governs the mothership functions will require significant development.

D. Chemical Incapacitants

It is important to put chemical incapacitants for use in non-lethal MAVIS applications in perspective by comparing their effects to conventional weapons and to medications. The accepted manner of defeating a human adversary on the battlefield is to cause irreversible and catastrophic physical disruption of bodily functions such that the body cannot recover: the adversary dies. This can happen through scrambled internal organs caused by a tumbling 5.56 round from an M-16 or by using larger rounds/indirect fire that result in dismemberment and a rapid bleed out. Unless shock sets in immediately, the last minutes of life resulting from one of these injuries will be agonizing. This is the accepted result of modern combat. During WWI, chemical weapons produced equally agonizing deaths and injuries and were eventually banished from the battlefield. Unfortunately, chemical incapacitants, no matter the intent of their application, are seen in the same light as deadly chemical weapons. However, we would never banish from the battlefield a chemical used in a medical application, no matter how close the chemical structure was to a banned chemical weapon's compound. What matters is not the structure of the chemical, but its intended result. Medicines are used to prevent diseases, and

MAVIS is used to prevent collateral damage. MAVIS incapacitants should be thought of in terms of medicines, not weapons.

a. Chemical Weapons Policy

"Temporary incapacitants" are classified as a form of chemical weapon, a "toxic chemical,"[30] and the psychological and policy barriers thus imposed are significant but surmountable. It is important to note that the original intent of chemical weapons, be they nerve, blood, or choking agents, was no different than that of a bullet or artillery shell: to irreversibly maim or kill humans. It's the intent that separates the banned WWI-era chemical weapons from the reversible chemicals proposed for MAVIS: to temporarily incapacitate I/Ts and the unfortunate innocent civilians they hide behind. Thus, with a proper understanding of the humane intent of the incapacitant, it is proposed that chemical incapacitants will eventually be allowed to return to the battlefield in support of irregular warfare.

b. Possible Incapacitants

Chemical incapacitants have been used in the COIN/IW fight and show that an injection approach is preferable to an aerosol approach. A recent example is the Russian rescue of over 700 hostages from Chechen rebels in 2002.[31] Strapped into suicide vests, the rebels took 800 innocents hostage with the intent to kill them if their demands weren't met. The Russians pumped quick-acting gaseous chemical agents into the theater and effectively defeated the rebels' plan. Unfortunately, over 90 hostages died due to the unregulated dosing of the gas. But over 700 hostages returned to their families. The lesson to be learned here is that incapacitants work when fighting I/Ts, but dosing is critical for proper application and lower mortality rates. Injecting metered amounts of MAVIS compounds directly into I/Ts and the unfortunates immediately around them is better than an unregulated aerosol dose. Moreover, an aerosol

approach would contaminate the battlefield, similar to a smoke grenade, and require US fighters to don the entire ensemble of personal protective equipment (MOPP4) in order to avoid the effects of inadvertent inhalation/contact. The USAF forcing grunts to don their gas masks is unacceptable. Thus, MAVIS should dose via injections.

Presently, carfentanil (also known as carfentanyl or the trade name Wildnil) is one powerful chemical compound that could meet the requirements for a MAVIS incapacitant. Only a few milligrams will effectively sedate large animals such as moose, elk, or deer.[32] Carfentanil is from the family of fentanils (or fentanyls), and could be modified (e.g., with ethyl groups) to produce a less powerful compound that is more tailored to human use. Carfentanil as used on animals is also reversible within minutes using diprenorphine.[33] And while carfentanil takes a few minutes to produce the desired effect in large animals, this response time, if it were the same for humans, would still be useful in many military applications. This discussion highlights the fact that there exists today an incapacitating compound that could be used as a starting point for MAVIS applications: carfentanil quickly produces incapacitation with a very small dose and is reversible. Whether carfentanil or a more tailored compound based on the fentanil family is used, at least a decade of studies and toxicology tests is required before the MAVIS incapacitant is ready for human use. In the interest of transparency with our international partners, it is recommended that any incapacitant used be approved by the FDA for human use.

E. Sensors

As there are a wide variety of sensors presently available for the micro-air vehicles presented in this paper (Draganflyer X4, AirRobot AR100-b, and CyberQuad), it is evident that the state of sensors is mature. The author's experience in researching and testing sensors for unattended ground sensor systems in the past five years is further confirmation.

F. Gap Analysis: System Requirements vs. Current Status

Based on the foregoing discussion of the elements of the MAVIS system, it appears that MAVIS development will involve mostly an integration of COTS/GOTS components with modifications as needed. The immature areas needing dedicated development are 1) the flapping-wing drones, 2) the AI software for the mothership, and 3) the exact compound used as the chemical incapacitant. Also, the greater policy issues related to chemical compounds use on the battlefield must be addressed before MAVIS may be used to reduce collateral damage.

III. MAVIS System Definition

MAVIS is a non-lethal capability that uses UAVs to directly inject a metered dose of chemical incapacitants using both direct control via lasers and indirect wireless control. Reviewing available literature has not yet revealed a system similar to MAVIS or an openly proposed concept by DoD on its non-lethal weapons website.[34] Aside from the non-trivial development of smaller flapping-wing drones, AI for the mothership, and a suitable chemical incapacitant, MAVIS is a hardware integration effort using COTS/GOTS elements.

A. Platform Selection

To attack a dynamic I/T target, the injection platform can be either a single aerial vehicle or a swarm of aerial vehicles (or, in the case of MAVIS, both). Military history bears out that swarming is a "style of fighting that is pretty effective."[35] Swarms provide advantages over single vehicles in that they maintain a level of redundancy and persistence that a single vehicle cannot achieve: compromise or destroy the single vehicle and the capability is gone, but a swarm can continue its mission until the last vehicle is rendered non-mission capable. The single platform approach is mature and available now for ISR and kinetic capabilities, but the swarming approach is still under development. Because the swarms must get close to humans and often

operate indoors, this limits the size of each individual vehicle to a micro-UAV scale: no larger than a small bird.[36] To gain the advantages of mass for a single vehicle (to fly through wind gusts) and the advantages of swarms, it is proposed that MAVIS be composed of a mothership to cover large distances while carrying a stowed swarm that can be released for the close-in attack.

a. Block 1 Capability: Rotary-Wing Mothership

The first element of the MAVIS acquisition (Block 1) will be the mothership. This mothership will be modeled after the presently available CyberQuad (as shown in Figure 1), but must be scaled down to roughly 12 inches in diameter. Other modifications will include adding a removable ring around the periphery of the vehicle to house 16 future drones and removable sensor/injector payloads along the axes between the ducted fans. In keeping with the acquisition intent of providing capability as soon as possible, this MAVIS Block 1 system will provide a limited and fieldable incapacitating/ISR capability even without the drones.

b. Block 2 Capability: Flapping-Wing Drones

For Block 2, the flapping-wing drones, based on the scaled down DARPA Nano-Air Vehicle, will be incorporated into the MAVIS mothership. These drones should be no more than an inch in length in their stowed configuration.

B. Command and Control Approach

The C2 scheme for MAVIS is bimodal and comprised of a "Man-In-The-Loop" mode where an operator on site will be able to rapidly command and control MAVIS to navigate a dynamic environment, e.g., urban terrain. The other mode is "Semi-Autonomous" where MAVIS is controlled at a remote site and must rely on its programming AI for navigation from point to point.

a. Man-In-The-Loop Mode (Block 1)

This is part of the initial capability provided in Block 1. It is envisioned that the operator will use a control stick, similar to a policeman's nightstick, which will have a laser pointer at one end. For short distances (less than about 100 meters), the operator would simply point the laser light to the target of interest and MAVIS motherships would follow—this is the same approach used for precision laser-guided bombs since the Vietnam War. Pointing error would not be much of a concern for this close-in work. For longer distances, the control stick would have an optical sight that would allow the operator to precisely place MAVIS. Once the MAVIS motherships are at the desired location, the operator would press the appropriate sequence of buttons to command them. To issue commands, the laser beam would be "chopped" at different frequencies that would trigger behavioral algorithms such as subdue, harass, recon, standby, and return. Provisions would also be made to ensure that the MAVIS control stick could be mounted onto a rifle. Since the laser is a line-of-sight tool and could be obscured while MAVIS flies to its destination, the laser would also attempt to capture and transfer grid coordinates to MAVIS using a laser rangefinder capability.

b. Semi-Autonomous Mode (Block 4 Capability)

This capability will be provided in the last block of the MAVIS acquisition due to its complexity. It will allow a remote operator the ability to command the MAVIS system to navigate to a point, but MAVIS must rely on its AI to avoid obstacles. MAVIS will rely on a robust full-motion video (FMV) capability to ensure that the remote operator has sufficient situational awareness to conduct operations. This FMV will also allow the operator to fly the MAVIS motherships without preprogrammed waypoints. While indoors, the MAVIS motherships will set up a wireless network and distribute themselves to ensure two-way

communication between the MAVIS mothership doing the scouting and the remote operator. Also, remote operators would be able to switch between motherships and assume control of them as desired. Note that these remote operators could be thousands of miles away in the US or they could be a ground operator just around the corner in a Mine Resistant Ambush Protected vehicle using virtual reality goggles.

C. Incapacitant Administration

Proper doses of incapacitants will be administered in two ways: via the mothership, and via the drones.

a. Rotary Wing Mothership (Block 1 Capability)

For the mothership, one of the payload spaces between the ducted fans will house a retractable injection system. This system would be aligned with the optics of the FMV to allow for the remote flying capability of Block 4. To employ this mode, the MAVIS mothership would make direct contact, instantly extend a needle, and inject the target with the incapacitant. This needle would apply sufficient force to pierce thick clothing. It is not expected that this initial capability MAVIS will be able to subdue most targets due to its large size. In order to be effective, the mothership must rely on the distraction caused by the drone swarm.

b. Flapping-Wing Drones (Block 2 Capability)

The drones will be the main force responsible for conducting and executing the primary MAVIS mission: incapacitation. They will be equipped with stingers and carry enough incapacitant to "knock out" four men. Their primary target will be any exposed skin; i.e., heat signature. In the event that no exposed skin is available and attempts to inject through clothing prove unsuccessful, the drones will fly in a harassing manner to distract the target while the

mothership delivers the "knock-out blow." With 16 drones on each mothership, it is theoretically possible for each mothership to incapacitate 64 men.

D. Packaging

MAVIS will be delivered to the battlefield in two manners: ground delivery as a piece of equipment organic to the MAVIS operator, and air delivery from a fixed-wing platform.

a. Ground Delivery System

For ground delivery, the system would be stored in two sections: 1) all the elements of the MAVIS system without the incapacitants, the responsibility of the ground controller, and 2) the drones (packaged in a ring that would clip onto the periphery of the mothership) and the injection payloads loaded onto the mothership, the responsibility of the local medical unit. The ground operator would be responsible for ensuring the drones and mothership injector payload were correctly installed.

b. Airborne Delivery System (Block 3 Capability)

For airborne delivery as described in the "Enhanced Reaper" vignette, a set of 36 MAVIS motherships fully mission-capable would be assembled and loaded into a dispensing munition. This munition would be loaded onto a fixed wing aircraft and the dispensing munition would deliver the 36 MAVIS motherships to a remote location. Note that this is a Block 3 capability and that the semi-autonomous mode of Block 4 is not available. This means the capability for Block 3 is an aerial delivery of the MAVIS system for ground control.

IV. MAVIS CONOPS

With a defined acquisition and technical approach and operational vignettes presented earlier, the applicability of MAVIS CONOPS to winning irregular wars must be established, or else MAVIS is of only academic interest. The intent of the MAVIS system is that it will be used

in an "area attack" fashion and subdue all humans within a given radius of a target point. The reason for this less-than-precise approach is twofold: one, the ability to identify the exact person or target firing from a crowd or building is difficult, and two, configuration is simpler in the sense that the swarm vehicle does not require a multitude of sensors and algorithms to accurately identify the target. The swarm simply goes where directed and subdues all, with reversible effects that wear off over time in a vast majority of cases. It is easy to envision the benefits of MAVIS in an irregular war. Rather than legally bomb a home or mosque that I/Ts are using as a firing position, an airman would send in MAVIS and issue the "subdue" command. Friendly ground forces would then recover I/Ts, process them for intelligence, and remove them from the battlefield. For the civilians affected, an obvious US nontrivial responsibility exists to ensure their safety while incapacitated—this could be done equally well by coalition partners, military conscientious objectors trained especially for such duties, or trusted NGOs. In fact, requesting coalition partners exclusively for humanitarian civilian recovery duty could potentially expand our coalitions. The key benefit to MAVIS is that it prevents I/Ts from exploiting our destructive power to their benefit. Once the global community understands the US intent behind MAVIS and sees the results—significantly reduced collateral damage and captured I/Ts—the nature of irregular warfare will change. There will be an undeniably stark contrast between our humane, non-lethal approach and the bloody, reckless approach of I/Ts. With minimal collateral damage, the hearts and minds of the populace will soon follow, thereby satisfying the political goals of the irregular war. Our noble motives will be reflected in our capabilities. Thus, it is envisioned that MAVIS will simultaneously satisfy the military goals of capturing I/Ts, and, more importantly, the political goals of minimizing collateral damage while protecting the populace—a key concern for proving the legitimacy of the government and thus winning irregular wars.[37]

A. Storage and Transport

The MAVIS system would be stored in two sections for storage and transport: 1) all the elements of the MAVIS system without the incapacitants, and 2) the drones (packaged in a ring that would clip onto the periphery of the mothership) and the mothership injection payloads, stored and transported separately. It is highly likely that the developed incapacitant would require special environmental conditions (e.g., refrigeration) to ensure maximum shelf life. The local medical unit would be able to provide secure, environmentally suitable storage.

B. Delivery/Control Schemes

Once the MAVIS acquisition reaches the final Block 4 capability, all permutation of the delivery/control schemes will be possible. There are four possible delivery/control schemes:

a. Ground Delivery/Ground Control

This is the initial Block 1 capability. It entails the ground operator employing the MAVIS mothership in ground operations and exercising control using the control stick.

b. Ground Delivery/Airborne Control

This is a Block 4 capability. It entails the ground operator employing the MAVIS mothership in ground operations and transferring control to a remote operator. This transfer of control would be desirable when the ground controller was required to rapidly retreat from a location and could not recover MAVIS without taking undue risk. This condition could also arise if further, more detailed reconnaissance is required, but the ground controller must move out with his assigned unit.

c. Airborne Delivery/Ground Control

This is the Block 3 capability, required when a ground controller requires additional MAVIS capability. Airborne delivery can, with its 36 MAVIS motherships, potentially

incapacitate 2,304 humans if the incapacitants were ideally administered. In addition, MAVIS could be preset to automatically go into an attack mode from its airborne delivery and incapacitate anyone not wearing an IFF tag. This mode would be useful in an area where mass killings are occurring to stop the slaughter until help could arrive.

d. Airborne Delivery/Airborne Control

This is a Block 4 capability and entails the delivery of MAVIS from a fixed wing platform to a typically remote location. This mode, with its ability to remotely fly MAVIS motherships, would be useful anytime reconnaissance of a suspect ground location is required.

C. Maintenance and Disposal

The maintenance of the individual MAVIS motherships would be the responsibility of the trained MAVIS operators. The maintenance of the incapacitating elements, the drones and the injection payload for the mothership, would also be the responsibility of the trained MAVIS operator once these components were checked out from the medical unit. In general, all elements of the MAVIS flying system would be disposable. If possible, the incapacitants would be highly volatile in that they would readily evaporate when exposed to the atmosphere.

V. MAVIS Development

A. System Development Timeline

It will take roughly 25 years to develop the full Block 4 capability of MAVIS with its full range of operational options. For Block 1 (the mothership alone for use with a ground operator), it will take five years (2015) to scale down the COTS quadrotor and integrate its control with a laser-equipped control stick. This will include the time required to set up the acquisition and secure funding. It will take another five years to develop the swarm drones, integrate them into the mothership, and verify their operation (2020). Block 3, the airborne delivery of the MAVIS

system, will require another five years (2025) and will be dominated by traditional flight testing using fixed-wing assets, such as the MQ-9 Reaper and the Joint Strike Fighter. The final Block 4 capability, which includes a robust remote MAVIS operation capability and the inclusion of the actual incapacitant, will require 10 years for development, testing, and fielding (2035). Note that a simulant will be used in place of the incapacitant for testing purposes. It is expected that it will take at least 15 years (if not the entire 25 years of the MAVIS program) to get international approval on the use of incapacitants to reduce collateral damage.

B. Chemical Incapacitant Challenge and Mitigation Strategy

The chemical incapacitant used in MAVIS will be subject to the Chemical Weapons Treaty.[38] Presently, CS gas, a reversible incapacitant, is banned from warfare use according to the Chemical Weapons Treaty. The reason for this was not CS itself, but the way in which it was employed. Soldiers would use CS gas to force the enemy out of foxholes and then kill them. This is exactly the opposite of the prevent-collateral-damage intent of MAVIS. The United States must use this distinction to become a leader in the worldwide development of non-lethal capabilities while proposing/promoting MAVIS. The secondary effects of this advocacy would increase US stature worldwide, as our rhetoric of promoting human rights would be backed up by a system designed exclusively to protect terrorized, innocent populations. Compared to the bloody kinetic solutions for protecting people in irregular wars, a chemical approach done with honorable intent should be an easy sell. But nothing is certain in politics.

VI. Discussion

A. MAVIS Impacts on National Instruments of Power

When considering whether to fund MAVIS (and non-lethal weapons in general), it is important to view its favorable impact on *all* the national instruments of power (IOP):

diplomatic, information, military, and economic. For the diplomatic IOP, the US will gain favor with nations that have criticized our use of military power in applications that have resulted in collateral damage. Our response to these criticisms thus far has been to build smaller bombs. Building and fielding MAVIS will show the international community that protecting civilians whenever possible is not just rhetoric, it's manifest in the way we conduct operations on foreign soil. For the information IOP, MAVIS will reduce the number of civilian deaths in a COIN/IW conflict and deprive the insurgents of their anti-US propaganda. Using MAVIS will ensure that our message to the people—that we are there to protect them—has merit. We will show them how and why we use MAVIS so they will know what to expect when the I/Ts invade. The people will be much more likely to call on US assistance if they know they and their families are much less likely to die. For the military IOP, MAVIS will help to restore tactical control of tactical units. In many cases during COIN/IW conflicts, higher-level commanders have seen fit to become involved in tactical decisions due to the fact that any round has the ability to have strategic impacts. This deprives tactical commanders of their ability to command and, in the long run, weakens our military by overly centralizing military operations. The problem here is that tactical commanders have only the binary option of killing or not killing. Providing them a different option, such as MAVIS, will restore tactical control to tactical units as MAVIS will be used in situations of imperfect intelligence with only temporary, not fatal, results if targeting mistakes are made. Yes, MAVIS will slow down the fight, but the COIN/IW fight, by its very nature, is a long, slow fight. For the economic IOP, using MAVIS will reduce death and destruction, ergo reducing the payments we make to the families of the dead and to construction projects that repair the damage bombs have caused. Taken together, it is clear that MAVIS will significantly enhance all of our national IOPs.

B. The Downside of MAVIS

There are some significant downsides to the MAVIS capability. The most obvious is the requirement to protect those that MAVIS incapacitates. This will slow down the tempo of any military operation. As suggested earlier, this may be mitigated by requesting the assistance of coalition partners that, due to their nature, are reluctant to send combat forces to a specific conflict or even NGOs, such as the Red Cross, Red Crescent, or Doctors Without Borders. It's quite possible that a new NGO, composed of individuals who recognize the importance of MAVIS on the battlefield, will form specifically for the task of recovering incapacitated civilians. In addition to the incapacitated citizenry problem, there is the concern that MAVIS swarms could be defeated by simply closing a door or using netting. For the "closed door" scenario, MAVIS would need to be used in conjunction with a human to knock down the door. MAVIS would be the first to enter the room. For the net scenario, MAVIS could be equipped with a payload to cut through a net—the enemy will seek to defeat MAVIS and future upgrades must include payloads that can counter these measures. But the very fact the I/T adversary would be forced to employ such methods would be another way of forcing them to raise their profile while working among the masses and potentially tip their hand, which could help head off attacks.

C. Other MAVIS applications

A MAVIS-like capability could be useful in numerous other situations with domestic security and military applications. These include hostage situations, riots, or dealing with the folks displaying violent, irrational behavior; e.g., mentally deranged, drugged, or drunk. MAVIS could be used as a "Police Wingman" mounted on patrol cars for ready availability in the same way it will be used for soldiers on a mounted patrol.

VII. Conclusion

The USAF has an excellent opportunity to build a non-lethal MAVIS system suitable for fielding no later than 2035. A survey of available literature suggests that the hardware components of MAVIS are either readily available or feasible with present technology. Also, a suitable incapacitant, such as carfentanil, is available but requires toxicology tests to ensure safe use in humans. During the development of the MAVIS concept, this author has come to appreciate the potential capabilities of swarms of insect-sized drones with flapping wings in a quiescent indoor environment—and DoD seems interested in developing them. But they are limited in that they have little mass and can be easily blown about. They would have a difficult time reaching a distant target in unfavorable winds. To ensure nano-swarms can effectively reach their target, the mothership/drone concept will be used. The mothership that appears most promising is a disc shape with four enclosed rotors for protection of the propulsion system. At the periphery of the disc fuselage will be a swarm of flapping wing drones, in a compact stowed mode, carrying incapacitants. The mothership will also carry its own incapacitant delivery system for those situations unsuitable for the drones. Once the mothership reaches the target, the drones will deploy to subdue the combatant(s). The DoD FY2009-*2034 Unmanned Systems Integrated Roadmap*[39] references flapping wing drones ("nano-flapping air vehicles") but does not have the mothership as proposed here. Essentially, two levels of MAVIS swarming will be possible: mothership swarms, and drone swarms.

This paper has presented vignettes to illustrate MAVIS employment, operational effects, and benefits. It's expected that the ground operators of MAVIS will be enlisted airmen with hybrid medic and combat arms training as well as specialized MAVIS training. These airmen will be embedded with ground units (Army, Marine, or SOF) to provide timely and essential

non-lethal capabilities. Also, an airborne delivery system, based on the Wind Corrected Munition Dispenser system, will ensure MAVIS can be delivered to an austere location via long-loitering ISR platforms such as the MQ-9 Reaper or other fixed-wing assets, such as the Joint Strike Fighter.

A. Summary

This paper has shown the need for systems like MAVIS to complement conventional capabilities in light of USAF difficulties in fighting irregular wars. A concept for MAVIS employing a swarm of micro-air vehicles to incapacitate insurgents/terrorists has been presented. Despite contentious chemical agent treaty issues, the possibility of MAVIS fielding in 2035 is good assuming senior leader support. At this point, it is important to highlight the fact that MAVIS is no panacea for saving *all* innocents. As with any medical treatment, risk is present and unanticipated civilian deaths will occur due to dosing irregularities or outlier responses. But the number of these deaths will pale in comparison to those caused by our present aerial kinetic approaches. MAVIS is an intriguing non-lethal approach to help solve the USAF problem of collateral damage and deserves further investigation.

B. Recommendations

It is recommended that the USAF strongly consider funding MAVIS capabilities that rely on chemical incapacitants to subdue combatants in the COIN/IW fight. An opportunity exists to jointly fund MAVIS with other government entities, such as the Department of Justice or Department of Homeland Security, which could use MAVIS for domestic applications, such as border monitoring/enforcement. Further, the USAF should be the champion for all MAVIS development.

VIII. References

[1] Filkins, "Stanley McChrystal's Long War."
[2] Smith, *The Utility of Force*, 19.
[3] Briefing, Miniature Munitions Systems Group, subject: Small Diameter Bomb Increment I.
[4] Smith, *The Utility of Force*, 20.
[5] Smith, *The Utility of Force*, 19.
[6] University of Missouri-Columbia, "Smaller And More Efficient Nuclear Battery Created."
[7] Blanchard, "An Experimental Investigation of Wall-Cooling Effects on Hypersonic Boundary Layer Stability in a Quiet Wind Tunnel."
[8] PBS, "Vietnam Passage. The Perspectives: Landmines: War's Lingering Menace."
[9] Human Rights Watch Backgrounder, "Cluster Bombs in Afghanistan."
[10] PBS, "Vietnam Passage. The Perspectives: Landmines: War's Lingering Menace."
[11] *FY2009-2034 Unmanned Systems Integrated Roadmap*.
[12] Schlichting, *Boundary Layer Theory*, 14.
[13] Tsuzuki, et.al., "Design Guidelines of Rotary Wings in Hover for Insect-Scale Micro Air Vehicle Applications."
[14] Raney and Slominski, "Mechanization and Control Concepts for Biologically Inspired Micro Air Vehicles."
[15] Pines and Bohorquez, "Challenges Facing Future Micro-Air-Vehicle Development."
[16] Holder, *Unmanned Air Vehicles*, 57.
[17] DARPA, "Nano Air Vehicle."
[18] Warwick, "Nano-UAV Video."
[19] DARPA, "Nano Air Vehicle."
[20] Innovative UAV Aircraft & Aerial Video Systems, "DraganFlyer X4."
[21] Innovative UAV Aircraft & Aerial Video Systems, "DraganFlyer X4 Helicopter Tech Specs."
[22] AirRobot UK, "AirRobot AR100B."
[23] AirRobot UK, "AirRobot AR100B Technical."
[24] Hambling, "Aussie Hovering Drone is Straight Outta Avatar."
[25] Lewis and Weiss, "Intelligent autonomy and performance metrics for multiple, coordinated UAVs."
[26] Ilaya, et.al., "Control design for unmanned aerial vehicle swarming,"
[27] Chandler, "Rethinking artificial intelligence."
[28] Singer, *Wired for War: The Robotics Revolution and Conflict in the 21st Century*, 231.
[29] Singer, *Wired for War: The Robotics Revolution and Conflict in the 21st Century*, 233.
[30] Chemical Weapons Convention Treaty.
[31] McGeary and Quinn-Judge, "Theater of War."
[32] FDA, NADA 139-633 WILDNIL.
[33] FDA, NADA 139-633 WILDNIL.
[34] Joint Non-Lethal Weapons Program official Web site.
[35] Singer, *Wired for War: The Robotics Revolution and Conflict in the 21st Century*, 230.
[36] Huber, *Death by a Thousand Cuts: Micro-Air Vehicles in the Service of Air Force Missions*, 5.
[37] Army Field Manual (FM) 3-24, Counterinsurgency, 1-21.
[38] Chemical Weapons Convention Treaty.
[39] *FY2009-2034 Unmanned Systems Integrated Roadmap*.

Bibliography

AirRobot UK, "AirRobot AR100B." http://www.airrobot-uk.com/air-robot-products.htm

AirRobot UK, "AirRobot AR100B Technical." http://www.airrobot-uk.com/images/products/technical.pdf

Army Field Manual (FM) 3-24, *Counterinsurgency*, December 2006.

Blanchard, Alan. "An Experimental Investigation of Wall-Cooling Effects on Hypersonic Boundary-Layer Stability in a Quiet Wind Tunnel." PhD dissertation, Old Dominion University, December 1995.

Briefing. Miniature Munitions Systems Group. Subject: Small Diameter Bomb Increment I, 19 April 2006.

Chandler, David L. "Rethinking artificial intelligence." *MIT news*, 7 December 2009. http://web.mit.edu/newsoffice/2009/ai-overview-1207.html

Chemical Weapons Convention Treaty. http://www.cwc.gov/cwc_treaty_full.html.

Defense Advanced Research Project Agency, "Nano Air Vehicle." http://www.darpa.mil/DSO/thrusts/materials/multfunmat/nav/index.htm

Filkins, Dexter. "Stanley McChrystal's Long War." *New York Times Magazine*, 14 October 2009. http://www.nytimes.com/2009/10/18/magazine/18Afghanistan-t.html.

Food and Drug Administration, "NADA 139-633 WILDNIL - original approval." 26 Sep 1988. http://www.fda.gov/AnimalVeterinary/Products/ApprovedAnimalDrugProducts/FOIADrugSummaries/ucm111261.htm

FY2009-2034 Unmanned Systems Integrated Roadmap, Department of Defense, 2009.

Hambling, David. "Aussie Hovering Drone is Straight Outta Avatar." *Danger Room*, 17 December, 2009. http://www.wired.com/dangerroom/2009/12/australian-drone-perches-stares/

Holder, Bill. *Unmanned Air Vehicles.* Atglen, PA, Schieffer, 2001.

Human Rights Watch Backgrounder, "Cluster Bombs in Afghanistan." October 2001. http://www.hrw.org/legacy/backgrounder/arms/cluster-bck1031.htm

Huber, Lt. Col. Arthur F. *Death by a Thousand Cuts: Micro-Air Vehicles in the Service of Air Force Missions*. Maxwell AFB, AL: Air University Press, July 2002.

Ilaya, O, C Bil, and M Evans, "Control design for unmanned aerial vehicle swarming," *Journal of Aerospace Engineering*, (2008) 549-569.

Innovative UAV Aircraft & Aerial Video Systems, "DraganFlyer X4: Quad Rotor Flight Stability." http://www.draganfly.com/uav-helicopter/draganflyer-x4/

Innovative UAV Aircraft & Aerial Video Systems, "DraganFlyer X4Helicopter Tech Specs." http://www.draganfly.com/uav-helicopter/draganflyer-x4/specifications/

Joint Non-Lethal Weapons Program official Web site. https://www.jnlwp.com.

Lewis, Scott A. and Weiss, Lora G, "Intelligent autonomy and performance metrics for multiple, coordinated UAVs." *Integrated Computer-Aided Engineering* 12 (2005) 251–262.

McGeary, Johanna and Quinn-Judge, Paul. "Theater of War." *TIME*, 4 November 2002. http://www.time.com/time/europe/magazine/2002/1104/cover/story.html.

Public Broadcasting System, "Vietnam Passage. The Perspectives: Landmines: War's Lingering Menace." http://www.pbs.org/vietnampassage/perspectives/perspectives.landmines.html

Pines, Darryll J. and Bohorquez, Felipe. "Challenges Facing Future Micro-Air-Vehicle Development." *Journal of Aircraft* 43, no. 2 (Mar-Apr 2006): 290-305.

Raney, David L. and Slominski, Eric C. "Mechanization and Control Concepts for Biologically Inspired Micro Air Vehicles." *Journal of Aircraft* 41, no. 6 (Nov-Dec 2004): 1257-1265.

Schlichting, Hermann. *Boundary Layer Theory*. New York, NY, McGraw Hill, 1987.

Singer, P.W. *Wired for War: The Robotics Revolution and Conflict in the 21st Century*, New York, NY: The Penguin Press, 2009.

Smith, General Rupert. *The Utility of Force*. New York, NY: Vintage Books, 2007.

Tsuzuki, Noriaki, Shunicki Sato, and Takashi Abe, "Design Guidelines of Rotary Wings in Hover for Insect-Scale Micro Air Vehicle Applications." *Journal of Aircraft* 44, no. 1 (Jan-Feb 2007): 252-263.

University of Missouri-Columbia (2009, October 9). "Smaller And More Efficient Nuclear Battery Created. *ScienceDaily*." http://www.sciencedaily.com/releases/2009/10/091007124723.htm.

Warwick, Graham. "Nano-UAV Video." Aviation Week, 1 July 2009. http://www.aviationweek.com/aw/generic/story_generic.jsp?channel=defense&id=news/NANO070109-3.xml&headline=Nano-UAV%20Video