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<b>14. ABSTRACT</b> The use of bees in warfare predates 400 BC. The unique characteristics of the honey bee are currently being exploited in three ways which may advance military capabilities in the future. First, using the Free Flight Method of Landmine Detection, trained bees are released near a suspected minefield and within minutes they detect and congregate over landmines. Secondly, inside Contained Detection Devices trained bees extend their straw like tongues, called proboscises, when they encounter the odors of explosives. The bees' reaction, known as the Proboscis Extension Reflex (PER), is captured by pattern-recognition software, it statistically translates the bees' behaviors into an electronic response which then alerts the operator. Thirdly, in the Hybrid Insect Micro-Electro-Mechanical Systems (HI-MEMS) project, researchers are attempting to develop technology to create cybernetic organisms, cyborgs, out of bees and other insects. The objective is to control the cyborgs' flight and motions by remote control. Used individually or in swarms, cyborgs could potentially conduct reconnaissance missions, deliver toxins, collect intelligence, track targets, and retrieve samples, all while blending in with the environment.					
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MASTER OF MILITARY STUDIES

MILITARY APPLICATIONS OF APICULTURE: THE (OTHER) NATURE OF WAR

SUBMITTED IN PARTIAL FULFILLMENT  
OF THE REQUIREMENTS FOR THE DEGREE OF  
MASTER OF MILITARY STUDIES

BY  
ASSISTANT SPECIAL AGENT IN CHARGE LOIS DELANEY  
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## EXECUTIVE SUMMARY

**Title:** Military Applications of Apiculture: The (other) Nature of War

**Author:** ASAC Lois Delaney, US Drug Enforcement Administration

**Thesis:** Historical uses of apiculture in warfare are largely primitive; however, the unique characteristics of the honey bee may advance military capabilities in the future.

**Discussion:** Historical uses of bees in warfare predates 400 BC, when Aeneas Tacticus, aka Aineias the Tactician, author on the art of war, wrote *How to Survive under Siege*, which discusses deployment of bees in defense of a fortified position. Throughout the globe, across the sea, and in the American Civil War, the World Wars, and the Vietnam War, honey bees have been unwitting participants.

*Free Flight Method of Landmine Detection-* Landmines continue to be a threat to the military and civilians. Traditional mine detection is slow and dangerous. Recently, scientists have exploited the honey bees' exceptional sense of smell, and through Pavlovian conditioning have trained bees to detect the scent of various explosive materials. Conditioned bees can be released near a suspected minefield and within minutes they detect and congregate over landmines.

*Contained Detection Devices -Proboscis Extension Reflex (PER)-* Researchers keyed on the bee's natural instinct of extending its straw like tongue, a proboscis, when it encounters odors it associates with food. Bees trained to associate the scent of explosives with food, exhibit the Proboscis Extension Reflex (PER). The bees are being placed in portable detection units; pattern-recognition software statistically translates the bees' PER behaviors into an electronic response which is then displayed on a Personal Data Assistant (PDA). The unit has accurately detected explosives on persons, in places and things.

*Hybrid Insect Micro-Electro-Mechanical Systems (HI-MEMS)-* The HI-MEMS project is attempting to develop technology to create cybernetic organisms, cyborgs, out of bees and other insects. The objective is to control the cyborgs' flight and motions by remote control. The cyborgs are to be outfitted with one or multiple sensors, such as a microphone, video camera or gas sensor and will have the capability to stream collected data. Used individually or in swarms, cyborgs could potentially conduct reconnaissance missions, deliver toxins, collect intelligence, track targets, and retrieve samples, all while blending in with the environment.

**Conclusion:** The free flight method of landmine detection is a promising technique which will likely be utilized on a global scale for humanitarian demining. Contained Detection Devices (PER) units need to be implemented in prolonged actual real life conditions before its military operability can be determined. The HI-MEMS project is still under development; therefore, its actual viability is unknown. Historically, currently and futuristically, military applications of apiculture are relevant.

## Preface

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In 2007, I became aware of Colony Collapse Disorder (CCD), a global phenomenon in which honey bees are disappearing in record quantities. Honey bees are pollinators of 80 percent of our agricultural products; CCD is having a negative impact on pollination and food production. The emerging crisis motivated me to become a beekeeper in an effort to help repopulate the honey bee.

An unintentional by-product of maintaining several hives was plentiful honey, which led to my high school aged daughter establishing a nonprofit honey company, Bee Blessed Honey. In partnership with a community recycling group the honey is bottled in recycled glass jars. Raw, unpasteurized wildflower honey, such as ours, contains pollens derived from the local flora and is proven to naturally build the consumer's immunity against seasonal allergies. The medicinal benefits have secured customers preordering the entire amount of honey produced every season and all profits are donated to charity.

The study of apiculture has been rewarding and has led me to delve into many other related topics. Early on in my beekeeping literature I had read a reference to Romans' soldiers catapulting hives, later when enrolled in the Command and Staff College, I became interested in researching historical and current military applications of honey bees.

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This paper will briefly discuss the association between war and insects; it will then examine past and futuristic military applications of apiculture. The Defense Advanced Research Agency (DARPA), has sponsored honey bee research in the areas of Free Flight Landmine Detection, Contained Detection Devices based on Proboscis Extension Reflex (PER), and Hybrid Insect Micro-Electro-Mechanical Systems (HI-MEMS). The unique characteristics of the honey bee can be exploited to advance demining, security, and other military capabilities in the future.

War and insects have always maintained a clandestine relationship. The most direct linkage has been through insect-borne diseases such as typhus, transmitted through the bite of lice and ticks; bubonic plague, contracted through lice and fleas; and malaria and yellow fever, transmitted by infected mosquitoes. During war, overcrowding, mixing of populations, limited medical care, decreased hygiene, and malnutrition are common; these factors make soldiers more susceptible to disease and facilitate epidemics.<sup>1</sup> Spontaneous insect-borne epidemics have greatly influenced or even determined the outcome of wars. Napoleon Bonaparte's *Grande Armee* suffered high casualties; however, for each soldier killed in battle four others died from disease.<sup>2</sup> Of the casualties in the American Civil War, two-thirds were caused by disease. In both cases, the primary causes of the diseases were insect-borne pathogens.<sup>3</sup>

Aside from the natural spread of disease by insects, there are three ways insects have been weaponized. Insects have been used to deliberately transmit pathogenic microbes in order to spread disease among the enemy, to introduce agricultural pests intended to destroy livestock and crops, and to perform direct attacks on humans to infect injury or fear.<sup>4</sup> The conscription of insects has been a documented practice for centuries. Deployed hornets defeated enemies in the *Old Testament*, according to EXODUS 23:28 "I will send the hornet ahead of you to drive the

Hivites, Canaanites and Hittites out of your way,” DEUTERONOMY 7:20 “Moreover, the

LORD your God will send the hornet among them until even the survivors who hide from you have perished,” and JOSHUA 24:12 “I sent the hornet ahead of you, which drove them out before you--also the two Amorite kings. You did not do it with your own sword and bow.”<sup>5</sup>

For insect missions aimed at inflicting injury or fear and which may require pursuit, flying venomous bugs which can be deployed in mass, such as hornets, wasps and bees, are well suited.

Among these, the bee, and specifically *Apis Mellifera* - the honey bee, is evidently the favored winged warrior. Perhaps the bond of over 5000 years of beekeeping has helped to make man and honey bee trusted allies. The practice of apiculture, the harvesting of honey and bee's wax, is commonly performed in near proximity of one's residence. The construction of some

medieval castles, forts, and homes included recesses on the outer walls, called bee boles or bee niches, where bee hives were kept. Not only did the recesses protect the hives from foul weather, the bees were readily accessible, and the hives could be pushed off the ledge by

reaching through a passage hole on the inside of the wall. The falling hives hampered enemies who were attempting to penetrate or scale the structure.<sup>6</sup> The Romans believed that bees provided omens which foretold the outcome of military conflicts, a sighting of a swarm signaled misfortune.<sup>7</sup> Experts in bee management, the Romans made panoptic use of bees in warfare.

Romans routinely catapulted beehives over the walls of garrisons or fired the hives directly into enemy forces; the practice was so widespread that it is believed to have endangered the number of hives towards the end of the Roman Empire.<sup>8</sup> In some cases, even the bee's honey was used a weapon. While fighting in Asia Minor against the Heptakometes, Roman soldiers led by Pompeii the Great, consumed jars of honey they had discovered along a mountain path. The soldiers became seriously ill and “were afflicted as if they had all gone mad.”<sup>9</sup> The



Heptakometes then emerged, attacked and defeated the soldiers. The Heptakometes had set the honey out as bait because they knew that the honey was derived from the nectar of the local Rhododendron plants, a substance safe for bees but poisonous to humans. Understandably, when the Romans later conquered the region, they refused to accept honey as payment for the war tax.<sup>10</sup> In 946, the Slavic St. Olga, the first saint of the Russian Orthodox Church and a ruler of Kiev, avenged her son's death with the use of mead, also known as honey wine. She served the mead to 5000 of her enemies who were attending her son's funeral. Once intoxicated, they were slain by St. Olga's allies.<sup>11</sup> In the 1100's, Roman Catholic monk and historian, William of Malmesbury, reported that under the reign of King Stephen of England, army commander Robert Fitzhubert "used to expose his prisoners, naked and rubbed with honey, to the burning heat of the sun, thereby exciting flies and other insects of that kind to sting them."<sup>12</sup>

A sacred Mesoamerican text, the *Popul Vuh*, details accounts of the ancient Mayans in Guatemala constructing warrior manikins to make their army appear larger. The heads of the manikins were hollowed gourds filled with bees. When the enemy attacked, the gourds dislodged, broke and released the bees; the Mayans then gained the advantage in the ensuing chaos.<sup>13</sup> The Mayans also molded hollow clay spheres with a small entrance hole in each. The spheres were placed near bee colonies which soon took up residence. Before battle, the spheres' entrances would be plugged with grass which effectively trapped the bees inside, but permitted oxygen flow. During battle, the "bee grenades" would be lobbed into the ranks of the enemy, shatter, and release the angry bees.<sup>14</sup>

In 400 BC, Aeneas Tacticus, aka Aineias the Tactician, a General of the Arcadian League and Greek author on the art of war, wrote *How to Survive under Siege*, which discusses methods of defense in a fortified position. He prescribes "besieged people to release wasps and bees into

tunnels being dug under their walls, in order to plague the attackers.”<sup>15</sup> Tacticus’ method proved successful for Ethelfleda of Mercia in 908, when the fortification surrounding the city of Chester, England was attacked by Danes and Norwegians led by Hingamund (Old Norse: Ingimundr). The Scandinavians were unable to break through the walls so they dug tunnels and were undeterred until the inhabitants threw all the city’s beehives into the burrows.<sup>16</sup> In 939, Geiselbert Duke of Lorraine attacked a fortified position of King Otto I of Germany. Bee hives were thrown at the Duke’s cavalry, the horses were stung severely and panicked; it caused the siege to be a complete failure.<sup>17</sup> The citizens of Gussing in Burgenland (now Austria) repelled Duke Albert of Austria and his army in 1289, by deploying a combination of “hot water, fire bands and bee hives.”<sup>18</sup> An English manual on military weapons by Walter de Milemete in 1326, contains a sketch of a windmill type device launching bee hives, a second sketch depicts the hives descending on a fortress and its soldiers being attacked by bees.<sup>19</sup> The *Kissingen Parish Chronicle* (Bavaria) reported that in 1642, Swedish soldiers led by General Reichwald attacked the town and were forced to retreat when the defenders threw bee hives on them.<sup>20</sup>

In the 18<sup>th</sup> century, a number of violent conflicts between the Austrians and the Turks took place in Belgrade. At one point the Turks penetrated the city walls but were stopped by a barrier of bee hives.<sup>21</sup> Honey bees also served in the Navy, “As early as 332 BCE, earthen hives were thrown onto enemy decks, and with the advent of the catapult, bees and hornets became standard projectiles on the high seas. Across the Greco-Roman and Syro-Palestinian worlds and into the Middle Ages, warships carried bee hives as part of their arsenals.”<sup>22</sup> Records kept by Abbe Della Rocca in 1790 relay an incident in which a small privately owned war vessel was chased and boarded by an armed Turkish galley. The crew of the smaller vessel climbed its rigging and threw earthenware hives at the Turks.<sup>23</sup> In Nigeria, the Tiv people fed a portion of their bees

poison, allegedly causing the sting to be lethal.<sup>24</sup> On the battlefield the Tivs projected the poisoned bees at their enemies through “bee cannons,” created from large custom-made horns.<sup>25</sup>

During the American Civil War, at the Battle of Antietam, brigades under Union General William French, crossed the fields of the Roulette Farm, outside of Sharpsburg, Maryland.<sup>26</sup> While advancing, the rookie 132nd Pennsylvania Volunteers sought cover in the Roulette’s bee yard until a Confederate cannon ball tore through a row of hives. “The slapping, swearing regiment was disintegrating and the Union commanders worried the panic would spread across the entire front. The Pennsylvania unit was ordered to double-quick march past the Roulette farm, which allowed the troops to escape the bees but left them without cover. The Confederates exploited the opportunity with a devastating volley of musketry.”<sup>27</sup>

A woman in Georgia used her honey bees to prevent both Union and Confederate soldiers from plundering her farm. The woman fastened a cord to one of her hives and ran the cord through a hole into her house. As soldiers approached, she pulled the cord, the hive fell, and angry bees drove the soldiers away. This line of defense was successful on numerous occasions.<sup>28</sup>

In World War I, the Germans used trip wires strung to bee hives in order to delay advancing British troops.<sup>29</sup> In a separate incident, Belgian soldiers trapped in an apiary managed to escape, in part by throwing frames of bees at the Germans.<sup>30</sup> During the Italian conquest of Ethiopia (1935-6), the natives dropped bee hives from mountain heights on to Italian tanks and “the bees easily entered the tanks, terrorizing the Italian drivers and causing the loss of several tanks.”<sup>31</sup> Attacks by bees were also a concern for US tank soldiers in Vietnam. The book *Vietnam Tracks: Armor in Battle, 1945-1975*, states “A swarm of bees descending on a tank was no trivial matter, and several crews became seriously ill as a result of multiple stings.”<sup>32</sup> The Asian honey bee,

*Apis Dorsata*, is larger and more aggressive than domestic honey bees, and both the North and South Vietnamese devised booby traps to disrupt the wild hives in the jungle.<sup>33</sup>

In the past, honey bees have been used in both defensive and offensive measures. A recent defensive application under development involves the detection of landmines. Landmines have been widely used as weapons of war since the mid 19<sup>th</sup> century. They are easily manufactured, inexpensive and effective.<sup>34</sup> Landmines serve three functions in warfare: (1) to delay forces resulting in a loss of synchronization and loss of surprise; (2) to damage or destroy vehicles and dismounted soldiers; and (3) to cause fear and anxiety in enemy troops.<sup>35</sup> Unfortunately, even with the assistance of the United Nations and humanitarian organizations, many post conflict nations lack the resources and infrastructure to clear their minefields and innocent civilians have become the primary victims.<sup>36</sup> Additionally, the presence of landmines prevents civilians from resuming normal activities, such as farming, which in turn delays the country's post conflict recovery.<sup>37</sup> An estimated 45-50 million mines were not yet cleared in 2001.<sup>38</sup> A 2003 study conducted by the RAND Corporation, estimates 15,000 - 20,000 casualties are caused by landmines each year, of which over 30 percent of the victims are children.<sup>39</sup> Blast survivors commonly suffer the loss of limbs, have shrapnel wounds and may be blinded.<sup>40</sup> The RAND study suggests that at the current rate in which minefields are being cleared by government and nongovernmental organizations, it will take between 450-500 years to clear them all, and that is if no new landmines are laid.<sup>41</sup>

In conventional mine detection, an area is divided into grids and a deminer using a metal detector and a prodding stick, sweeps the detector close to the ground and slowly advances forward.

When the detector sounds an alert, the deminer probes the area with the stick. If the object is

determined to be a mine, it is detonated using one of an array of detonation methods. This type of mine detection is extremely dangerous and slow, it has changed little in the past 40 years. The RAND report, *Alternatives for Landmine Detection*, evaluated multiple emerging and innovative mine detection technologies. RAND grouped the landmine detection systems into five major categories: Electromagnetic, Acoustic/Seismic, Bulk Explosives, Advanced Prodders/Probes and Explosive Vapor; each system has strengths and limitations.<sup>42</sup> Detection of explosive vapors is the method which identifies the location of mines by their emanating odor. This category includes the use of trained sniffing dogs and more recently the use of trained honey bees in free flight landmine detection.<sup>43</sup>

Nearly all buried landmines leak explosives or chemical derivatives into the ground.<sup>44</sup> Approximately “95 percent of the explosive will absorb to the surrounding soil, the remaining 5 percent will travel away from the mine, mostly through dissolution in water in the soil pores. Some of this explosive will migrate to the ground surface in vapor form.”<sup>45</sup> Thus the concentrations of vapors present for detection are exceptionally low, requiring the sensor (i.e. dogs or bees) to be able to perform detection at an incredibly low threshold.<sup>46</sup> Demining dogs are valuable assets in locating landmines; some dogs possess a higher olfactory sensitivity than mechanical detection instruments.<sup>47</sup> Demining dogs, trained to react to the odor of trinitrotoluene (TNT) and other explosive compounds, proceed through minefields followed by their handlers. When the dog detects an explosive scent, it sits down and the handler or another deminer examines the area with a probe to determine if it is a mine. Although sniffing dogs are effective, the degree of effectiveness varies from dog to dog. A dog’s training and the ability of its handler are factors, as well as environmental conditions such as weather and terrain.<sup>48</sup> Utilizing

demining dogs is problematic in that the dog's weight can trigger landmines, multiple dogs cannot be deployed at once, making the search process slow, and because a minefield must be searched thoroughly and repeatedly dogs quickly become fatigued.<sup>49</sup>

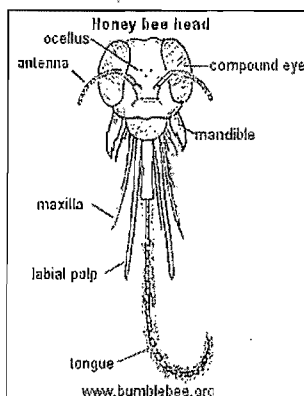
DARPA has a billion dollar a year budget to test innovative ideas for defense applications.<sup>50</sup>

DARPA began seeking researchers to develop safer, more efficient methods of locating landmines. Aware that scientists at the University of Montana (UM) had already capitalized on the foraging characteristics of honey bees to assist in monitoring environmental conditions, DARPA contracted the UM to perform research to determine if the honey bees' keen sense of smell could be exploited to detect explosives.<sup>51</sup>

For the previous thirty years, UM researchers had been utilizing honey bees to collect samples of the environment. Honey bees are natural foragers; they forage for water, nectar, propolis, and pollen. Honey bees are diligent workers and cover large distances; in order to create one pint of honey, the bees visit approximately 5 million flowers.<sup>52</sup> Additionally, bees from just one hive often make tens of thousands of foraging flights a day. They routinely travel within a two-three mile radius, encompassing almost 6000 acres.<sup>53</sup> Honey bees have branched hairs all over their bodies which create a static charge. The hairs pick up chemical and biological particles from the environment. UM researchers positioned hives near areas of interest, such as landfills or chemical plants, and relied on the bees to take passive samples. When the bees returned to their hive, the trace particles on the bees were tested, as well as the honey and the bees wax. Through the sampling data scientist are able to evaluate the environment by testing for pollutants. The

method also has a military application because the environment can be assessed in the same way for the presence of biological warfare agents or explosives.<sup>54</sup>

At DARPA's direction, UM scientist subsequently focused their efforts on conditioning their bees to seek specific "odors of interest."<sup>55</sup> The bees' sense of smell, or olfactory abilities, is extraordinary. Bees' two antennae consist of 3,000 microscopic sensory organs, which can distinguish over 170 various scents in nature.<sup>56</sup> Bees use their olfactory abilities to locate food, but also as a method of communication. Bees produce a variety of pheromones, which are chemical scents. The release of pheromones triggers behavioral responses from other bees. The scent can be used as a navigational aid; it can communicate a bee's developmental status, wellbeing, sexual attraction, urgency for productivity, or alarm.<sup>57</sup>



## FREE FLIGHT LANDMINE DETECTION

UM researchers succeeded in orientating honey bees to specific "odors of interest" by supplementing the bees' food with trace amounts of explosive byproducts used in landmines.<sup>58</sup> The bees quickly learned to associate the scent of the explosives with food.<sup>59</sup> Caffeine, which improves the bees' memory was also added to the bee food along with a unique mixture of other substances (patent pending), which bees actually prefer over their natural food sources.<sup>60</sup> After

just one or two days of conditioning, a colony of bees (approximately 40,000) can be released in the area of a minefield and they will seek out the scent of the explosive compounds they were conditioned for, while completely ignoring the flora.<sup>61</sup> The conditioning method requires very little effort, is inexpensive, and can be used to train tens of thousands of bees at one time to detect a variety of explosive compounds.

The University of Montana, DARPA, Sandia National Laboratories (SNL) and the Air Force Research Laboratory (AFRL), have participated in a number of trials held at Fort Leonard Wood Army base in Missouri. Fort Leonard Wood maintains minefields and utilizes them for testing purposes. The mines are active but are unfused. Colonies of conditioned bees were positioned safely on the outer perimeter of one of the minefields. Within minutes of being released, the bees detected the landmines' vapor plumes and followed the scent of the plume several meters to its source.<sup>62</sup> The bees dwelled above the source and although they didn't receive a food reward, they continued to visit the spot repeatedly. Those areas which became densely covered with bees and where bees exhibited longer dwelling time indicated where the explosives were buried.<sup>63</sup> The tests were conducted with explosive chemical concentrations so small that they are measured in parts-per-billion (ppb) and parts-per trillion (ppt). An example of one ppb is the equivalent of a single drop of ink in one of the largest tanker trucks used to haul gasoline; the ink concentration would be 1 ppb.<sup>64</sup> The concentration of one ppt is equivalent to one drop of ink in a string of railroad tanker cars ten miles long; the ink concentration would be 1 ppt.<sup>65</sup> The explosive chemical 2,4-dinitrotoluene (DNT), which is a byproduct of trinitrotoluene (TNT) manufacturing, is the overriding chemical found from the majority of landmines.<sup>66</sup> In the tests, using 2,4 DNT in vapor concentrations at ppb and ppt, the bees' detection rate was between 97



and 99 percent.<sup>67</sup> The average vapor concentration in minefields is approximately 0.01 -100 ppb; therefore, is well within the range of detection by honey bees.<sup>68</sup> Additionally, scientists “calculated a 1.0-2.5 probability of false positive, and less than a 1 percent probability of false negative, based on three different statistical sampling strategies. Calculated receiver operating characteristics (ROC) curves for 10 ppb through 0.0001 ppb indicated that for doses higher than 0.01 ppb (10 ppt), the bee system behaves like a very fine-tuned, nearly ideal, detector.”<sup>69</sup>

The bees’ ability to detect explosive odors at low concentration exceeds that of nearly all manmade detection methods and can equal that of demining dogs.<sup>70</sup> The bees were able to correctly identify the targets over a plotted area in less than one hour, while a search of the same area by demining dogs would have taken hours or days.<sup>71</sup> There are several additional advantages of utilizing bees rather than dogs: 1) bees weigh one-tenth of a gram so they won’t trigger mines; 2) bees do not require a handler to enter the minefield; 3) bees can be trained and deployed within a day; 4) bees operate autonomously and search areas repeatedly; 6) once deployed the bees need no guidance and they independently return to the hive at dusk ; 7) bees from local beekeepers across the globe can be used, and 7) overall costs are far lower than dog teams.<sup>72</sup>

There are limitations to utilizing bees for the detection of mines; bees do not fly at night, during heavy rain or strong winds, and they remain in the hive when temperatures are below 40 degrees Fahrenheit.<sup>73</sup> These limitations are almost inconsequential given mine detection is not a nighttime activity and detection based on vapors will be severely hampered in rain or winds in and of itself.

A major obstacle to deploying bees over large areas to locate landmines is the ability to track and plot the bees effectively.<sup>74</sup> Bees can easily fly upward of 2 ½ miles from the hive in a single foraging trip; therefore, visual observations and use of cameras or video are only feasible at short-range.<sup>75</sup> Initial, and since abandoned tracking techniques included dusting the bees with a reflective florescent powder and fitting the bees with miniature radio frequency tags.<sup>76</sup> At the Fort Leonard Wood trials tracking became far more proficient with the use of Light Detection and Ranging (LIDAR) technology. In coordination with the National Oceanic and Atmospheric Administration (NOAA), a LIDAR system which was developed and utilized for tracking fish was adapted to map the position of the bees.<sup>77</sup>

LIDAR is similar to radar which uses radio waves, and to sonar which uses sound waves. LIDAR emits a pulsed laser light in conjunction with a photomultiplier. The unit scans back and forth, horizontally over a specified area.<sup>78</sup> As it strikes the bees, the light is reflected back and the return signal indicates the location of the bees.<sup>79</sup> Essentially, "Individual bees are located by synchronizing the detection of scattered light with the timing emitted laser pulses and the position of the beam."<sup>80</sup> With the generated data, the location and dwell time of the bees was mapped and showed an accurate depiction of the placement of the mines.<sup>81</sup> Interestingly, in the same trial, the LIDAR also detected bee congregation in an area outside the mine area, in what was believed to be a mine free control area. Throughout the three day trial, a number of the bees gathered on the exact same spot in the control area. A sample was taken of the pinpointed soil and was determined to contain TNT and DNT. The bees had located an explosive contaminate in the control area which no one had been aware of previously.<sup>82</sup> The LIDAR system is

undergoing refinement and modifications to make it more light-weight and field-portable.<sup>83</sup>

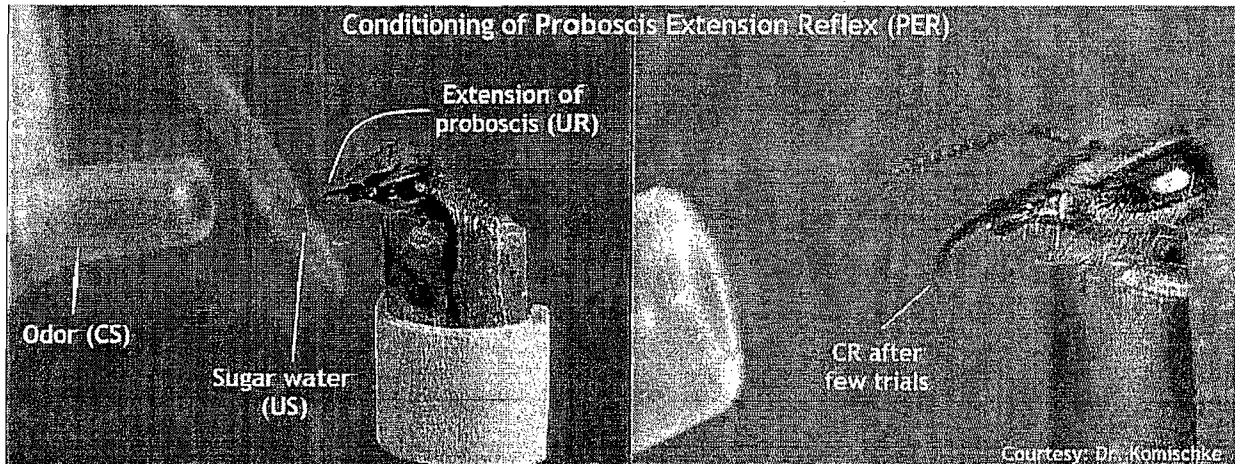
Although further sophistication in LIDAR is being sought by researchers, the simplicity of the bee detection system still allows beekeepers across the globe to rapidly and inexpensively use the low-technology version. Theoretically, a beekeeper only needs a sampling of mine contaminated soils and sugar water to train his bees, along with a ladder and binoculars to observe the bees in a suspected mine laden area.<sup>84</sup>

The use of bees for mine detection is most beneficial in area reduction, which is the process which reduces the size of an initial area thought to be contaminated with mines to a smaller area. Area reduction frees up land so that it can be repopulated, serve as transportation routes, be used for farming or other post war recovery purposes. During war, bee colonies can be disturbed or destroyed; therefore, establishment of additional bee hives also assists in the recovery process because bees are essential for pollinating many crops.<sup>85</sup> It is unlikely that bees will replace the use of dogs in mine detection; however, bees can be used in combination with the efforts of demining dogs and other methods, decreasing the time and costs of demining.<sup>86</sup>

#### **CONTAINED DETECTION DEVICES - PROBOSCIS EXTENSION REFLEX (PER)**

After determining honey bees could be trained to detect explosive chemicals, researchers began seeking military applications in addition to the free flight method used for landmine detection. With sponsorship from DARPA, the Los Alamos National Laboratory (LANL), in New Mexico, initiated the Stealthy Insect Sensor Project, as a collaborative effort of its Bioscience, Chemistry and Environmental Protection Divisions.<sup>87</sup> In this instance, researchers keyed on the bee's natural instinct of extending its straw like tongue, a proboscis, when the bee encounters odors it

associates with food. Again using Pavlovian conditioning techniques, the bees were exposed to puffs of air which contained vapors from explosives and immediately afterward were then given a reward of sugar water. As the bees became conditioned, they exhibited the Proboscis Extension Reflex (PER) when they detected the chemicals in the air.<sup>88</sup>



<http://abidhussaini.com/info/research/phd/project-1/honeybee-conditioning>

Since bees only use their proboscis for feeding, the PER indicates a positive detection response for substances it associates with food. LANL researchers developed a shoebox sized prototype unit, called a sniffer box, in which three restrained bees were placed. A camera inside the box was focused on the heads of the bees and the image was transmitted to a laptop computer.<sup>89</sup> When activated, the unit obtained air samples from the exterior, pulled it into the box and blew it over the bees. The bees showed no reaction when exposed to uncontaminated air samples and exhibited PER when exposed to air samples containing trace explosive vapors.<sup>90</sup> In 2005, LANL researchers held a demonstration for representatives of DARPA, the US Southern Command, and the US Marines.<sup>91</sup> The researchers constructed three test settings designed to simulate real life explosive detection scenarios. In a curbside explosive scenario, the sniffer unit was exposed to an uncontaminated crate and a crate containing TNT. For a terrorist scenario,

two individuals were checked by the sniffer unit, one individual wore a vest containing C4 and the other did not. During a checkpoint scenario, an empty vehicle and a vehicle loaded with both C4 and TNT were subjected to the sniffer unit. The guest representatives along with the researchers were able to observe the bees' images on the laptop computer and in each scenario; the bees correctly identified the objects containing explosives by exhibiting the PER.<sup>92</sup>

A United Kingdom (UK) based biotechnology company, Inscentinel Ltd., improved upon LANL's prototype sniffer box.<sup>93</sup> When air samples were drawn into LANL's sniffer box, a human operator was required to observe the bees' image on a computer screen, determine if all or some of the bees were exhibiting the PER, and make a conclusion if the bees' behavior was a positive or a negative response.<sup>94</sup> In the more advanced Inscentinel's detection unit the VASOR 136, which uses Volatile Analysis by Specific Olfactory Recognition (VASOR), the need for human observation and interpretation are eliminated. A camera inside the VASOR 136 is linked to movement and pattern-recognition software which statistically translates the bees' behaviors into an electronic response and is then displayed on a Personal Data Assistant (PDA) screen.<sup>95</sup> A single dysfunctional bee will not cause the software to trigger a false alarm.<sup>96</sup>

The VASOR 136 detection unit is a hand held device that resembles an automobile vacuum. In order to load and operate the unit, conditioned bees are first subjected to cooler temperatures which do not harm the bees but slows down their movements for ease of handling. Thirty-six (36) bees are then placed into humane, reusable bee harnesses; once secured, they are allowed time to acclimate. The harnesses are then snapped into six (6) cassettes and loaded into the unit.<sup>97</sup> Inside the unit, a clean filtered airstream is continuously passed over the bees until the

operator activates a button which draws in an unfiltered sample of air from the immediate area.

Air samples containing even trace vapors of a substance the bees are conditioned for, will cause the bees to PER. The responses of all 36 bees are immediately interpreted by the software and a result is displayed on the PDA screen which can be read by any operator.<sup>98</sup> The PDA displays red for a positive result, meaning the bees detected the targeted substance; a green display indicates a negative result.<sup>99</sup> The bees are resilient and diligent; they can easily perform a weeklong tour of duty before being returned to their hives.<sup>100</sup>

In addition to DNT, TNT and C4, bees can be trained to exhibit PER when they detect a wide array of explosives compounds. Bees can detect Howitzer propellant grains which can be used in Improvised Explosive Devices (IEDs).<sup>101</sup> They can also detect Semtex, PE4, DMNB, gunpowder, and hydrogen peroxide which is sometimes an ingredient of homemade bombs.<sup>102</sup> Triacetone triperoxide (TATP), an explosive used by Richard Reid, the shoe bomber, is often difficult for dogs to detect but not for bees.<sup>103</sup> The design of the VASOR 136 is more versatile than most electronic units. The majority of electronic sensing units are either narrowly specific to a single compound or to just a few compounds. The VASOR 136 contains 36 bees, each performing as an individual sensor.<sup>104</sup> Depending on which explosive compounds an operator desires to screen for, the bees could be trained differently for those tasks.<sup>105</sup> It allows for "all 36 bees can be trained to a single target odour to produce maximum confirmation of a detected target substance. Alternatively, bees can be trained in small groups to detect multiple target substances effectively resulting in a versatile screening system. Detection always relies on a statistical group of bees."<sup>106</sup> In cases in which an enemy attempts to circumvent detection by substituting a previously unused compound, bees can be retrained to detect the new compound

and be ready for redeployment in less than a day.<sup>107</sup> The cost of retraining bees is minimal, but it would take 4-6 months and cost roughly \$38,000 to train a dog to detect an alternate compound.<sup>108</sup> In an environment where counter detection measures are continually evolving, sensor technology can be outpaced and the adaptability of the bee becomes more valuable. Inscentinel Ltd., is currently developing a detection unit which will house seventy-eight (78) bees and be capable of detecting twelve (12) different chemicals at once.<sup>109</sup>

The VASOR 136 has been independently tested outside of laboratory settings. In 2004, the US military funded and performed a test of Inscentinel's bee sensor technology in order to evaluate its effectiveness in detecting car bombs. At a military facility in Arizona, local honey bees were trained, placed in Inscentinel sensing instruments, and were proven able to successfully detect car bombs from a string of vehicles.<sup>110</sup> In an independent test conducted by the UK Office for Security and Counter Terrorism (OSCT), the Inscentinel VASOR 136 was evaluated against an electronic detector, the Smith's Detection Sabre4000, in airport checkpoint scenarios. During the trial, the Inscentinel VASOR 136 was able to detect explosives in concentrations in the ppb range.<sup>111</sup> Detection units such as the Inscentinel VASOR 136, can be used for defense and security to detect roadside bombs, persons wearing explosives, persons having handled explosives, car bombs and explosive packages. The detection unit can be used as a portable device, remain static as persons or objects are passed by it, or it can be loaded on robotic equipment to be used in conjunction with bomb handling and disposal.

In order to survive in the wild, bees are very skilled at isolating the scent of specific flowers which are preferred food sources. Bees can detect and follow a single preferred scent through a

bouquet to other scents.<sup>112</sup> Through the sugar reward training, bees prioritize the scent they are conditioned for above others. Researchers found the bees to be incredibly diligent in their duties, despite attempts to distract them by masking the targeted scent with lotions, oils and even insecticides; the bees still performed the PER when presented with the conditioned scent.<sup>113</sup> Reinforcing the bees' training is as simple as exposing the bees to a "boost" of the targeted scent with food each morning.<sup>114</sup>

Researchers have found that the ability to learn and to detect scents do differ in individual bees.<sup>115</sup> Some bees have keener olfaction characteristics and researchers are exploring genetic and physiological differences between bees. Studies are also being conducted on bees' antennae, biochemical and molecular mechanisms have been discovered which may lead to a better understanding of bees' differing learning and retention abilities.<sup>116</sup> Ideally, a superior bee could be developed through genetic engineering

Honey bees can be trained to target almost any odor; so there are many other application possibilities. "In 2010, bee training in the fields of defense and security, medicine, food, and building industries is big business. Bee training is essentially the same as it was in 1999, but the results are attained with more sophisticated and less expensive technology."<sup>117</sup> Bees have already been trained to detect illicit narcotics, and could be taught to seek cadavers.<sup>118</sup> Simply by being exposed to a patient's breath, bees can detect the scent of certain diseases and hormones; bees are "being used as early detectors of lung and skin cancers, diabetes and TB, as well as to monitor fertility cycles and confirm pregnancies."<sup>119</sup> Detection of rapidly spreading bacteria such as *Escherichia coli* and salmonella in foods are also being tested.<sup>120</sup>



## HYBRID INSECT MICRO-ELECTRO-MECHANICAL SYSTEMS (HI-MEMS)

Since 2007, DARPA has been utilizing bees in an innovative defense project entitled Hybrid Insect Micro-Electro-Mechanical Systems (HI-MEMS).<sup>121</sup> The HI-MEMS project is attempting to develop technology to create cybernetic organisms, cyborgs, out of bees and other insects.<sup>122</sup> DARPA has provided funding to a number of universities and businesses, including the Massachusetts Institute of Technology, Cornell University, University of California, University of Michigan, and the Boyce Thompson Institute, to perform fundamental research and embed micro-electro-mechanical systems (MEMS) chips into developing insects' pupae during the initial stages of metamorphosis.<sup>123</sup> "Since a majority of the tissue development in insects occurs in the later stages of metamorphosis, the renewed tissue growth around the MEMS will tend to heal, and form a reliable and stable tissue-machine interface."<sup>124</sup> The objective is to control the cyborgs', or fondly called cybugs', flight and motions by remote control, using Global Positioning Systems (GPS), Radio Frequencies (RF), optical or ultrasonic signals.<sup>125</sup> Once remote control is accomplished, the cyborgs would be outfitted with one or multiple sensors, such as a microphone, video camera or gas sensor and would have the capability to stream the collected data.<sup>126</sup> The design of the MEMS chip seeks to "harvest enough energy from the insects' movements to power its wireless transceiver, sensors and probes."<sup>127</sup> Plans also include integrating very small fluidic devices to carry chemicals that could be delivered through the cyborgs' sting.<sup>128</sup> Ultimately, DARPA hopes to "hack into the insects' own natural senses, allowing the remote-control operator to look out of the insects own eyes, instead of attaching a video camera for it to carry."<sup>129</sup> Used individually or in swarms, cyborgs could potentially

conduct reconnaissance missions, deliver toxins, collect intelligence, track targets, and retrieve samples, all while blending in with the environment.<sup>130</sup>

DARPA spokespersons have confirmed that "this technology is being developed with defensive, offensive and national security strategies in mind."<sup>131</sup> The DARPA HI-MEMS website contends "we have used horses and elephants for locomotion in wars" and "more recently, olfactory training of bees has been used to locate mines and weapons of mass destruction;" therefore, the HI-MEMS technology is being developed to provide "more control over insect locomotion, just as saddles and horseshoes are needed for horses locomotion control."<sup>132</sup> DARPA asserts the "derived technologies will enable many robotic capabilities at low cost, impacting the development of future autonomous defense systems. The realization of cyborgs with most of the machine components inside the insect body will provide stealthy robots that use muscle actuators which have been developed over millions of years."<sup>133</sup> DARPA's enthusiasm is not universally shared; certainly there are ethical and legal implications of creating living robots for military and security purposes, especially if the cyborgs are weaponized with biological agents or other toxins. Concerns about the potential domestic use of the cyborgs for surveillance purposes have already been raised by the Electronic Frontier Foundation (EFF), a digital rights and civil liberties group. EFF Spokesman Peter Eckersley said "Anyone who is just a little bit creative can imagine both useful and non-productive applications of remote-controlled animals-- especially if ordinary people mistake them for normal animals."<sup>134</sup>

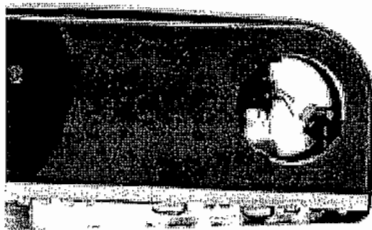
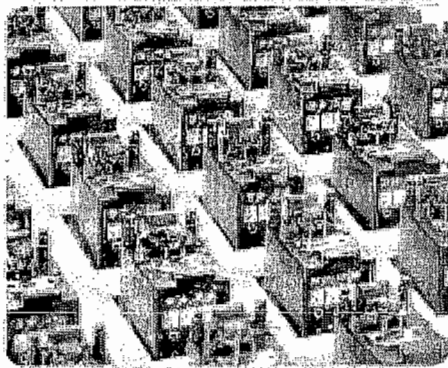
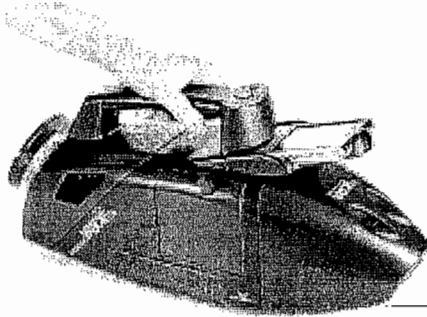
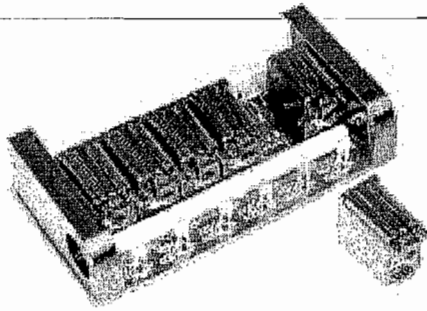
DARPA's primary interest is in creating cyborgs from flying insects; however, it also offers funding for research on hopping and swimming insects.<sup>135</sup> As of 2009, DARPA had invested

\$12 million into the project.<sup>136</sup> The HI-MEMS project is to be developed through three phases: the first phase is to create bio-electro-mechanical interfaces to the insects, the second phase is to control the locomotion using MEMS platforms, and the third phase is to scavenge power from the insects.<sup>137</sup> "To be considered successful, the final HI-MEMS cybernetic bug must fly 100 meters from a starting point and then be steered into a controlled landing within 5 meters of a specified end point. On landing, the insect must stay in place."<sup>138</sup> Despite many skeptics, the project is reported to be "progressing at a rapid pace."<sup>139</sup> Phase one has been accomplished, "DARPA funded research groups have succeeded in inserting a MEMS chip into an insect's pupae, with the adult being hatched successfully."<sup>140</sup> Cornell University demonstrated it had passed phase two in 2008, when tobacco hornworms implanted with MEMS chips developed into mature "moths whose muscles could be controlled with the implanted electronics."<sup>141</sup> Since 2009, videos have surfaced of various other cyborg insects taking flight which include horned beetles, butterflies, wasps, and naturally, bees.<sup>142</sup>

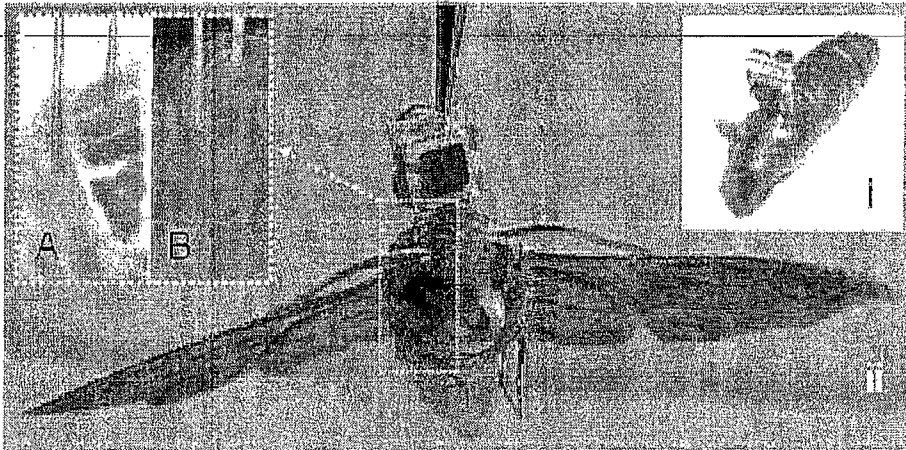
## CONCLUSION

The free flight method of landmine detection is highly effective and is a promising technique which will likely be utilized on a global scale for humanitarian demining. However, time constraints and conditions for bee management make it unfeasible for mine detection on the battlefield. The PER detection units have had outstanding results in laboratory tests, in controlled field tests, and in independent testing; however, units need to be implemented in prolonged actual real life conditions before its military operability can be determined. Even if these detections unit are never implemented on the battlefield, they can be of great value domestically at border crossings, airports, seaports and post offices. The HI-MEMS project is

still under development and a large portion of the project is classified; therefore, its actual viability is publically unknown. Conceivably, in addition to reconnaissance, cyborg insects could be fully weaponized and a single cyborg swarm could be used to simultaneously spread disease, destroy crops, infect food supplies, and engage in attacks on humans. The unique characteristics of the honey bee can be exploited to advance demining, security, and other military capabilities in the future.



<http://www.inscentinel.com/InscentinelLtd/Pages/technology.html>



*Figure 6: Pupal stage insertion (i) and successful emergence (ii). The microsystem platform on (ii) is held with tweezers to show wing opening of the moth. The X-Ray image of the dotted part (A) shows the probes inserted into the dorsoventral and dorsolongitudinal flight muscles. CT images (B) show components of high absorbance indicating tissue growth around the probe.*

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