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*There's always more room at the bottom (8/10/17)*

Though they may appear differently to those directly involved,[1] to the external observer the exploits of special forces operatives are the stuff of romance, and are governed by the logic of the adventure cinema. The romance of the commando is the romance of the ninja, the individual who by virtue of dedication and training has achieved more than human strength, stealth, and skill in the martial arts, and his[2] exploits take a familiar form: the assault by a small company upon an impregnable fortress, impervious to frontal assault; as we have seen it depicted in *The Guns of Navarone*, in the first installment of the *Mission Impossible* franchise, with its classic penetration of CIA headquarters, and in *Zero Dark Thirty*, which made a very bad argument for enhanced interrogation and a very good argument for targeted assassination.

Placed in this context, the concept of the special forces seems fixed and self-limiting. We can add a few technical improvements, stealth helicopters or HALO jumps, amplify the capabilities of our ninjas to reflect advances in related sporting activities like parkour and rock climbing, and (in film, at least) make the concession that every team must now include a hacker,[3] but the basic premise is always the same, and the plot varies only if we specialize to the more individualistic genre of the spy movie, in which Bond alone must penetrate the island of Dr. No, get captured, and against all odds outwit the evil mastermind and

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[1] Of course, I doubt it.

[2] The gender assumption is natural, though I'd take Michelle Yeoh over Roger Moore every time.

[3] Though making the movie about the hacker himself has not generally worked well, see *Swordfish* or *Blackhat*.

escape, killing a few dozen minions and blowing everything up in the process.

For the ninja himself, however, we can imagine no improvements other than better grips on his throwing knives, cooler utility belts and fingerless gloves, and maybe noncarcinogenic chewing tobacco; should an unwelcome realism enter our calculations, we might imagine better performance-enhancing drugs than mere amphetamines, or perhaps better communications gear, with features like heads-up map displays and network access to AIs which can translate foreign languages. In extremis we might imagine research on materials with negative refractive indices will pan out and our heroes may be able to fly in and out in invisible planes like Wonder Woman's, or don cloaks of invisibility like the Predator's. But any fundamental change in the job description seems impossible.

However the recent cinema — relying as it so often does now on previous published research in the comic books — indicates a way out of this impasse which, despite being absurd on the face of it, does show considerable promise.

I refer, of course, to *Ant-Man*; in which, though to be sure the protagonist is, indeed, a cat burglar who demonstrates pretty impressive ninja credentials before he puts on the suit, and the action does, of course, culminate in an assault on an impregnable fortress, the premises are modified by supposing the hero can shrink himself to the size of an insect by "reducing interatomic

distances."[4] And here it is particularly interesting that he is not a lone secret agent, but the commander of many varieties of ants, over whom he can exert some kind of telepathic control; one of them a miniature Pegasus he can ride while flying forth to his missions.

In fact it is this detail that renders the others moot, since it is obvious that the hero himself is superfluous; or would be, if as a complement to his telepathic ability to influence the actions of his ants he could in addition receive and synthesize their sensory inputs. For that would establish telepresence, indeed allow him to be many places at once, and make all the growing and shrinking unnecessary. — Of course this would leave us with a action movie without a human protagonist, which would bomb at the box office. But I think we can regard that as a secondary consideration.

The rest, however, seems completely plausible. Insects could penetrate any fortress, spy on anyone, anywhere, physically invade computer systems, injure or even kill anyone they encounter, and, if their efforts were sufficiently multiplied, damage or destroy any facility or military target. (Indeed it's worth noting that the most effective form of missile defense would be to insinuate insects into the silos, corrupt the weapons, and thus render them unusable before they can be launched.)

The only issue is communication and control.

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[4] Parenthetically this *is* in principle possible, or would be if one possessed a magic wand which when waved over the body of the ninja instantly turned all the electrons in his constituent atoms into muons. (One should also note that the energy required for the magic wand to function would be equivalent to the detonation of a hydrogen bomb and would be emitted in the form of gamma rays when he resumed normal size, that his weight would increase when he shrank so that his legs snapped and he sank through floors, etc., etc., but file all that under suspension of disbelief.) — This would be a very useful trick for other reasons: nuclear fusion could be achieved at very low temperatures, e.g.

Though it is possible that a combination of genetic engineering and cyborgian surgery may produce real insects that can be manipulated in the required fashion,[5] the simplest way to accomplish this is probably to replace them with robotic functional equivalents.

But really once we have stated the premise the rest is fairly obvious. Nothing speculative is involved; it is simply a matter of perfecting the design of existing prototypes.

We require flying and crawling insects in a variety of sizes. It is useful to think of the coordinated application of robots resembling ants, bees, butterflies, and hummingbirds in the appropriate circumstances. (Nanotechnological manufacture or biological programming may eventually extend to the employment of bacteria, but that lies in the more distant future.) Clearly flight is useful; burrowing may be employed to get into underground facilities; though individual actors may be directed by remote operators in the fashion of contemporary drones, in many situations the use of networked swarms, numbering in thousands or millions, may be necessary.

Swarm behaviors can be programmed on the assumption of local communication as a supplement to, or substitute for, top-down single-instruction-multiple-processor programming. Since not all environments will permit direct radio communication between the controllers and individual robots, mutual communication of the units will be required in any case to transmit information back to the center of operations.

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[5] See the fascinating description of recent experiments by the Draper company of Cambridge, Mass., with dragonflies controlled by miniaturized control backpacks in Ackerman, Evan; "DragonflEye project wants to turn insects into cyborg drones." *IEEE Spectrum*, 25 January 2017.

In addition since sensor sizes and quality may vary, e.g. if we employ robot gnats, algorithms for synthesizing high-resolution three-dimensional data from a large number of low-quality inputs will be necessary. These may be expected to improve once problems like the real-time assembly of 3D video of sporting events from input from large numbers of stadium-audience cameras are addressed, which will happen when augmented-reality interfaces become commonplace (i.e. once 5G coverage is rolled out.) — The operational interface itself, incidentally, is certain to involve augmented reality.

One would guess that the requisite degree of miniaturization has already been achieved, given that the average smartphone circa 2017 contains a multiple-core CPU, 32-128 gB of memory, a 3000 mAh lithium-ion battery, several kinds of radios, a couple of cameras with video recording capability, accelerators, compasses, GPS location, and assorted other bells and whistles in a package whose size is mainly determined by the dimensions of the human hand, and whose weight, 120-200 grams, is largely that of the screen and case. And, indeed, not only do we find projects underway like the RoboBee project at the Wyss Institute at Harvard,[6] but near-commercial endeavors like the TechJect Dragonfly,[7] crowdfunded by Indiegogo, which promised to deliver a robotic dragonfly which could fly like a bird and hover like an insect, pitched as a vehicle for aerial photography, patrolling for security and surveillance, even interactive gaming; a palm-sized four-winged ornithopter whose capabilities were claimed to include cameras, stereoscopic vision, GPS, accelerometer, gyroscope, magnetometers, light and humidity sensors, and pressure sensors, among others; i.e. everything that goes into a smartphone in a smaller (25 gram) package — and

[6] https://wyss.harvard.edu/technology/autonomous-flying-microrobots-robobees/

[7] Burns, Matt. "Another $1 million crowdfunded gadget company collapses." *TechCrunch, 7* November 2015.

which would, in addition, fly. The fact that the company crashed and burned indicates not technological impossibility (it was an attempt to exploit research performed at the Georgia Institute of Technology), but entrepreneurial incompetence.

The principal problems would then appear to be the following:

(1)    Power. Lithium-ion batteries have specific power of 250-340 watts/kg. This compares favorably with estimates of the output of insect muscle,[8] but the need for frequent recharging could present difficulties; the TechJect Dragonfly was projected to have maximum flight times of 25-30 minutes, e.g., but only 8-10 minutes when hovering. Solar cells don't seem like a viable solution at the scale imagined, let alone indoors or underground, though one might imagine some scheme for beaming power to them by laser; forward-deployable recharging stations (i.e. less mobile queens) seem necessary in some form or other. Depending on the situation it may be possible to transmit current along chains of linked ants, or to drag wires in; requiring, again, coordinated operation of different kinds of individual robots.

(2)    Communications. Direct links between individual units and operators will not always be possible. Communication will probably be mediated by the network, entailing —

(3)    Programming. Individual units will often need to be largely autonomous. Since no artificial intelligence we can foresee at present will fit into the head of an ant, intelligence will have to

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[8] Ellington, C.P. "Power and efficiency of insect flight muscle." *J. Exp. Biol.* **115**, 293-304 (1985), estimates mechanical power output as between 167 and 568 watts/kg., depending on the efficiency of elastic storage. Peak output for maximum wingbeat frequency may reach 860 w/kg. Muscle efficiency is argued to be low on the basis of estimates of metabolic power generation based on measurements of oxygen consumption, perhaps less than 10%. Hovering makes maximum energetic demands, explaining why only insects and hummingbirds can sustain it.

reside in the network, and communications will have to be conducted between the operators and a collective entity. This may require advances in the theory of cellular automata.

(4)    Mass production. In all likelihood applications will require the deployment of thousands or millions of individual robots. This may present interesting problems in nanomanufacture.

(5)    Stealth. Obviously if no one expects robot insects, no one will be looking for them. Nonetheless even in the giddy epoch of their first deployment there may be problems: a robot dragonfly would be difficult not to notice. Size may matter. And even though we may assume radar will not detect them, e.g., other signatures may be apparent even to automated surveillance: motion, for instance, or, in the case of flying insects, noise. (Radio silence may be maintained by chaining signals from one unit to another back to the exterior of the penetrated facility.) One admittedly speculative possibility (again) might be the exploitation of materials with negative refractive index to minimize visibility. — However one must note it may not matter that you suddenly notice a thousand robotic ants crawling across the floor of your bunker. Particularly if their charges go off simultaneously.

Nothing here seems insurmountable. The real difficulty may be

(6)    Cool, or rather the lack of it. Are ninjas to be replaced by yet another geek squad? This seems tragic.

Nonetheless we must admit that, though the occasional deployment of real people with throwing knives may still occasionally be necessary, for the most part the replacement of ninjas by hackers is inevitable. In the old days one might have imagined a daring mission behind enemy lines to sabotage the electrical grid of an opposing nation; the same can now be accomplished by remote control, and indeed Russian operatives

have not only staged such attacks on Ukraine and Estonia, but are actively preparing for an attack on the United States.[9] At least in the operations here envisioned the human operator still has a role, and may even get to wear black and affect fingerless gloves.

Moreover missions that were difficult or impossible beforehand now appear to be relatively straightforward: commandos need not infiltrate the fortress housing the Guns of Navarone, they can direct an army of ants to crawl into the caves, each carrying a grain of explosive which can be assembled remotely and detonated or — even simpler — just hack the digital controllers that aim the guns, in the manner of the famous Stuxnet exploit, and render them nonfunctional; Ethan Hunt needn't crawl through the ventilation system of the CIA himself, he can send a hummingbird with a flash drive in its beak to plug into the airgapped mainframe and retrieve the NOC list; the SEAL team needn't risk their lives on the basis of guesswork, robot bees can enter the compound, verify bin Laden's identity, sting him to death and everyone else into unconsciousness — after which they can drive up to the gate, open it, retrieve the body, and drive away with no one in the neighborhood the wiser. And the Ant-Man needn't risk shrinking too far and entering the Quantum Realm; his six-legged buddies can do all the work of sabotaging the evil corporate dicks. Basically all that stands in their way is better networking and some way of recharging their batteries.

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9 Cf. Kim Zetter, "Inside the cunning, unprecedented hack of Ukraine's power grid," *Wired*, 3 March 2016; Kevin Poulsen, "U.S. power companies warned 'nightmare' cyber weapon already causing blackouts," *The Daily Beast*, 12 June 2017.

That said, I still regard Guy Pearce's daring 2075 assault on an orbital prison in *Lockout* [Luc Besson, 2012] — cracking wise continuously, with an anachronistic cigarette hanging from his lip — and think nonetheless that impregnable fortresses, and the need they create for dauntless ninja warriors who can penetrate their walls, must always be with us. But then, I'm a hopeless romantic.