Uninhabited Aerial Systems: Disruption or Prescription?

T. X. Hammes

As societies around the world struggle to understand the impact of the Fourth Industrial Revolution, it is not only appropriate but essential that airmen ask if Uninhabited Aerial Systems should be considered a disruption or a prescription. In fact, we must go beyond the indeterminate phrase of Uninhabited Aerial System (which implies a human might be controlling the platform) and explore whether truly autonomous aerial systems are the more likely evolutionary replacement to manned aircraft.

The thesis of this paper is that while there will remain a role for manned aircraft and remotely piloted uninhabited aircraft, task specific autonomous systems will come to dominate the air domain – likely within the next two decades. This seems like a truly bold statement. In fact, it is much like saying that basically trained peasants armed with pikes would defeat armored knights, who represented centuries of perfecting metallurgy, animal husbandry, and training techniques, Or like saying in 1919 that the fragile, cloth winged aircraft flying from primitive aircraft carriers will soon defeat battleships which represented the peak of technologies as varied as metallurgy, armaments, and steam power. Both predictions seemed highly improbably at the time. Both came true.

Like all major revolutions in military history, these two were based on the convergence of advances in the political, social, economic, and technical spheres. Individual pikemen did not dominate armored knights. Massed pikemen in tight formations did. Because they stayed massed, they could use the superior range of the pike to defeat the knights. Yet, it was only the evolution of Swiss political systems that generated peasants with sufficient stake in society to stand together against professional warriors.

And as Dr. Williamson Murray has pointed out, it took both the French and the Industrial Revolution to create the political, social, and economic systems that could provide the massive national mobilization necessary to field the forces that fought WWI. Those same systems allowed innovators to exploit the convergence of technologies to develop the aircraft that dominated fleet engagements by WWII. It also required a mental shift from envisioning naval power as massed battleships under central control to swarms of small aircraft creating the same cumulative effect but at a much greater range.

It was these social changes, convergence of technologies, and mental shifts that revolutionized warfare in their eras. An obvious question is whether we can envision a similar convergence of technologies today that, if combined with a mental shift, could dramatically alter air warfare.

The technologies

To this question, this paper will examine five key, existing technologies that have the potential to revolutionize air warfare: small warheads, 3D manufacturing, drones, task- specific artificial intelligence and cheap space. Other new technologies, particularly biological based ones, will in time make major impacts, but these five are having immediate impact

Small warheads

As early as 2002, nano-explosives demonstrated an explosive power twice that of conventional explosives.[1] Since then, for obvious reasons, very little has been published on the subject. One open source update, the 2017 book *Nanoweapons: A Growing Threat to Humanity* asserts that the Department of Defense is using "nanoaluminum to create ultrahigh burn rate chemical explosives, with ten times greater energy release than conventional explosives."[2] The obvious implication is that the same weight of explosive can be an order of magnitude more powerful – lending massively greater destructive power to small drones.

A second approach for increasing the destructive power of a small warhead is the use of explosively shaped penetrators (EFP). An EFP approximately 2.5 cm in diameter with as little as 30 grams of high explosive can penetrate up to 1.4 cm of steel.[3] Such a device is small enough to be mounted on a wide variety of small drones. By adopting the concept of "bringing the detonator not the explosive," such a drone could be used to detonate the very large explosive potential of an aircraft's fuel tanks or any fixed fuel or ammunition point. Truly dramatic results appear to have been achieved by a Russian or Ukrainian separatist drone attacks on a Ukrainian ammunition dumps.[4] EFPs could also be used for mission kills against radars and other sensors as well as mobility kills against unarmored vehicles. EFPs are not new but drones provide a new way to deliver these lethal charges to selected targets that provides precise delivery at long ranges. It is also possible to create warheads with multiple penetrators[5] and self-forging fins[6] to increase stand-off ranges and lethality.

To date, the primary limitation on EFP production has been the requirement for high-quality curved copper or steel cones that form the penetrator when the charge is detonated. Production used to require a skilled machinist with high-quality machine tools. Today, 3D metal printers that can print the cones are proliferating rapidly.[7] The printers may also be adapted to

---

[1] Dr. Andrzej W. Miziolek, "Nanonenergetics: An Emerging Technology Area of National Importance," AMPTIAC Quarterly, Vol 6, No 1, Spring 2002, http://ammtiac.alionscience.com/pdf/AMPQ6_1ART06.pdf, p. 45.

[2] Louis A. Del Monte, *Nanoweapons: A Growing Threat to Humanity,* (U.S.: Potomac Books, 2017), 47–48.

[3] "EFP Charge Demonstration Video," ISSEE, https://www.youtube.com/watch?v=G0ZOPFiuOL8.

[4] Kyle Mizokami, "Another Ukrainian Ammo Dump Goes Up in Massive Explosion," *Popular Mechanics,* September 27, 2017, https://www.popularmechanics.com/military/weapons/news/a28412/ukrainian-ammo-dump-explosion/.

[5] Richard Fong, et.al., "Multiple Explosively Formed Penetrator (MEFP) Warhead Technology Development," 2004, www.dtic.mil/get-tr-doc/pdf?AD=ADA432897.

[6] Jian-qing Liu, et.al., "Formation of explosively formed penetrator with fins and its flight characteristics," *Defence Technology,* June 2014, Vol 10, Iss 2, pp. 119-123, https://www.sciencedirect.com/science/article/pii/S2214914714000348.

[7] Eddie Krassenstein, "Plus-MFg's +1000k Multi Material Metal 3D printer Shows its Power," http://3dprint.com/87236/plus-mfg-3d-metal-printer, accessed 6 Aug 2014.

print the forms for multiple penetrator warheads and fin equipped penetrators. Combining nano-explosives, advanced EFPs, and 3D printing is creating much more powerful small warheads.

3D manufacturing

3D manufacturing, also known as additive manufacturing, is the vehicle that will allow the production of tens of thousands of small, smart, but cheap drones. In the last few years, 3-D printing has transformed from an interesting hobby to an industry producing a wide range of products. The explosion of additive manufacturing means it is virtually impossible to provide an up-to-date list of materials that can be printed, but as early as 2014 a top ten list included: metals, such as stainless, bronze, steel, gold, nickel steel, aluminum, and titanium; carbon fiber and nano-tubes; stem cells; ceramics; and food.[8] Researchers are exploring the application of 3-D manufacturing to fields from agriculture and biology to design and manufacturing.
Progress in 3D manufacturing is accelerating. During 2015 alone, MIT developed a $7,000 multi-material printer than can print ten materials in the same object during a single fabrication process;[9] Voxel8 revealed a new printer ($8,999) that printed a complete, operational drone with electronics and engine included;[10] and Australian researchers printed a jet engine.[11]

As 3D pioneers mastered various materials and techniques they began to focus on speed of printing. In April 2016, Carbon introduced a commercial 3D printer that is 100 times faster than previous printers.[12] It plans to push the speed to 1,000 times faster. The Department of Energy's Oak Ridge National Laboratory is partnering with Cincinnati Incorporated, a manufacturer of high quality machine tools, to develop a process to print metal 200 to 500 times faster.[13] In May 2017, MIT developed Rapid Liquid Printing which is both faster and allows much greater range of products.[14] Even as the technology has advanced at an incredible pace, the products produced by additive manufacturing have increased in both quality and complexity.

Drones

---

[8] Nancy S. Giges, "Top 10 Materials for 3D printing," *American Society for Mechanical Engineers,* August 2014, https://www.asme.org/engineering-topics/articles/manufacturing-processing/top-10-materials-3d-printing.

[9] David Szondy, "MultiFab mixes and matches 10 different materials in a single 3D print," August 25, 2015, https://newatlas.com/multifab-3d-printer-10-materials/39074/.

[10] Dario Borghino, "Voxel8 Paves the Way for 3D-printed Electronics," *Gizmag.com*, January 14, 2015, www.gizmag.com/voxel8-3d-electronics-printer/35489.

[11] Rose Troup Buchanan, "3D Printer Creates Jet Engine in World First," *Independent,* February 26, 2015, http://www.independent.co.uk/life-style/gadgets-and-tech/3d-printer-creates-jet-engine-in-world-first-10072740.html.

[12] Nicholas St. Fleur, "3-D Printing Just Got 100 Times Faster," *The Atlantic,* Mar 17, 2015, https://www.theatlantic.com/technology/archive/2015/03/3d-printing-just-got-100-times-faster/388051, accessed Jul 17, 2017.

[13] ORNL, Cincinnati partner to develop commercial large-scale additive manufacturing system, February 17, 2014, https://www.ornl.gov/news/ornl-cincinnati-partner-develop-commercial-large-scale-additive-manufacturing-system, accessed Apr 3, 2016.

[14] Laura Cox, "Transforming manufacturing," *D/SRUPTION,* May 17, 2017, https://disruptionhub.com/3d-printing-evolves-rapid-liquid-printing, accessed May 22, 2017.

The dramatic increase in speed has major implications for militaries. In 2014, researchers at the University of Virginia successfully 3D printed a drone in one day. By snapping in place an electric motor, two batteries, and an Android cell phone, they made an autonomous drone with a range of approximately 50 km. It took about 31 hours to print and assemble the drone at a total cost (excluding the printer) of about $800.[15] While it could be controlled by a ground station, the GPS in the phone allowed the drone to fly a specified route autonomously. While such a system would be vulnerable to GPS jamming, a number of new approaches are being developed that will allow drones to navigate in GPS denied environments.[16]

Other programs allow cell phone camera to identify people and objects even under low light conditions.[17] Combining the two can create autonomous, cheap weapons drones that can range for dozens of kilometers, hunting and engaging specific targets. Think of them as IEDs that hunt you. And UPS has already created a factory with 100 printers that accepts orders, prices them, prints them, and ships them in the same day from the adjacent UPS shipping facility. UPS has plans to expand the plant to 1000 printers to support major production runs.[18] A small factory with only a hundred Carbon 3D printers could make 10,000 drone bodies a day. A Carbon 3D manufacturing plant expanded to the 1,000 printers could print 100,000 drones a day. The limitation is no longer the printing but the assembly and shipment of the finished products. Both processes can be automated with robots. In the near future, drones could be produced at a rate exceeding many types of ammunition—and often for less per round.

While it is possible to manufacture tens of thousands of drones a day, is there any feasible way to launch them? Both the U.S. Navy and the Peoples Liberation Army have demonstrated the ability to launch large numbers of drones. The U.S. Navy LOCUST program used a 24 round launcher for an experiment[19] and the PLA have operational launchers that carry 18 Harpy drones on a single medium truck.[20] A Harpy Battalion can launch 162 drones in minutes. For small drones the size of the U.S. Marine Corps' Switchblade,[21] it would be possible

---

[15] Jordan Golson, "A Military-Grade Drone That Can Be Printed Anywhere," *Wired,* Sep 16, 2014, http://www.wired.com/2014/09/military-grade-drone-can-printed-anywhere, accessed May 23, 2016.
[16] Riley Bauer, Shannon Nollet, and Dr. Saad Biaz, "A Novel Approach to Non-GPS Navigation Using Infrasound. Technical Paper #CSEE14-03," September 11, 2014, www.eng.auburn.edu/files/acad_depts/csse/csse_technical_reports/csse14-03.pdf.
[17] Hillary Grigonis, "Google designed an object-recognition program that won't need the internet," *Digital Trends,* June 15, 2017, https://www.digitaltrends.com/mobile/google-mobilenets-open-source/.
[18] Parija Kavilanz,"Louisville plant, 100 printers, 3 employees,"*CNN Money,* May 4, 2015, http://money.cnn.com/2015/05/04/smallbusiness/cloudddm-3d-printing-factory-ups/.
[19] Eric Limer, "Watch the Navy's LOCUST Launcher Fire Off a Swarm of Autonomous Drones," *Popular Mechanics,* May 24, 2016, http://www.popularmechanics.com/military/weapons/a21008/navy-locust-launcher-test-2016/.
[20] Chinese Military Aviation, http://chinese-military-aviation.blogspot.com/p/uav.html.
[21] AeroVironment, "Switchblade," https://www.avinc.com/uas/view/switchblade.

to load hundreds onto a single medium truck. By thinking of drones as expendable rounds of ammunition used as artillery, it is easy to visualize how they can be employed in the thousands. A swarm of tens of thousands of autonomous but non-coordinating drones is clearly possible.

Currently, range is a problem for many cheap drones. While the early University of Virginia drone was limited to 50 kilometers, commercial firms are making dramatic progress. The Aerovel Flexrotor has a range of 3,400 kilometers, the Defiant Lab DX-3 over 1,400 kilometers.[22] While the Flexrotor may seem expensive at $200,000 a copy, it costs less than operating a F-35A for three hours or firing one Javelin anti-armor missile. While not technically stealthy, the small size of these systems mean they have the radar signature of a small bird.[23] Like most new technologies, these systems can be greatly improved for relatively little money.

On the military side, progress has been even more dramatic combining range with payload. The U.S. Navy's experimental TERN can deliver 225 kilograms to a range of 1,000 km.[24] Israel's much smaller but currently operational Harop also has a range of over 1,000 kilometers with a payload of 25 kilograms.[25] Kratos, a U.S. firm, has developed the QX222 *Valkyrie* autonomous drone. It can deliver 225 kilograms of ordnance (a pair of Small Diameter Bombs) a distance of 2,400 kilometers at speeds up to .85 mach. Since it is projected to cost only $2 million each, it can also be sent on one way mission out to 4,800 kilometers. The QX222 also makes use of stealth configuration (but not coatings) to reduce its radar signature significantly. All of these military drones except the Harop can recover vertically. Another Kratos product, the UTAP-22 *Mako*, can carry 160 kilograms out to 2,400 kilometers with a top speed of .9 mach. The *Mako* has already be used in a small swarm controlled by an AV-8B Harrier.[26]

Cruise and ballistic missiles

While not a truly new technology, cruise and ballistic missiles must be part of the conversation concerning the transition from manned to unmanned aerial platforms. They already significantly outrange manned tactical aviation. Thus unless an air force has massive tanker support, the enemy's missiles can range its fighter airfields. In June 2017, *First Strike: China's Missile Threat to U.S. Bases in Asia* examined the outcome of a Chinese first strike using

---

[22] "Defiant Labs Launches Next Gen Drone: DX-3," Defiant Lab Press release, February 10, 2017, https://news.usaonline.us/press-releases/Defiant-Labs-Launches-Next-Gen-Drone-DX-3-86383.

[23] Tyler Rogoway, "Meet Israel's 'Suicide Squad' of Self-Sacrificing Drones," *The Warzone,* August 8, 2016, http://www.thedrive.com/the-war-zone/4760/meet-israels-suicide-squad-of-self-sacrificing-drones.

[24] Henry S. Kenyon, "Navy Turns to Tern to Make Every Ship an Aircraft Carrier," *Signal,* November 1, 2017, https://www.afcea.org/content/navy-turns-tern-make-every-ship-aircraft-carrier.

[25] "Harop Loitering Munitions UCAV System," *Air Force Technology,* www.airforce-technology.com/projects/haroploiteringmuniti/.

[26] Tyler Rogoway, "Unmanned Tactical Aerial Platform & Low Cost Attributable Strike Demo Platform," *The Warzone,* February 17, 2017, http://www.thedrive.com/the-war-zone/7449/more-details-on-kratos-optionally-expendable-air-combat-drones-emerge.

ballistic and cruise missiles against U.S. facilities in Japan. Using just 20 percent of its Short Range Ballistic Missile inventory, 25 percent of its Medium Range Ballistic Missiles, and between 34 and 95 percent of its cruise missile inventory (depending on which source one uses for the total available), the first strike accomplished the following:

> --almost every major fixed headquarters and logistical facility struck, with key headquarters struck within the first few minutes of the conflict
> --almost every U.S. ship in port Japan struck pierside by ballistic missiles
> --in most cases, cratering by ballistic missiles of every runway and runway-length taxiway at all major U.S. air bases in Japan
> --as a result of runway cratering, headquarters destruction, and air defense degradation, more than 200 trapped U.S. aircraft destroyed on the ground in the first hours of the conflict.[27]

Cruise missiles will be able to deliver a much larger payload for even less money. And the cost may decrease significantly. Lockheed expects to be able to cut the cost of two new satellites by forty percent using advanced manufacturing.[28] If DoD can obtain similar cost savings on cruise missiles, Tomahawk Land Attack Missiles will cost about $606,000 each or about 4 hours of B-2 flight time. These missiles carry a thousand pound warhead for a distance of up to a 2500 kilometers.[29] Obviously the Tomahawk is a very old cruise missile system but it provides a guide for how much the cost of cruise missiles will be reduced by advanced manufacturing. Further, by employing nano-explosives the warhead can be made either much more destructive or its weight reduced and the missile's range extended.

While somewhat expensive, missiles such as these can provide long-range heavy strike capabilities. Since cruise missiles can be fired from a variety of land and sea launchers, they can be either dispersed in a cluttered environment or hidden in an underground facilities or even warehouses until minutes before launching. They will thus be immune to most pre-emptive strikes and much less expensive than ballistic missiles. The combination of cheap drones and much more capable cruise missiles may offer small- and medium-sized states anti-access/area-denial (A2/AD) and precision, long-range strike capabilities.

Task-specific artificial intelligence

There is a great deal of disagreement over when or even if general artificial intelligence will emerge. While an interesting discussion, it is irrelevant for the purposes of this paper. Much more important is the current state of limited or task-specific artificial intelligence. When applied

---

[27] Thomas Shugart and Javier Gonzalez, *First Strike: China's Missile Threat to U.S. Bases in Asia,"* Center for New American Security, June 2017, p. 15. https://s3.amazonaws.com/files.cnas.org/.../CNASReport-FirstStrike-Final.pdf.

[28] Andrea Shalal, "Lockheed aims to build satellites 40 percent quicker, lower costs," *Reuters Business Insider,* March 8, 2016, http://www.businessinsider.com/r-lockheed-aims-to-build-satellites-40-percent-quicker-lower-costs--2016-3.

[29] "Missiles of the World," Center Strategic and International Studies, https://missilethreat.csis.org/missile/.

to specific problems like chess, go, or certain types of object recognition, task-specific artificially intelligence has clearly reached the point it can provide the navigation and target acquisition necessary for swarms of drones to work. As noted, remote control drones will continue to have great value for some missions but there is simply no way to train enough pilots to control every drone in a swarm of 10,000.

To create truly autonomous drones, designers must address two issues. First is navigation – getting the drone from the launch point to the area the commander wants engaged. Second is to identify the correct targets when the drone arrives in the area. GPS dependent drones can already navigate for great distances autonomously. The Harpy is designed to use GPS guidance to arrive in a target area and then shift to visual, infra-red, and electronic search modes to identify and attack a target. Obviously, such systems are vulnerable to GPS jamming systems.

However, autonomous navigation in the form of inertia and visual guidance systems has been in use since the advent of the land-attack Tomahawk missile in Operation Desert Storm in 1991. Today, a wide range of institutions are seeking non-GPS reliant autonomous navigation systems. Just as the Tomahawk combined inertial guidance with visual to achieve exceptional accuracy, new systems are doing the same for a fraction of the cost.

As noted, targeting is a separate problem. It will require the autonomous system to be able to identify a specified target and then maneuver through obstacles to strike it. While this is a very challenging issue, commercial firms are already deploying autonomous air taxis and ground vehicles based on a range of ever more effective, precise, and cheaper sensors which have obvious applications in improving the hunting capability of autonomous drones. Aerialtronics just put a new AI-driven camera on sale that is 11cm by 10 cm by 7 cm, weight .67 kilograms yet has a 30x magnification HD camera with an integrated forward looking infrared camera.[30] It can integrate the two images to provide better target identification. Google has released its MobileNets family of lightweight computer visions models that can identify objects, faces, and landmarks.[31]

Larger drones like the QX222 *Valkyrie* or UTAP *Mako* sidestep this requirement because they can deliver existing smart weapons such as small diameter bombs and air to air missiles. These weapons provide their own navigation and targeting. As the primary function of a strike aircraft becomes getting "smart" ordnance to the right airspeed and altitude, relatively cheap drones will execute that mission and change the cost curve for precision, long-range strike. And the development of nano-explosives will dramatically increase the terminal effect of the ordnance they deliver.

---

[30] Caroline Rees, "Aerialtronics Announces New AI-Driven Camera for Drones, *Unmanned Systems Technology,* February 19, 2018, http://www.unmannedsystemstechnology.com/2018/02/aerialtronics-announces-new-ai-driven-camera-drones/.

[31] John Mannes, "Google releases new Tensor Flow Object Detection API," *TechCrunch,* June 16, 2017, https://techcrunch.com/2017/06/16/object-detection-api/.

A key issue is whether or not to have the drones coordinate their actions within the swarm or simply count on the sheer numbers for effect. Both have potential downsides. Coordination requires communication between drones which is both more expensive and provides a path for an enemy to either jam or seize control of the drones. Sealed drones operating independently will be harder to disrupt but will inevitably suffer from fratricide when employed in large numbers. Extensive computer modeling is required to determine which approach is most effective. Both approaches will probably be developed with coordination limited to more expensive drones while cheaper drones are treated as rounds of ammunition that do not require coordination. Think artillery time on target missions.

Cheap space

Given the very long range of new drones, a third major technical problem is locating the targets. Until recently, only major powers had access to the space sensors necessary to search very large areas. However, over the last two decades, the development of cube satellitesand the infrastructure to launch them cheaply in large numbers has made space imagery commercially available.[32] The growth of these systems has been exponential. The first cube satellite was launched in 2003. In the next nine years, 112 cube sat missions were flown by 80 organizations from 24 countries. By July 2017, 829 were operational.[33] On 15 February 2017, India launched 101 cubesats and 3 larger satellites on a single rocket.[34] Planet, a private company, owned 88 of those cubesats and added them to its imagery network. Its satellite network now takes sub-meter resolution imagery of the entire planet *daily* and sells these images on line.[35] The days of hiding military activity or fleets at sea are clearly drawing to a close. Cube sats mean every country and many non-state actors have access to space imagery.

Range obsolescence

These five technologies are dramatically extending the capability of autonomous combat drones. The most important advance is in range. Historically, the death knell for many weapons systems has been range obsolescence. It is not that the new system had vastly greater capabilities than the old. In fact, the new weapons system often lacked the combat power and survivability of the old. However, by virtue of superior range, the new could batter the old system until it was destroyed – all while staying out of range. Further, since emerging technologies cost much less to improve than mature systems, the new systems often cost less than the old and improve rapidly with little investment. Unfortunately, the west is entering a period where a large number

---

[32] "What are small sats and cube sats?" NASA, February 26, 2015, https://www.nasa.gov/content/what-are-smallsats-and-cubesats.
[33] Nanosatellite & Cubesat Database, http://www.nanosats.eu.
[34] Samantha Mathewson, "India Launches Record-Breaking 104 Satellites on Single Rocket," *Space.com,* February 15, 2017, https://www.space.com/35709-india-rocket-launches-record-104-satellites.html.
[35] Nathan Hurst, "How Daily Images of the Entire Earth Will Change the Way We Look At It," *Smithsonian.com,* March 13, 2017, http://www.smithsonianmag.com/innovation/how-daily-images-entire-earth-will-change-way-we-look-it-180962467/#J24AmE8xz2EVa3j8.99.

of its key legacy systems are facing range obsolescence. It is essential we heed the historical record and stop investing in outclassed systems.

Two examples separated by centuries provide interesting examples – the musket and the aircraft carrier. Starting in the 16th Century, the musket (then called a harquebus) began to its century long path to replace the musket. It replaced the pike in European infantry formations for the simple reason the musket equipped formation could destroy the pike formation before it closed enough to employ the pike. In close combat, the pike remained a superior weapon to the musket with a bayonet. But the pike formation was thinned to the point it could not overcome the musket based formation.

Four centuries later, superior range also allowed carriers to replace battleships as the fleet's capital ships. While a battleship could, and today still can, deliver more firepower faster than a carrier and remains much more survivable, it simply can't get within range of the carrier to deliver its devastating firepower. Lack of range made it irrelevant in a naval fight and thus obsolete for that function. Compounding the problem, at the time, the carrier cost significantly less than a battleship and its aircraft were also cheap.

In both cases, the legacy system remained highly capable – and in fact dominant if it could get in range to engage. But it didn't matter how good the pike formation or battleship was, there was simply no way to increase the range of their weapons to match those that defeated them. They were range obsolete.

For Australia, the most important system facing range obsolescence is the F-35. In 2015, the United States Department of Defense Selected Acquisition Report estimated the Combat Radius for the F-35A was 630 nautical miles (or 1170 km).[36] New generations of ballistic and cruise missiles as well as relatively cheap drones already outrange it. This situation will simply get worse with time. It is extremely difficult to extend the range of existing aircraft but cruise missiles and drones are rapidly increasing their operational ranges. And while the F-35 remains vastly more capable and versatile than these systems by almost every measure – it is facing the same range obsolescence that defeated the pike formation and the battleship. The chart below provides a partial list of the drones, ballistic and cruise missiles which currently have superior range to the F-35A. Missile ranges are drawn from the Center for Strategic and International Studies' Missile Defense Project.[37] Ranges for drones are from manufacturer websites.[38]

---

[36] "Selected Acquisition Report: F-35 Joint Strike Fighter Aircraft (F-35) As of FY 2017 President's Budget," U.S. Department of Defense, December 2015, p. 6, https://fas.org/man/eprint/F35-sar-2016.pdf.

[37] "Missiles of the World," Center Strategic and International Studies, https://missilethreat.csis.org/missile/.

[38] Mike Hanlon, "Kratos to show low-cost Valkyrie and Mako 'wingman' combat drones," *New Atlas,* June 15, 2017, https://newatlas.com/kratos-valkyrie-mako-combat-drones-paris/50044/; "Harop Loitering Munitions UCAV System," *Air Force Technology,* http://www.airforce-technology.com/projects/haroploiteringmuniti/; "Flexrotor," Aerovel, http://aerovel.com/wp-content/cache/wp-rocket/aerovelco.com/flexrotor/index.html_gzip; "Defiant Labs Launches Next

Vulnerable bases

At the heart of its range obsolescence is the fact the F-35A must operate from large, easy to find but difficult to defend bases. An opponent does not have to fight modern fighters in the air. Instead he can send hundreds or even thousands of drones after each base to destroy these advanced aircraft on the ground. These attacks can be a mix of high-capability expensive systems such as ballistic and cruise missiles and very large number of cheap drones that overwhelm the defense with sheer numbers. The fact these missiles and drones can be launched beyond the range of the F-35 means the F-35 cannot be used to preempt the attacks.

While support aircraft, such as tankers, AWACs, and transports, can be based at greater distances, they are even more difficult to protect on the ground than fighters since building shelters for such aircraft is an order of magnitude more expensive. Further, while on paper these support aircraft bases may seem to be out of range of most drones and cruise missiles, they are not. The Russians are selling an entire family of cruise missiles in standard 20 and 40 foot shipping containers.[39] For example, they sell the Kaliber family of missiles. The anti-ship version ranges out to 640 km but the land attack variant can reach 2500 km. Thus, any ship that can handle standard containers is a potential weapons platform. It can carry the weapons containers within range of essentially any airbase in the Indo-Pacific region. To get an idea of the magnitude of the potential threat, China has 200,000 ocean-going fishing vessels.[40] By packaging them in standard shipping containers, the Russians have created a system that places essentially all airfields in the Indo-Pacific Theater within range -- even airfields in Australia.

The fact many cruise missiles and long-range drones are mobile systems with vertical launch and recovery clearly provides a further major advantage over conventional aircraft. Finding and destroying a mobile systems in the short period between when it breaks cover and launches its weapons is extremely difficult. Despite the massive expenditure of effort, western forces had zero success hunting mobile systems in Desert Storm.[41]

The mental shift

As with previous military revolutions, the biggest challenge in confronting the one driven by the Fourth Industrial Revolution is the mental shift required. For almost fifty years, air power has been defined by ever more sophisticated aircraft. We moved from aircraft that were relatively cheap and plentiful to aircraft that are truly exquisite but few in number. The premier allied fighter of WWII was the P-51which cost about $50,000 dollars in 1945 or under $700,000 in 2017 dollars. Manufacturing techniques were widely distributed so the United States could

---

Gen Drone: DX-3," *The Sky Guys,* Dec 6, 2016, http://www.marketwired.com/press-release/defiant-labs-launches-next-gen-drone-dx-3-2180933.htm.

[39] "Club K," Rusoboronexport, http://roe.ru/eng/catalog/naval-systems/shipborne-weapons/klab-k/.

[40] Zhang Hongzhu, "China's Fishing Industry: Current Status, Government Policies, and Future Prospects," July 9, 2015, https://www.cna.org/cna_files/pdf/China-Fishing-Industry.pdf.

[41] Thomas A. Keaney and Eliot A. Cohen, *Gulf War Air Power Survey Summary Report,* Washington DC, 1993, pp. 84-85, www.dtic.mil/dtic/tr/fulltext/u2/a273996.pdf.

produce tens of thousands per year. In contrast, when the F-35 program reaches peak production in 2023, it will produce 160 aircraft a year or fewer than 14 per month[42] – clearly not enough to replace combat losses. Nor can mass production be rapidly achieved – the processes are simply too complex to quickly expand the number of plants available. Further, the aircraft is made is a number of countries thus the challenges of mobilization will be greatly magnified.

The Chinese have clearly started to make the mental shift. The Peoples Liberation Army has assembled a force that provides a viable option to fighting the F-35 in the air. If employed as described in *First Strike,* it has the potential to eliminate tactical aircraft in Japan. No doubt they could severely degrade U.S. forces and facilities in Guam too.

As advanced manufacturing continues to make long-range drones cheaper and more capable, range obsolescence will become a fact for current fighters. In a world where a single production plant could produce 100,000 autonomous drones a day, 14 F-35s per month spread over eight air forces, one navy, and one marine corps that are currently scheduled to fly them are clearly inadequate.

How do we get there?

Oddly enough, history can help us with this futuristic problem. It demonstrates that the critical mental shifts were not made in a single step. In each of the historical cases, there was a pattern. The new system started out as a assistant to the old. As it improved it became a partner and, with continued improvement, a replacement. During the first part of the 16th Century, the Spanish integrated muskets into their battalions of disciplined pikemen. Yet because of the few muskets available, their high cost, and their slow rates of fire, they were not initially seen as a threat. A pike battalion could simply overrun and butcher any formation of musketeers. However, some forward thinkers saw how these primitive muskets could provide support to the massed battalion. These innovators placed them on the flanks of the formation where they helped by firing into the enemy formation without complicating the battalion's maneuvers. As muskets improved and became standardized, they were moved inside the formation to fight as a full partner with the pikemen. With the development of the socket bayonet that allowed a musket to fire with the bayonet fixed, the pike passed from the scene.

Aircraft followed a very similar path in replacing the battleship. At first, aircraft were seen as a way the help battleships with scouting and gunnery—essentially they became the eyes of the fleet. Speed and altitude made them an obvious scouting platform and as communications between aircraft and the fleet became feasible, they were used to spot the fall of shot. As battleship main batteries increased in range, the rounds fell over the horizon and thus could not easily be adjusted on target by the crew. Spotting was perceived as so important that in the 1920s, U.S. battleships added seaplane catapults to their aft turrets to insure aircraft were available. To increase availability of aircraft and relieve battleships of the burden of recovering their aircraft, these functions were soon assigned to aircraft in the newly developed aircraft

[42] "Lockheed hits 2017 F-35 delivery target despite production hiccups," *CNBC*, December 18, 2017, https://www.cnbc.com/2017/12/18/lockheed-hits-2017-f-35-delivery-target-despite-production-hiccups.html.

carriers. As the carrier air wing evolved into a mix of capable fighters, dive bombers, and torpedo bombers, the carriers moved from being assistants to being full partners. When World War II proved conclusively that carrier aviation could destroy battleships at range, the carriers replaced the battleship as the key striking element of fleets.

Both weapons system displayed the same evolutionary pattern. Each technology emerged as an interesting hobby or experiment. As the technology of each improved, they moved from assistant to partner to replacement. Neither was a straight replacement. The time required for these two transitions ranged from over a century for the musket to just over two decades for the aircraft carrier. However, the Fourth Industrial Revolution is happening faster than any previous revolution, thus we should expect the new generation of small, smart, and many to quickly replace the old generation of few and exquisite weapons. As with these two examples, success or failure will be based on the ability to develop concepts and organizations that play to a society's strengths while optimizing the use of the new capabilities.

Where to from here?

By considering where new technologies and concepts are on the path from assistant to partner to replacement, we can invest to speed the process. It is essential that the investments include both the specific technology and the experiments and operational tests that develop the concepts to maximize the new technology.

Focusing on the Royal Australian Air Force, it is essential to understand that drones and cruise missiles have become full partners for manned aircraft in some areas and are already replacements in others. It is also crucial to look to the areas where drones can quickly assist the RAAF in operations. The table below provides some examples in each area. The column titles do not mean the RAAF has or will have those capabilities. They indicate when those capabilities will be operational and available for procurement.

Drone Relation to F-35 Missions

	Currently	Near Future	More than a decade
Assistants		Electronic Warfare/Comm Relay	
Partners	Strike/Close Air Support	Air-to-Air	
Replacements	Long-range strike (beyond F-35 range)/ High-risk Strike/Persistent surveillance	Strike/Close Air Support	Air-to-Air Strike EW/Comms

Conclusion

The program asked if Uninhabited Aerial Vehicles will be a disruption or a prescription. There is no doubt they will disrupt warfare in all domains. But they are not just a prescription – they are an inevitability. Further, most will not just be uninhabited but autonomous. Because the air domain is the simplest for artificial intelligence, it has and will continue to lead the change in the character of war. Thus, airmen are well-positioned positioned to lead this revolution.

The key will be to manage the inevitable transition with two goals in mind. First, maximize the benefits from existing assets. Your nation has invested heavily and there are clearly areas where the current platforms can play major roles in the assistant to partner to replacement progression. The early experiments controlling a small swarm of *Makos* from an AV-8 show a potential powerful partnership in the air-to-air, strike, and close air support missions.[43] The key is to seize the advantages available at each stage.

The second goal is to move swiftly but methodically to accelerate the process. Start by examining where drones are on the assistant-partner-replacement path for each air mission. Then explore how to integrate technology and concepts to advance drones to the next step in those mission areas. Historically, concepts and technology have coevolved. As new technologies emerge operators can see how they can be applied to current operational concepts with an eye to completely rethinking those concepts. It is essential to cast off the limitations inherent in the very mature technology of manned aircraft and think through what the convergence of new technology offers.

Experiment ruthlessly. Nothing, particularly bases, can be made off limits. Autonomous systems must be included. Free play wargames against creative, aggressive Red Teams should guide concept development. These wargames should range from simple table tops to sophisticated, joint, computer-supported simulations to combined simulations/live exercises. Figure out what works. It is vital to let the chips fall where they may. Do not make the mistakes the Japanese and French made prior to World War II. They conducted rigorous wargames. But when the results showed their doctrine and operational concepts to be losers, they changed the games not the doctrine.

In parallel with experimentation, study how others have succeeded. There is a rich body of literature on how enthusiasts of new technologies have succeeded and failed in the very complex task of changing how a service fights. Millett and Murray's *Innovation in the Interwar Period* is a great place to start. Remember that simply getting the technology right has always been insufficient. In 1940, the French had more and better tanks than the Germans but had failed to change their organizations and concepts to use them effectively.

The Fourth Industrial Revolution is not a death knell for air forces – particularly small air forces. In fact, the technologies of the Fourth Industrial Revolution seem to heavily favor smaller nation's defense against any nations attempting to project power. It offers great opportunity for air minded people to rethink how to defend their nations. For small nations, it will offer the opportunity to move to true aero-space force that can exploit new opportunities to create a more robust, capable organization that can provide real deterrence even against major powers.

----

[43] Claire Apthorp, "The unmanned wingman: high-speed drones to support fighter aircraft," *Air Force Technology,* February 12, 2017, http://www.airforce-technology.com/features/featurethe-unmanned-wingman-high-speed-drones-to-support-fighter-aircraft-5731459/.

Dr. T. X. Hammes is a Distinguished Research Fellow at the U.S. National Defense University. The views expressed here are solely his own and do not reflect the views of the U.S. government, Department of Defense, or the National Defense University.