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A Conceptual Perspective

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Aerial Drones in Future Wars: A Conceptual Perspective

Unmanned platforms in all three mediums—air, land, and sea—have always been the preferred choice for fighting wars. Their induction, proliferation, and usage was only limited by the technologies available in the domain of aviation. The advantages of aerial drones in wars were realised at the dawn of aviation itself, with the Curtiss biplanes being used as the first unmanned aircraft—as "Air Torpedoes"—during World War 1 (WWI). They were not remotely controlled but timer operated.[1] Post World War-II (WWII), militaries have used remotely piloted aircraft (RPAs)—both jet powered as well as propeller driven—as practice targets for their air and ground weaponry. A number of experimental UAVs were also designed and flown at the same time for other military purposes—some even as remotely piloted winged bombs—early after WWII. However, they saw very limited usage, the use being limited by the state of technology at that time.

RPAs have evolved continuously post WWII, and were used in various wars during the 1970s and 1980s in limited roles (for example, by Israel during the Yom Kippur war in 1973, in which they were used mainly for photo recce and decoy purposes; they were also used in the Bekka Valley operations in 1982[2] for aerial recce, ELINT gathering,[3] and target

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1 World War I Gallery, Curtiss-Sperry Aerial Torpedo (replica), Cradle of Aviation Museum and Education Centre, at https://www.cradleofaviation.org/history/exhibits/exhibit-galleries/world_war_i/curtiss_sperry_aerial_torpedo.html, 23 July 2019.

2 Mary Dobbing and Chris Cole, "Israel and the Drone Wars: Examining Israel's Production, Use and Proliferation of UAVs", *Drone Wars UK*, January 2014, at https://dronewarsuk.files.wordpress.com/2014/01/israel-and-the-dronewars.pdf, accessed 17 July 2018.

3 Yaakov Katz, "How Israel Took a Toy and Made It a High-Tech Weapon", *Commentary Magazine*, December 2016, at https://www.commentarymagazine.com/articles/how-israel-took-a-toy-and-made-it-a-high-tech-weapon/, accessed 25 July 2018.

designation). However, drones started coming to the forefront of military operations in the 1990s with the growing sophistication of drone technology.

Computerised and armed with advanced weapons and sensors, UAVs started getting designed to perform all the roles that a manned aircraft could do—albeit in limited capacities, as in some roles they demanded more perfection in technology. A wide variety of unarmed UAV showed up globally in many nations, and were put to use in surveillance, reconnaissance, and ELINT operations.

With technology stepping into the realms of miniaturised electronics, computerisation and digitisation, AI and IoT, satellite and ring laser gyro assisted navigation, composites, intelligent weapon systems, etc.—all have increased the capability of unmanned platforms immensely. Over the years, they have shifted gradually towards centre-stage in military operations. It is envisaged that, in time, these would replace the manned platforms to a great extent for military roles.

Reference to the word 'drone' has widened over the years to encompass not only aircraft which make drone like humming sounds from their propellers but also surface/sub-surface craft, and even space craft. The nomenclature of drones varies as per the type of control, role, altitude of operation, endurance, etc., and commonly heard substitutes are Unmanned Aerial Vehicles (UAVs), Unmanned Combat Aerial Vehicles (UCAVs), Remotely Piloted Vehicles (RPVs), Quadcopter, etc. Similarly, Unmanned Ground Vehicle (UGV), Unmanned Surface Vehicles (USV), and Unmanned Sub-Surface Vehicle (USSV) as the most used names for land operated as well as water surface and sub-surface vehicles. Other terms for aerial drones are HALE (High Altitude Long Endurance), MALE (Medium Altitude Long Endurance), etc., referring to their flying characteristics.

The most commonly and prominently used are the unmanned aerial vehicles, or aerial drones. With increasing autonomy and intelligent functioning, aerial platforms are being progressively employed for complex tasks, especially in warfare by militaries—although, at the same time, these are also emerging as potent warfare tools for non-state militia and terrorists. The use by Hezbollah and Houthi are examples. New types of drones are also under conceptualisation, experimentation, and development, including very small nano-sized ones (the size of grasshoppers). However, these are still far from any useful military applications, being a fledging technology.

Military Usage

While their use in non-lethal military roles has burgeoned, and the 'Dull, Dirty, Dangerous and Deep' tasks related to these roles are being performed by drones more than ever before, there is still caution about employing these unrestrictedly in warfare. The main issues are about cost-benefits vis-à-vis their survivability and effectiveness in hostile conditions, as also of ethos in the use of drones for enforcement and combat roles which will certainly involve the use of force, lethality, and destruction. This is sometimes seen as cold blooded.

Aerial drones would be a part of all kinds of military operations, be they land, naval, or air operations. This is because the integration and interoperability of the various arms of the military will increase in the future. The huge numbers of drones, and their use by air as well as surface forces, would necessitate mostly automated/autonomous/centralised usage monitoring and coordination of their flying activity.[4] As is clear, due to the commonality of the medium of air in which these operate, it would be almost impossible to declutter/de-conflict their missions as well as identify friends, foes, and unhooked[5] entities. How all this will evolve in the future

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4 All military UAVs /other resources would require to be hooked to a Battle Management System Network in the future through various channels at different levels which would provide for their networked monitoring, control, coordination, and regulation of friendly battlespace entities. Even though mission tasking for the UAVs/other resources would be decentralised, such a centralised coordinating system would be needed for proper control, preventing misidentification, and identifying hostile elements. For related details, also see, Atul Pant, "Internet of Things: Centricity of Future Military Operations", *Journal of Defence Studies,* Vol. 13, No. 2, April–June 2019, pp. 25–58, at https://idsa.in/system/files/jds/future-military-operations-apant.pdf.

5 During military action involving a large number of UAVs, at times, some may become unhooked from control due to technical problems. These would not be hostile though.

is difficult to tell; however, their move towards the centre-stage of military operations—which has been visible since the Gulf War 1 (1990-91)—will no doubt only increase even further. In the future, it is probable that integrated or unified command and control structures will emerge as the way for regulating their operations and all other such networked resources. This aspect is discussed later in the paper.

Non-lethal Roles

ELINT gathering, surveillance, reconnaissance and observation, communications, target designation, Directing of Own Artillery Fire (DOOAF), electronic warfare (EW), search and rescue, photography, and enforcement are a few of the non-lethal combat roles among many others for which drones are being employed in the military sphere currently.

The non-lethal employment of UAVs would take place both in contested and uncontested airspaces in the future; however, present utilisation is mostly in uncontested spaces. The reason for this is primarily the yet nascent nature of technology employed in drones. Drones are still part of an evolutionary process in which the present ones are mostly designed for low speeds (they are propeller driven), with limited manoeuvrability, mostly with nil self-defence capability, with early developmental software as well as AI versions. Moreover, most of them are radio link dependent for many-a-thing, making them particularly vulnerable to hostile actions. Smaller drones also have limited range and endurance. However, as newer technologies which are at various stages of experimentation and development—like composites and advanced materials, blended structures, supersonic design, stealth, jet propulsion, AI, nano-technology, etc.,—will make them more potent as they mature. It is quite possible that, in the not too distant a future, drones will become the most favoured platforms for even contested spaces.

Lethal Roles

In lethal roles, drones are limitedly being employed for precision targeting, using air to ground missiles/bombs and as sacrificial weapons against

[6] Targets are mostly Radars for such sacrificial drones. Cruise missiles, used for precision attacking on such targets, are also seen as members of the drone family.

some sensitive targets[6]—again mostly in uncontested airspaces. In the future, all the combative roles that a manned fighter aircraft performs would also be shared by the UAVs. The change will be brought about by the autonomous operations capability as the technology advances, viz., air-to-ground targeting, aerial combat capability, enhancement in speed, manoeuvrability, endurance, payload carrying capacity, advancement of sensors/weapons, computation and software. Automatic target engagement, Anti-access/Area Denial (A2AD), airspace sanitisation, airspace dominance, no fly zone enforcement, teamed operations with manned platforms, providing armed cover to surface missions, and combat search and rescue—both during hostilities and crises—would be some of the armed roles seeing the employment of UAVs in about a decade or so. Anti-terrorist operations would see a major participation of drones.

Future Employment

Drones are on the way to becoming the future force multipliers for most militaries. Their role would be critical in warfare in the future. As seen in the previous paragraphs, drones are being developed in multiple designs, and for multiple roles. At places, as in the case of sacrificial drones, the commonality with weapons allows them to be seen as either. Examples include the Harop, Harpy, and cruise missiles. Broadly, aerial drones are either in the conventional fixed winged aircraft design, or rotary wing design (helicopter or quadcopter), or a combination of these. There are more designs under experimentation, like flapping wings (ornithopter), and miniaturised spy drones. However, the most useful ones for military purposes are likely to be the first two only in the foreseeable future. Role specific design optimises performance and helps contain costs. In the case of drones, such an approach for military drone development is likely to be more fruitful.[7]

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7 To understand a little more in depth, drones integrated with the land forces offensive (in battlefields) for recce and directing fire would need to be in the hovering design (rotary wing), which can also effectively utilize the terrain and obstacle cover to protect themselves by remaining stationary behind cover; otherwise drones flying high in such contested battlespaces are likely to be targeted rather easily. Similarly, the drones integrated with the first wave of attack in a frontal land assault need to be small, expendable/self-sacrificial winged swarms

In general, as technology develops, and miniaturization and the modular design concept of the role equipment becomes prevalent, small and medium drones are likely to be the choice of military where possible, which could be role modified by fitting the required equipment—as is done in manned fighter aircraft. Larger drones are expensive (both in unit cost and operation wise), difficult to manoeuvre, easily detectable, and targetable. In some cases, though, large drones are also essential. In the foreseeable future, drones are likely to be of both the currently prevalent types—expendables and recoverable. Very small drones would generally be the expendable kind (with exceptions), whereas the larger ones would generally be recoverable, except in few cases like cruise missiles.

Future Design Philosophy

Modular design as well as miniaturisation are likely to be the predominant design philosophies in the future. These would allow easier transportation, assembly, equipping, and role switching, and a more role equipment/payload carriage. AI incorporated on-board operating software is likely to give these the target engagement autonomy in a battlespace environment using inputs from multiple systems. Software operated flight controls (fly-by-wire concept) and system integration have already become imperatives of modern drones as these enable a full flight envelope and capability exploitation as well as optimise coordination and functionality of on-board systems for optimum performance and efficiency. Various UCAVs under development are already seeing the fitment of state-of-the-art avionics that are equivalent to modern day fighter aircraft—including radars needed for combat employment.

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swooping in, and intelligently targeting soldiers or combat entities at speed and causing a large number of casualties/damage. Besides being low in cost, these would bring shock and awe. These would be much more effective than a few high flying slow drones targeting enemy positions and combatants, where they are likely to be rather easily targeted by the enemy. Larger drones, though, would be needed in some supportive roles. Perdix swarming micro-drones being developed by the USA and even the ALFA-S swarming micro-drones conceptualised by the Defence Research and Development Organisation (DRDO) India, for surface offensive purposes, follow such an approach.

The key technology which is going to bring about face change in the employment of drones in warfare is the AI which, together with miniaturisation of electronics, is likely to give immense capabilities to even smaller drones.[8] AI would eventually make the combat performance of drones as good as any of the manned combat aircraft—or may be it would make it even better because of the absence of human limitations, like fatigue, G-limitations, etc. Features like Geo-fencing in the target area would add to safety, and make the drone operation more trustworthy.

AI would open up a wide range of functional capabilities in drones, many of which were so far considered unviable to be performed autonomously by machines. This is because AI, as a technology, is to a large extent a substitute for the human brain for future machines, functioning to coordinate and control the machine's components as the brain does human body parts, besides processing information from/to the outside environment.

Some capabilities delivered by AI would be: optimisation processing and fusion of sensor inputs and other information related to its environment as well as its analysis for building situation awareness (for itself and other team entities/commanders), automatic co-ordination with other entities in the mission and battlespace, optimisation of flight path and trajectory requirements in adverse conditions/obstacles, target identification/selection/distribution (with mission entities), autonomous attack profile build-up, selection of appropriate on-board systems for a situation, weapons selection, power distribution to on-board systems, optimisation of communications and data exchange, self-damage negotiation, gun and missile dodging, air combat capability, take-off (or launch) and landing (or recovery, besides many others. AI would be the enabler for swarming operations, particularly for flight path coordination, target distribution, and swarm healing. Degree of AI infusion into drones would depend on the role and size of drones.

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8 See Atul Pant, "Future Warfare and Artificial Intelligence: The Visible Path", IDSA Occasional Paper, August 2018, at https://idsa.in/system/files/opaper/op-49-future-warfare-and-artificial-intelligence.pdf, accessed 18 August 2019.

Besides AI, the other key technology would be the Internet of Things (IoT)—a recent concept of a data network based system of systems, enabling the machines to talk to each other meaningfully by exchanging data through various connection modes for such exchange. This would be an essential complementary technology for the AI to optimally function.[9]

Role Accomplishment

Both large and medium/small sized drones could be equipped for more than one role at one time: for example, recce equipment with self-protection EW suite, or air to ground weapons with self-protection EW suite. These drones could be bundled to fly in small packages or swarms for missions—with drones in a package configured for different roles pertaining to an offensive mission. This could include recce, EW, attack, air-defence, etc., much like manned fighter aircraft are packaged. The drone equipping in a package for a mission would be complementary and mutually supportive, that is, different drones with different sensors/equipment in IoT based communication with other package members, thus enhancing the package combat power. In such equipping and packaging, even in case of losses, the costs would be contained.

Medium and smaller drones would also be less vulnerable to enemy fire due to their smaller size, and their inbuilt evasive manoeuvring and dodging capability. Since the unit costs would not be very high, large numbers could be packaged together for any mission, including a mix of recoverable as well as expendable/self-sacrificial drones in the package. Designed with stealth, jet engines, EW suite, and advanced weapons, such drone packages could become a force to reckon with.

As such, lethality in modern day air defence environment does not allow the offensive aircraft more than one attempt at attack, or even stay for a long time in hostile/contested territory. Drones would be a much more suitable weapon platform for action in enemy/hostile areas in such an

[9] For further reading and details, see Atul Pant, "Internet of Things Centricity of Future Military Operations", 2019, n. 4.

environment in the future, where their large package or swarm would take on multiple targets in designated areas in one quick sweep. With the use of expendable/low cost drones where possible in packages, even with some losses, costs would not be exorbitant, especially when compared to large drones or manned fighter aircraft. The recoverable ones (which may be somewhat bigger) in the package would return quickly after the mission, and be recovered at recovery points in one's own/friendly territory. Drone missions would be particularly leveraging where some penetration into enemy territory is required.

New concepts of warfare are already being worked on because existing warfighting platforms are becoming exorbitantly expensive and losses of which are becoming unsustainable. Two such evolving concepts are Mosaic warfare,[10] and Distributed Maritime operations.[11] These concepts are based on using a large number of cheaper and smaller (but modern) warfighting equipment/platforms, with limited roles. The roles would be complementary, and they would be operating in concert during any action.[12] This would avoid any kind of catastrophic or unsustainable losses. Drones would be the key elements of such warfare.

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10 DARPA Tiles Together a Vision of Mosaic Warfare", Defence Advanced Research Project Agency, at https://www.darpa.mil/work-with-us/darpa-tiles-together-a-vision-of-mosiac-warfare, accessed 20 September 2019.

11 Megan Eckstein, "Navy Planning for Gray-Zone Conflict; Finalizing Distributed Maritime Operations for High-End Fight", *USNI News*, 19 December 2018, at https://news.usni.org/2018/12/19/navy-planning-for-gray-zone-conflict-finalizing-distributed-maritime-operations-for-high-end-fight, accessed 19 September 2019.

12 This warfare is also being called LEGO warfare. Like LEGO bricks, a large number of small entities would be operating in concert to achieve just sufficient advantage over the adversary. With AI, the offensive would be with speed so as to leave the enemy incapable of effecting any credible counter, and the enemy's Systems Destruction Strategy is expected to be negated. Systems Destruction Strategy is another recent term, and refers to targeting the enemy's core systems which would be underlining his military capability or activity. There would also be no single point of failure during the operations.

The choice of drones for individual services would be a matter of the roles the services are tasked to undertake, which would vary from nation to nation. While the army would seek drones for its land warfare requirements—probably the low altitude shorter range ones—the navies would need all the short, medium, and long range ones due to its generally detached and independent nature of operations, away from the national territory in all the three dimensions: over the sea, land (coastal regions), and in the air. The roles for the air forces again, vary from nation to nation, and generally encompass both strategic as well as tactical roles in the same force. Air forces would also look for the entire short to long range kinds, but for requirements distinct from armies and navies.

However, with a large number of drones in the airspace of all the three services, and the increase in overlap in zones of engagement of their air defence weapons (brought about by their increasing ranges and the proliferation of strategic weapons, like cruise missiles), most drones in the future may see their regulation and control through integrated (common to services) management structures (along with related functions, like air defence). This is elaborated later in the paper.

Land Warfare

In land warfare, besides the lethal and non-lethal roles described earlier, against the critical targets in battlefields—which could typically comprise of trenched/sheltered/shielded soldiers, armoured and non-armoured weapon platforms, vehicles, support equipment, communication equipment, and fuel and ammunition dumps—a range of elemental lethal drones (for armies) specifically designed/configured/equipped for each target entity are likely to come up in the future. This will be necessary primarily due to each target type requiring a different kind of warhead, and often a unique attack profile to neutralise. Most of these drones are likely to be the low cost, expendable/sacrificial kind of micro/mini variety, along with their delivery mechanisms;[13]which would be in the form of

[13] Micro/Mini/Small aerial drones are likely to have short ranges of operation and so would often require delivery mechanisms, in the battlefields, which would deliver them closer to the target area to accomplish a mission.

larger aerial/ground drones, manned aircraft, canister carrying rockets/missiles, etc. Other important functions small drones could be used for are mine hunting and destruction.

Larger supportive role equipped drones, as described earlier in the paper, are likely to be also present in a drone offensive, as just the small drones are not likely to be successful by themselves in the face of advanced countermeasures deployed by the enemy. These supporting drones would be equipped with or carry EW capabilities, laser jammers/designators, smaller air-defence drones, electro-magnetic pulse generators, etc., to provide various kinds of protective covers to the smaller drones. Such drones would again not be the very long range kind, but would be probably vehicle launched (limited length launcher) or small improvised airstrip launched near battle front, but would be low cost and recoverable due to their vulnerability.

Micro/mini personal reconnaissance and observations drones (R&O), which are sometimes also referred to as organic air vehicles (OAV)[14], are likely to be essential in a soldier's kit for crammed battlespaces, like forests and urban areas. These could be operated at the platoon/section level also for multiple roles, including reconnaissance, target designation, isolated attacks, or even decoying.

These would reduce the dependence of the land forces on other services for frontal air offensive mission requirements (like air strike requirements) while also reducing the need for profuse artillery bombardment prior to a land offensive. Forward logistics, cable laying, aid in casualty evacuation, EW support, R&O, communications, and mine laying are also some of the other multitudes of roles envisaged for drones in future battlefields, especially in difficult terrains and situations of quick response. Most of the smaller drones are likely to be a part of the surface element of the land forces rather than the air arm, and that too with the forward deployed elements or missile units.

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14 J. Jayaraman, *Unmanned Aircraft Systems: A Global View*, New Delhi: Defence Research and Development Organisation, 2014, p. 11.,

Air Warfare

For the air forces per se, aerial drones would probably be the most revolutionary inductions after jet engines, radars, and missiles. These could prove to be the means to avoid manned aircraft from unnecessary exposure to the high lethality of the future battlespaces, especially during the early phases of war, in which the tempo of battles is likely to be very high and weapons plentiful. Besides independent or all-drone missions, these would be complementing and supplementing various manned air missions in many ways. The air forces would need a range of small to large drones. This is elaborated in the succeeding paragraphs.

From an air force's point of view, small drones are evolving to become very potent air launched intelligent autonomous weapons. With designs to launch from high speed aerial platforms as well as missile mounted canisters in swarms near the target, and armed with potent customised explosives, small sacrificial drones could splendidly serve the purpose of the air forces for striking soft and semi-soft targets deep inside enemy territory (like parked aircraft inside blast protected shelters in airfields, communication facilities, fuel bowsers, radars, etc., and even strategic value targets like cracking towers of oil refineries), while saturating the enemy airspace as well as radars (always the much preferred tactic by air forces).

On a target, intelligent micro-drones will be able to attack the most vulnerable spots on targets with the maximum probability of neutralising it.[15] With delivery through missile or drone, these could help avoid in-depth risky penetration of enemy territory by manned aircraft. Attacking multiple targets through a single drone laden missile would reduce the costs of operations, enhance efficiency and effectiveness, and avoid collateral damage. Also, repetitions would be easy to execute.

Even for missions like Battlefield Air Interdiction or Battlefield Air Strike (by the air forces or air arm), small drone swarms with larger drones in support roles (as in the case of land forces) are likely to become the

[15] Such vulnerabilities on any target could be pre-fed in the memory of the drones through statistical database and training data for the AI.

preferred choice in the future over fighter aircraft/attack helicopters. Rather than a high risk strike role for a manned fighter, aircraft are likely to be packaged along in all drone strikes to provide broader air cover. In fact, aircraft packaging is a fluid thing, and its composition can vary as much as resources, environment, and ingenuity allow.

The tactical employment of drones in contested airspaces is likely to be mostly in mass, where they saturate the airspace and make discernment of the actual lethal ones and the decoys difficult. Moreover, the future close-in-weapon systems (CIWS) and counter drone systems are certainly going to be faster reacting and highly lethal, with the capability to engage ever increasing number of targets simultaneously. These drones, with inbuilt dodging and evasive capabilities, are likely to survive more and execute tasks more successfully than other aircraft in such environments.

These are also likely to be designed against certain hardened targets, like armoured vehicles, and to be used in swarms against both static and dynamic enemy armour. AI would be the key tool for distinguishing the enemy armour from friendly ones, based on shape, size, transmissions, behaviour, etc. Small drone swarms could also be designed as intelligent mines, scattered at crucial places in the airfield/military congregations, and going-off/leaping at targets when an aircraft or other target is detected in proximity. Cluster munitions as mines are already in use (examples MW-1, MIFF, MUSA, MUSPA); but are scattered incoherently, whereas drones could intelligently place themselves at vulnerable points in an airfield.

Drone swarms would be self-healing—that is, in the case of technical failures or shooting down of some swarm elements, the task would be re-distributed automatically to others in the swarm. Their AI could also be designed for facial identification and for targeting specific crucial military/non-military individuals. In this manner, drones could be used as an effective anti-terrorist tool in the war against terror in sub-conventional warfare, besides being used to target key commanders/personnel in a conventional war.[16]An example of the above is the US DARPA project—

[16] The DRDO has stated its vision for developing Alfa-S swarming drones for such usage. See, n. 7.

called Offset Swarm Enabled Tactics (OFFSET)—undertaken with an aim to accelerate drone swarming tactics, especially of urban and built structures.[17]

All this may seem like a figment of the imagination presently; but with the development trajectories of various technologies, these possibilities are not unreal, and the initial versions of such capabilities are being demonstrated from time to time. The possibilities of drone employment are, in fact, huge, and all will depend on how the AI and its infusion into small drones develops. Much experimentation is underway in research labs globally.

AI is a very powerful tool for bringing ingenuity in warfighting. It is not generally well understood with regards to its immense potential. Even in the case of low data connectivity,[18] or a no connectivity environment, the AI could enable drones to perform tasks autonomously. AI would also help the drones in resilience against EW by identifying and selectively processing incoming transmissions as well as intelligently modifying the outgoing ones for a low probability of interception by enemy.

With increasing ranges of surface to air missiles (SAM) as well as their proliferation in the future, there is hardly any airspace which is likely to remain uncontested within 300-400 km of the borders where most of the battle action would take place. The ranges of air defence missiles, both air to air (AAM) and surface to air, is already being measured in hundreds of kilometres, and is likely to only increase. These missiles are also getting armed with better sensors and becoming increasingly intelligent, and this is only going to improve further in future. There is likely to be a practically unabated growth of SAMs and AAMs of varying ranges,

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[17] Geoff Fein, "DARPA to explore swarming operations", *IHS Jane's International Defence Review,* March 2017.

[18] Intermittent or limited range connectivity through radio data link while in flight.

resulting in multi-layered kill zones for intruding aircraft. While EW would be necessary counter/masking measures against these missiles during manned or unmanned missions, the burgeoning numbers of missiles would set the best option at combining EW with drone decoys.

Low cost high speed drones (small to medium sized, flying close to fighter aircraft speeds), equipped with radar cross-section enhancers, corner reflectors, low cost fictitious radar frequency transmitters (similar to ASPJs), and tactically coupled to own missions going into enemy territory could serve as excellent decoys for wasting enemy's missiles and diverting their combat air patrols. These would be programmable for realistic flying behaviour like combat aircraft as well as recovery in own territory for reuse (whichever survive enemy AD weapons). AI would give them manoeuvring capability (evasive). Such packaging would, indeed, be a much needed measure for air forces in the future to lower the risk to one's own modern combat aircraft with their exorbitantly high costs. Mixed packaging would also be important from the point of view of reducing opposition during ingression into enemy territory to increase the probability of success of missions.

It would also often be a necessity to use drones as decoys in one's own airspace against the intruding enemy missions to ward-off threat to one's own aircraft/drones, especially the high value ones, either in the air or on the ground during crisis and hostilities. They could also be used to lure their offensive aircraft/drones away and/or waste their missiles on these. Due to huge numbers of aircraft in future air offensives, the current set of measures—like chaff/flares/EW/evasive manoeuvring—may not be sufficient. Drones would give an offensive element to air defence.

While such measures would be taken by one's own forces, it should also be expected that the hostile forces would also make similar use of drones (both in offensive and air defence), which could result in gross wastage of friendly/own missiles. If the adversary is a weaker nation, then it is more likely to rely on the use of drones to make warfighting affordable. Though in the initial phases of hostilities, especially when the battle tempo is high, it is difficult not to target any unidentified flying object intruding at high speed into one's own territory with missiles. The sheer cost of the missiles would make it a difficult proposition, with the likelihood of there being a false drone trail. There was much debate in 2017 when a US$ 3 million Patriot missile was used to shoot down and US$ 200 drone.[19]

The solution probably would lie in using low cost drones themselves as air defence weapons (as missiles) that are recoverable (if they survive): that is, low cost drones (equipped with some kind of AI based IFF system—even for own/friendly aircraft identification) which could be directed against the intruding drones/aircraft using IR/visual/RF homing, and proximity fuse. This set of AD drones would need to be different from decoy drones, following a separate design principle (offensive kind). Such drones may also find use with ingression missions. All this is bound make the future air defence scenario very complicated.

In fact, for low speed drones, particularly in the case of swarms, an effective and feasible counter-measure is likely to be counter swarms of drones. These could be kept available in the form of containerised pre-programmed drones loaded on vehicles, and ready to be launched from the container itself at anticipated field/frontal locations. These could also be kept plugged into the battle management system (BMS) network—wired through their container or vehicle for instantaneous last minute programming/updates with the BMS AI when required.

Smaller aerial drones (micro/mini/midi class) seen so far are just one segment of the combat drone family, and would help fill up only a certain volume of overall battlespace expanse. There are roles and tasks for which small drones would not be suitable or sufficient. These would invariably require larger aerial drones for fulfilment.

A considerable amount of development work is going on in the field of larger autonomous combat drones, and many of them have already been inducted in the forces and being used in offensive roles. The current ones

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19 Samuel Osborne, "Small drone 'worth $200' shot down by Patriot missile worth $3m, says US general", *The Independent*, 15 March 2017, at https://www.independent.co.uk/news/world/americas/small-drone-quadcopter-patriot-missile-shot-down-us-general-david-perkins-army-a7631466.html, accessed 15 February 2019.

are the slow moving kind which can be used mostly in uncontested spaces as these are vulnerable to be easily targeted by air defence weapons: they are incorporated with fledging technology which gives them nil or very limited combat manoeuvrability or the capability of evasive actions/self-protection.

There is, however, extensive experimentation underway by the major powers for developing combat air drones which will have capabilities much better than manned fighter aircraft in all fields. In size, these are similar to manned fighters, or are smaller. In cost, these are cheaper and, eventually, will be far cheaper to procure and operate than manned combat aircraft. Their weaponry would be similar to manned fighters. Air forces/ air arms of surface forces would be the major users of these.

The main reason for seeking larger drones to replace manned combat aircraft is increasing human limitation. With a plethora of state-of-the-art avionics being installed in modern fighter aircraft cockpits, along with the information fed to the pilots gathered from the environment as well as incoming from external data links, the situation in the fighter cockpit have started saturating the pilots: it is going beyond human capabilities to effectively monitor and/or operate everything, fly the aircraft, do combat, communicate, etc.[20] In spite of 'intelligent' aircraft computers feeding only the necessary processed information to pilots, the information is still increasing and the human element is still falling behind in coping with it. The human element is rather increasingly becoming the limiting factor in the man-machine combine in the successful execution of missions.

These larger drones would have space for the fitment of a considerable amount of advanced avionics. These are likely to be armed much better than fighter aircraft in the future. The reason is the much higher rate of mission related data processing and decisions based on data logic, avoiding

20) When seen together with the task of flying the aircraft, monitoring the air situation visually, manoeuvring in combat, and also communicating. This is the prime reason for the modern concept of twin cockpits so that the load gets distributed between two pilots.

errors due to stresses, saturations, and feelings of the human element. This allows them to engage a larger number of targets simultaneously with much better efficiency, and also generate options and select from them in a much better way than humans in same conditions. Trials have proven these aspects. Stephan De Spiegeleire quotes an example of a 2016 simulated air combat exercise in which Psibernetix's artificially intelligent fighter pilot ALPHA soundly defeated US Air Force Colonel (Retd.) Gene Lee in a series of simulated dogfights. The "fuzzy logic" based system was able to process sensor data and plan combat moves in less than a millisecond (more than 250 times faster than the eye can blink), while using very little computing power.[21] The human element is, therefore, on the path of being excluded from machine intelligence led combat operations.

The ones under experimentation/prototyping/development are already being designed to be way better than manned combat aircraft. Blended structures, stealth, jet engines, mid-air refuelling, etc., are the technologies that are already being devised at the conceptual level itself for enhanced combat performance. Examples are discussed later in the paper. With the level of autonomy that has already been achieved in these prototypes/ technology demonstrators, it can easily be foreseen that, in about a decade or so, these drones would evolve to become independent mission and teaming capable with other UCAVs/manned aircraft. Papers on such conceptual level ideas have also been published, and are available on the internet.

Large drones would be very formidable "buddies" and team members to manned aircraft in mission packages. In fact, independent all drone packages are also a real possibility, as discussed earlier in the paper. Large drones would be useful for combat support roles too. Apart from the roles covered earlier in the paper, the roles would also include all the ones which currently manned aircraft are performing, including heavy lift,

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21 Atul Pant, "Future Warfare and Artificial Intelligence: The Visible Path", 2019, see n. 8.

passenger ferry, supply drop, AEW&C (with remote manning for manual control), mid-air refuelling, etc. In 2018, China demonstrated a full mock-up of its heavy-lift Tengden TW-365 cargo drone under development.[22] In the civil domain, Chinese Star UAVs has already contracted three AT-200 cargo UAVs for manufacture.[23]

These large drones would still be expensive to be used extensively in future battlespaces considering the likely high lethality vs. the cost benefit. The drones which are likely to see employment in large numbers are the mid-sized attritable drones. "Attritable" drones is the term that has evolved with the militaries in the last decade for the drones that can be reused, but are also cheap enough for a commander to use them aggressively and yet be comfortable with some losses in combat.[24]

The design and development of attritable drones is being driven by the low cost requirement, with the USA being the initiator. The US Air Force has already evinced considerable interest in such attritable drones, and was on the verge of placing orders for a number of these for trials from Kratos Defense in 2017.[25] Kratos Defense's XQ-58A Valkyrie drone had

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22 The Tengden company displayed a full-size mock-up of its TW-356 twin-engine unmanned aerial system designed for the transportation of heavy cargo in the Zuhai airshow. The TW356 can be configured to carry cargo on four underwing hardpoints, as payloads configured in pods, including cargo delivery, remote sensing, or electronic warfare packages. The company also develops a variant of the drone designed for operation at very high altitudes. The largest variant, TW-765, will be able to carry 22 tons of payload up to 7,500 km. See also, Tamir Eshel, "New Drones Dominate China's Airshow", *Defence Update*, 9 November 2018, at https://defense-update.com/20181109_new-drones-dominate-chinas-zhuhai-airshow.html

23 Kelvin Wong, "China's AT200 cargo UAV readies for operational evaluation", *Jane's*, 30 January 2019, at https://www.janes.com/article/86057/china-s-at200-cargo-uav-readies-for-operational-evaluation

24 Valerie Insinna, "US Air Force looks to fast track cash to KratosDefense for more Valkyrie drones", *Defence News,* June 2017, at https://www.defensenews.com/digital-show-dailies/paris-air-show/2019/06/17/us-air-force-looking-to-fast-track-cash-to-kratos-defense-for-additional-valkyrie-drones/, accessed 12 September 2019.

25 Ibid.

won a demonstration for the United States Air Force (USAF) in 2015.[26] USAF intended to demonstrate its link-up with the fifth generation fighters in December 2019.[27] Lockheed Martin Skunk works is also making considerable investments in such attritable UAVs, to fly teamed alongside manned fighters.[28]

These aircraft are likely to have near supersonic speed, long endurance, and high manoeuvrability, apart from most of the other combat related features described earlier in the paper, which could make these formidable partners for manned fighter jets.[29] These highly manoeuvrable, stealthy UASs can carry and deploy weapons or surveillance systems. The 30ft-long Valkyrie has a range of more than 3,000 nautical miles. The US Dynetics Gremlin Drone is another such drone being developed under aegis of DARPA which would be air-launched and air recoverable (through a larger transport aircraft) at a safe distance from targets/battlefields.[30]

The cost of such drones is likely to be one twentieth to one fiftieth of a modern manned combat fighter aircraft, allowing them to be pitched aggressively in combat situations. This is the characteristic that would be most appealing to the forces. The production cost of a Valkyrie drone has been envisaged to be US$2 million against the cost of an F-35 fighter aircraft which costs between US$94 million and US$122 million, and the F-22 which costs around US$ 150 million.

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26 Ibid.

27 Video: "Here's how the US Air Force is automating the future kill chain",| Dubai Air Show 2019, at https://www.defensenews.com/video/2019/11/16/heres-how-the-us-air-force-is-automating-the-future-kill-chain-dubai-airshow-2019/, accessed 28 November 2019.

28 James Drew, "Skunk Works Sees Big Opportunity for 'Attritable' UAVs, *Aviation Week,* 31 August 2017, available at https://aviationweek.com/defense/skunk-works-sees-big-opportunity-attritable-uavs, accessed 12 September 2019.

29 Inferred from the article by Valerie Insinna, "US Air Force looks to fast track cash to Kratos Defense for more Valkyrie drones", *Defence News*, n. 24.

30 "The Gremlins Program Fact Sheet", *Dynetics*, at https://www.dynetics.com/_files/strike-systems/Dynetics%20Gremlins.v2.pdf, accessed 28 September 2019.

The Valkyrie drone has, in fact, been envisaged to go under production within the next half a decade or so. The sixth generation manned combat aircraft is itself being conceptualised on the manned/unmanned (autonomous) team concept. The USAF sees it as a Force Multiplier.[31] These would also be capable of both teamed missions as well as independent missions.

Attritable drones are likely to be lightly armed as compared to the modern combat aircraft, but would carry weapons similar to them. As pointed out earlier, these drones would be equipped with gadgets, systems, weapons, and designed with features depending on the requirement of the particular force, the role these are envisaged to undertake, and the situation. These would be jet engine powered.

These mid-sized drones are likely to be different sets for the surface and air forces and could be inducted in large numbers due to low costs. The reason for holding these as separate sets for different forces is the requirement if these have to be pitched in large numbers simultaneously in battles in the initial phases to gain quick advantage, or to deny the adversary the same. These would be teamed with the manned aircraft/other drones for operations.

For the air forces, these will take away a major share of missions from manned fighters. It would, however, need to be kept in mind that the degree of attritability of various mid-sized drones would vary depending on their purpose and, therefore, their cost would also have to be contained accordingly to minimize financial losses. For example, the decoy drones are likely to suffer more losses, and have to be designed more attritable than air combat drones. In some cases, though, role switching could be feasible.

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[31] "Kratos to launch XQ-222 Valkyrie, UTAP-22 Mako at Paris Air Show 2017", *Air Force Technology*, 15 June 2017, at http://www.airforce-technology.com/news/newskratos-to-launch-xq-222-valkyrie-utap-22-mako-at-paris-air-show-2017-5845491/, accessed 4 March 2019.

Naval Warfare

In naval warfare also, the roles of drones would range from offensive to ISR, patrolling, communication, mine counter measures, EW, and all the other roles in a combination of air warfare and land warfare. In fact, drones would add significantly to the self-sufficiency of naval forces for independent operations, as their low cost and large number inductions would enable them to take care of the third dimensional aspect much better.

Air force drones would also see employment for naval requirements in coastal areas and the seas till wherever reach permits. In support of the navy, air force drones could do limited anti-shipping operations, particularly cruise missiles which generally have a very long range and could be employed suitably with sensor and warhead modifications. Naval drones, though, would face some additional challenges of preservation and operation in saline conditions and limitations of recovery techniques over ships.

Military Operations Other Than War (MOOTW)

In sub-conventional warfare or internal disturbances, drones would be better aerial platforms for rapid reaction, especially in roles like terrorist hunting and hideout destruction. Various techniques—like movement sensing, posture recognition, and facial recognition—would be the AI tools likely to be useful in these operations. In HADR roles, these could be sent the fastest in the affected zones to assess the situation and start relief preparation. The use of the drones, especially smaller ones, in providing security to airbases and vital installations is increasing. Not only are these being used to patrol perimeters and borders but these are allowing relatively easy surveillance in difficult terrains or sensitive points in the vicinity too. These could also be used to tackle or target the intruders with weapons in future. Such drone design concepts and technology demonstrators are plentiful on the internet.

Besides the new generation weapons being tried on drones and sacrificial drones being developed, there are other combat capability enhancement concepts being experimented with. In 2012, a UAV of Boeing company of the USA, named CHAMP, was revealed which carries the Non-Nuclear Electromagnetic Pulse (NNEMP) generation device onboard for use as a weapon against electronic systems. Broadcasting through drones on civil radio frequencies in one's own and enemy territory could become an information warfare tool.

Associated Aspects

Some aspects associated with future aerial drone operations are highlighted here for better insight and understanding.

Command and Control Structures

Considering the large number of aerial drones and their wide variety that would get inducted into the three services of the armed forces, their flight coordination would be a Herculean task as these would be using the common of the medium of air and, at the same time, share airspace with other users. For the same reason, air defence too would be problematic. Both these functions would require immense coordination and monitoring while flying, so that unfriendly drones and other flying entities get identified in a timely manner in the likely melee, and the hostile ones prevented from intruding and/or successfully executing their mission tasks.

At the same time, one's own flying entities should also not make mistakes and suffer fratricidal losses, especially in a hostile environment of war. Considering the high speed capability of most of the future drones, in most cases time would be critically short to take decisions or react—as happens in the case of aircraft. The physical separation of their places of launch by different services (due to services operating in separated locations) but overlap in the operation zones as also their autonomous flight would preclude manual coordination. Humans will probably be involved in higher level functions. The US Air Force Chief Scientist, Greg Zacharias, said in an interview that "[p]eople will function as air-traffic controllers rather than pilots, using smart, independent platforms. A person does command and control and drones execute functions. The resource allocation will be done by humans as higher level systems managers."[32]

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32 Kris Osborn, "Revealed: America's Lethal Stealth Drones of Tomorrow", *The National Interest*, 27 April 2016, at http://nationalinterest.org/blog/the-buzz/revealed-americas-lethal-stealth-drones-tomorrow-15958, accessed 03 October 2018.

For effective coordination and air defence, the requirement would be autonomous mission coordination of all flying entities through an AI based system, which may be a subset of the war management system (WMS), to which all the flying entities in a region would be data linked. This would also require a user friendly unified (common) drone operations format and principles as well as unified air defence function between the three services. To execute these properly, there would be a need for unified/common/integrated structures (organisations) wherever the services are sharing airspace.

These structures would also bring in much more efficiency in the use of airspace. The exact nature of the set-up, and the modalities of operation of such set-up/s, would be a matter of extensive study and is beyond the scope of this paper. It would also be logical to keep the command and control of certain drones, like cruise missiles, independently operating strategic and tactical UCAVs, Information Warfare drones, larger ISR, and even some EW drones with such structures rather than individual services.

Such a need of common structures and integrated or enhanced air defence is yet to be felt by the militaries because their numbers are still small and insignificant as yet. The case will, however, not remain so soon in the future.

Interestingly, the air defence function is going to expand vastly in future and will subsume other types of third dimension defences, including the ballistic missile defence also. On its website, NATO has recently indicated such a merger concept of multiple defences, which includes air defence, ballistic missile defence, theatre ballistic missile defence, cruise missile defence, counter rockets, mortar and artillery, and counter unmanned aircraft systems.[33] In India too, the Group of Ministers' 2001 report on

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[33] North Atlantic Treaty Organization, NATO Integrated Air and Missile Defence, at https://www.nato.int/cps/en/natohq/topics_8206.htm

National Security, also mentions such a need in para 5.109 (Safeguarding the Sanctity of Indian Air Space).[34]

Open Architecture War Management System

The employment of a large number of drones would call not only for an AI-based WMS in the future, but also its flexible and open (but secured) architecture to which the drones or their swarms would be connected for control and coordination, primarily by means of radio transmissions which will be Low Probability of Intercept (LPOI), and communicating only on need basis (to avoid tracking, cluttering up radio frequency/bandwidth as well as reducing the possibility of interception and intrusion). The number of drones at any point in time could vary considerably and, therefore, the architecture of the WMS would need to be open in which drones could plug-in and plug-out. Also, the levels at which command and control over different drones is exercised as well as their connection to the WMS may differ; but their mission data flow would be to the centralised system for effective autonomous coordination and de-confliction.

Future drones are going to be invariably autonomous. Thus, these would take updates/programming/mission data from the WMS, using the IoT principle. A number of nodes would be required wherever feasible in the battlespace for linking these to the WMS. These nodes could be in the form of airborne platforms (AWACS, etc.), movable or transportable ground based transmitters, or even other drones (relaying like the WiFi repeater, apart from their own transmissions) in the operating area. Satellites also would be important means for a two-way communication with larger drones, and one-way with smaller ones (for sending updates/ programming data etc.). Drones with required encryption and authentication

[34] "Appointment, Approach & Methodology", Chapter I, Report of the Group of Ministers on National Security, 2001, pp. 84–85, at https://www.vifindia.org/sites/default/files/GoM%20Report%20on%20National%20Security.pdf, accessed 17 September 2019.

[35] Atul Pant, "Internet of Things Centricity of Future Military Operations", 2019, n. 4.

data/algorithms would be able to link-up to the WMS through these nodes.

Of course, such connectivity would present a risk of intrusion and soft hostile actions into the WMS, and would demand a lookout and preventive measures. Pervasive computing in drones would be a much needed feature to reduce transmissions, and conduct independent operations. Some more details of issues/challenges related to communications in such IoT devices in battlespaces have been brought out in earlier papers on IoT in Future warfare.[35]

Many technological challenges related to drone capabilities have been keeping strategists and analysts sceptical as to what would be achievable in the foreseeable future—in about a decade to decade and a half. A look at the trends in technological developments in the civil domain should provide some clues. The sophistication in electronics, their miniaturisation, software, and the degree of AI infusion in the daily activities of the civil domain so far indicate that the concepts envisioned in this paper would see a fair level of materialisation within a decade or so—and, indeed, things could go beyond what has been envisioned here. Some of the prominent challenges are listed later in the paper. Such a visionary military proclamation during the Dubai Air Show 2019 was made by the US Air Force Chief David Goldfein's indicating the USAF's intention to move towards automation/ autonomy of the kill chain—that is, moving the human operator from *in* the loop to *on* the loop. This, in a way, spells out the future trajectory of military technology globally.[36]

Cost Benefit

The cost saving by using drones in warfare is a very crucial aspect, and would be multifaceted. The savings would be both direct and indirect. At present, though the costs of current drones are high and often quoted by sceptics to doubt their future employability, it is hardly realized that the

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[36] Video: "Here's how the US Air Force is automating the future kill chain", n. 27.

technology is maturing rapidly and, sooner than later, the costs are likely to peak out and likely to only downslide thereafter.

Simpler role specific designs, with fewer on-board systems as per the mission tasking, would accrue most of the cost benefits. Also, the system AI and integration of AI at various levels would reduce the need for the training of the human crew of the drones as almost all the aspects of the drone operations would be controlled by the software, right from mission planning, to flight performance, and to data interpretation, with little human intervention. The programmed/downloaded mission data would be used to 'train' the AI further (both itself and others). Savings on fuel due to smaller engines would be the direct cost benefit. The use of Commercial-off-the-shelf (COTS) components to manufacture the cheaper expendable drones would be another area of cost cutting.

M. L. Cummings, a professor at Duke University and a former fighter pilot with the USAF, gives an example of direct cost benefits through comparative hourly operating costs of the F-22 manned fighter aircraft (US$68,362) with the Predator Drone ($3,679) which is almost 18 times in case of the F-22 aircraft.[37] Even if a combat drone is jet engine powered, its operating costs are not likely to exceed half that of a manned fighter aircraft for a similar mission. Moreover, instead of a large sized drone, the employment of small narrow AI drone swarms would cost only a fraction of what would be spent otherwise. Major cost benefit would actually be realised through the operation of mid and smaller sized attritable drones.

Indirect savings would be in terms of the downsizing of the militaries that the use of these would make possible. Time saving in completing surveillance and reconnaissance would eventually be cost saving. The real benefits would only be realised with AI incorporation at every stage possible.

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[37] M. L. Cummings, "Artificial Intelligence and the Future of Warfare", Chatham House, January 2017, p. 3, at https://www.chathamhouse.org/sites/files/chathamhouse/publications/research/2017-01-26-artificial-intelligence-future-warfare-cummings-final.pdf, accessed 14 March 2018.

The maintenance costs of a fleet of machines would be lower than the maintenance costs of personnel due to lower recurring costs, like pay, kitting, health care, retirement benefits, etc. All these would make them preferable for both militaries and governments. Moreover, AI would bring in smart maintenance, thus reducing costs.

Recourse to drone development is gathering momentum all over the world, and with the cost demand being a fraction of manned aircraft, even smaller powers can be seen investing in drone development, including the armed versions. A good example is Pakistan, which has been able to successfully develop an armed drone (UCAV) called "Burraq"; it is armed with air to ground AR-1 missile.[38] A look at the country-wise lists of drones available on various websites is a good enough indicator of the importance being attached to the development of drones.

It is not that the overall cost of the warfare/defence for a nation would reduce; in fact, it would be the other way round, and the costs are bound to escalate in the foreseeable future due to many other reasons. The main reason for the costs to increase would be the drastic increase in the number of combat entities with the proliferation of drones. The cost advantage in using drones would be in getting a larger number of combat entities at the same/lesser costs. Also, in spite of increase in sophistication and combat capability significantly, drones will not totally replace manned fighter aircraft, though their share in various missions will keep increasing as time passes. The maintenance of some manned force would be necessary in case of situations like the disabling of a large number of drones through a cyber-attack.

Other Factors

Future conventional wars are likely to be short and intense in order to make quick gains, as more gains would be difficult to make after the initial

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[38] Usman Ansari, "Pakistan Surprises Many with First Use of Armed Drone", *Defense News*, 8 September 2015, at https://www.defensenews.com/air/2015/09/08/pakistan-surprises-many-with-first-use-of-armed-drone/, accessed 28 February 2019

phase. A lot would depend on the surprise factor and the initial massing of fire power. In both these aspects, the role of drones would be crucial.

Challenges

Environmental Issues and Natural Factors

Adverse conditions, like weather, lightening, forests, etc., would present humongous challenges to drone operations in warfare. Unstable phenomena like rain, fog, clouds, and lightening could become major disruptors of any military plans which are relying heavily on the use of drones. Rain, fog, and lightening could totally preclude the use of drones—especially the smaller ones—by not only disrupting communications but conditions like rain could physically prevent flying the smaller drones altogether.

Rain, fog, smoke, and dust would introduce opacity as well as noise in the environment, causing the distortion of visual images, the use of lasers/IR, the distortion of shapes, the masking of terrain, etc. Cluttered environments (like forests) would not only pose physical obstacles to drone operations but would also add to opacity as well as EM spectrum and connectivity related issues. Some of these disruptors in future are likely to become negotiable to an extent with the use of appropriate AI algorithms, EM frequency spectrum, a combination of technologies, and network connectivity patterns.

High altitude operations of UCAVs would be particularly challenging, and would demand separate set of drones. High altitude sustenance and the manoeuvrability of smaller expendable drones would be problematic issues in their employment in warfare. These would probably need negotiation through a very high altitude release of drones executing descending attack profiles. There would be other maintenance and engineering related issues with low temperatures. The variance of temperatures diurnally, seasonally, regionally, and with altitude would impose power source as well as equipment design limitations, which would have to be additionally catered for not only by the designers but also by the operators, and could bring unpredictability in strategic and tactical level plan executions. Their maintenance in harsh field conditions, including adverse weather, would pose a significant challenge.

Reliability

Another current concern is the reliability factor of drones when committed to operational missions. Though the failure rates of drones have been prominently higher than manned aircraft, the situation, however, is improving with the improvement of technology, where both the catastrophic as well as moderate failures have been reported to have come down in drones. The failure rate of the Predator UAV—which has probably been under maximum operational utilisation—has been reported to being lesser than the F-16. Other larger ones have also not been at too much variance with the USAF fighter aircraft statistics.[39] A factor to keep in mind here is the availability of technological expertise and resources for Predators with the USA—being the OEM nation. For others, particularly the ones importing the equipment, such level of maintenance may be difficult.

The autonomous failure diagnostics in the case of drones and actions thereafter for operations in hostile situations would need to be an inbuilt feature. Having an autonomous capability to proceed with the mission, or abort, or self-destruct would be especially critical during campaigns.

AI-related Challenges

Since AI would be a base technology in future drones, and there is a certain unpredictability in its decisions/actions due to the way it functions. Trust building in the AI system would be a challenge, especially during critical and nebulous situations, and particularly also for the use of weapons. In spite of the fact that one of the very purposes of AI is to guide or take decisions in such situations, the trustworthiness of AI for offensive actions is likely to take a long time after AI algorithms are seen to perform consistently in the right way, especially where the situations are very sensitive.

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[39] Extension version of conference paper by E. Petritoli, F. Leccese, L. Ciani, "Reliability and Maintenance Analysis of Unmanned Aerial Vehicles", *MDPI (Sensors)*,19 September 2018, at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6165073/, accessed, 03 March 2019

DARPA also emphasises on having predictability in machine behaviour,[40] which is a brick in building trustworthiness. The USA has proclaimed that they are delving in a big way into AI based Virtual Reality for training and simulation, and Computer Vision for ISR in the military systems.[41] Alongside, the US Department of Defence (DoD) has also invested in big data processing research and 'data hygiene' so that the AI is made to learn the right things and the right behaviour.

Ethics, accountability, and fixing responsibility will also become issues particularly with AI infused autonomous UCAVs, especially if the use of these leads to disproportionate or unintended killing and destruction. At times, it may become difficult to fix responsibility on either the commander or the mission handler or the programmer or the software/hardware designer on AI's autonomous decisions, particularly involving lethality.

As AI advances in the future, it is likely to require custom designed chips (integrated circuits) for drones, with higher processing power along with the miniaturisation of other electronic components and sensors, particularly for smaller drones. This would need an enhanced R&D effort in hardware designing, especially for the nations who are new to the field of drones and AI.

Resilience against EMP, EW, and cyber warfare will be other challenges in designing drone hardware. A very sensitive issue is the possibility of backdoors and trapdoors in the imported chips, electronics and software, making them vulnerable to cyber interference or attacks—which can render them totally unusable—even in mass at times.[42] Indigenisation in these fields would be essential.

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40 "Exhibit R-2: Budget Activity", Defense Advanced Research Projects Agency, p. 6, at http://www.dtic.mil/descriptivesum/Y2017/DARPA/stamped/U_0602303E_2_PB_2017.pdf, accessed 7 April 2018.

41 Ibid, p. 13.

42 See, Atul Pant, "Internet of Things Centricity of Future Military Operations", 2019, n. 4.

Miscellaneous

Power sources and the flight range for smaller drones are issues which would require intricate planning during designing and employment. In the case of smaller drones, providing/storing power for various drone related functions would be a particularly challenging issue to overcome as the technology seems some distance away from giving the required amount of energy densities and storage capacities for batteries/capacitors—though improvements are being reported with time.

Navigation design in unpredictable and varying environments would be a challenge, especially in the face of EW actions by hostile forces. Concepts like Differential GPS, multi-sensor navigation, and collaborative navigation would need further focus. Collision avoidance technology would be another essential feature of even military drones, especially the bigger ones, when operating in a melee. Programming drones in the fog of war (with right information) and in field conditions—particularly during hostilities—would be a challenge in spite of a likely networked programming technology. However, since the employability of drones is likely to be more in the initial phases of conflict, things would be easier to execute before the hostilities commence. AI would be a key enabler in all these.

Another important issue is the employability of drones in different levels of conflict situations against the adversary. Drones have been employed, and are being increasingly employed, in conflict zones globally. While within the territory of a nation, their employment against the adversary's militia, and externally sponsored or supported forces in grey zone situations or internal conflicts is not likely to carry any risk of escalation, their employment for targeting training camps or hideouts across national boundaries or in disputed zones would need careful consideration, as these could invite similar retaliation, or even escalation.

So far, it is seen that the use of small drones is less provoking than aircraft or missile attacks. Drone employment in West Asia, Afghanistan, and earlier Kosovo, has been against grossly inferior adversaries—both technologically and militarily—where the adversary did not have sufficient capability to retaliate effectively. Israel retaliates every time to any such attempts into its territory; but the retaliation is not too disproportionate, and not escalatory. Russia chose to forego retaliation when its base was attacked by a drone swarm in January 2018, which it countered with missiles and EW. The ownership of the drones, however, was left in a doubt in this case.

The transformative nature of drones in warfare has been contested by a few. In one of its commentary on *The Rand Blog*, the Rand Corporation had tried to dispel the transformative nature of drones as a myth. The blog mentioned an example of the impossibility of Iranian drones attacking inside Saudi Arabia; but this very attack allegedly happened on 14 September 2019,[43] in which almost two dozen drones precisely struck oil refineries deep inside Saudi territory in spite of their advanced air defence set-up.[44] There have been similar attacks earlier too inside Saudi Arabia, but without such success. The Rand blog also did not take into account the future capability of AI.

After the drone attacks on Saudi oil refineries in Abquaiq and Khurais (which caused considerable damage and hit Saudi oil production very badly) and after Iran's denial, there has been no immediate retaliatory military action by the Saudis or the USA. Besides lesser provocativeness, this also highlights the aspect of deniability, which the offender can always make use of in the case of drone intrusions and, at times, can also attribute this to drone malfunctions.

In volatile situations like when nations are at the brink of war, even isolated/low scale cross-border drone strikes may lead to escalation. Similarly, in some situations, a drone action would certainly invite a retaliatory

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[43] Lynn E. Davis, Michael J. McNerney, Daniel Byman, "Armed Drone Myth 1: They Will Transform How War Is Waged Globally", *The Rand Blog*, at https://www.rand.org/blog/2015/02/armed-drone-myth-1-they-will-transform-how-war-is-waged.html, accessed 16 September 2019.

[44] Ben Hubbard, Palko Karasz, and Stanley Reed, "Two Major Saudi Oil Installations Hit by Drone Strike, and U.S. Blames Iran", *The New York Times*, 14 September 2019, at https://www.nytimes.com/2019/09/14/world/middleeast/saudi-arabia-refineries-drone-attack.html, accessed 15 September 2019.

action of equal measure (for example, India-Pakistan), which may cascade into further escalation depending on the damage done, physically as well as politically.

The use of combat drones, particularly the expendable ones, would have to cater for the possibility of aborting the attacks. This may tend to restrict their usage in certain situations where it may be difficult to retract them. This could also need consideration for methods like self-destruction as essential drone features—where calling back is not possible. Its incorporation would seem to unduly add to the load for the drone; but it is something that would be a needed feature in military drones.

While the UAVs/UCAVs would increase the combat potential of forces, they would bring in a lot of unpredictability in warfare. While there will be situations, like heavy rains/lightening, which may prevent the use of UAVs/UCAVs, at the same time, their susceptibility to counter-measures would also make heavy reliance on them undesirable. On the one hand, they could bring out-of-proportion results; on the other, these could leave a military campaign in dire straits. These would, therefore, be more suitable as an adjunct at places, or their integration in major campaigns would require very careful planning, with back-ups and alternatives.

Gaming and simulator based training in realistic a environment of forces with the use of drones, especially during exercises, would be a much needed requirement. Even field training with especially manufactured sets of drones is a feasibility for training.

Developmental Trajectories

The USA and China have been at the forefront of drone development; but new and innovative drone designs are coming out of all continents. Security and military usage is mostly the core theme in their developmental trajectory. On the military front, the prevailing endeavour is to develop designs for UAV operations in hostile spaces. Since the subject is vast, only the important aspects of their development trajectories that are relevant for this paperpaper are being touched upon here. Detailed information is available through various sources, especially the internet, and can be gleaned from there. The number of operational drones is already in thousands globally; but the numbers are not being touched upon here as their importance is now undeniable, and this section only highlights their developmental trajectory to substantiate it.

The USA

While most of the USA's drone development programmes are quite publicised, there are possibly a few clandestine ones too—some of which keep getting revealed from time to time. Going by the list of UAV development programmes of various types the USA has undertaken from the 1940s, it is easy to judge the importance the USA has attached to the deployment UAVs in the military domain. In the past, they have utilised the drones for all kinds of roles—from target practice, to ISR, to weaponised platforms.

While the USA has been using the MQ-1 (General Atomics Predator) and MQ-9 (Reaper) drones for the last three decades, for both armed and unarmed roles in West Asia and Afghanistan, these have been the slow speed and human-in-the loop variety, especially for armament work. Other drones include the RQ-4 Global Hawk and RQ-170 Sentinel, the high altitude jet-engine variety; these have been flying since the last decade reportedly for ELINT and surveillance purposes. The RQ-170 was used to live stream the video of the operation against Osama-Bin-Laden at Abbotabad in Pakistan to audiences in the USA. Many other types of drones have also been operationalised, or are under different stages of development in the USA. If cruise missiles are taken into account, then these have been used extensively in the wars fought by the USA.

US focus on drone development has evolved over the last decade to making fully autonomous, stealthy, and high speed ones as well as the smaller sacrificial swarming drones that are deployable in contested spaces. A few have been highlighted earlier in the paper. There are several parallel programmes running for these in the USA. The recent notable technology demonstrators by the USA which came to light were the US Navy/ Northrop X-47 and the USAF/Boeing X-45, which are both fully autonomous versions of combat drones—the X-47 being capable of carrier operations too. Both these were subsonic, highly advanced, stealth featured, mid-air refuelling, and armament delivery capable. Though both the programmes were reportedly shelved on technical concerns of a stealth technology leak, there are other development programmes underway. The main ones reported in open sources are the Skyborg, the RQ-180 (Northrop Grumman UCAV),[45]the MQ-25[46] Stingray (for mid-air refuelling), the General Atomics Avenger (formerly Predator-C, a Jet-engine UCAV), and the Perdix swarming drones. These are expected to be operationalized in mid-20s as per info on various websites.

The USAF is sponsoring the development of the autonomous wingmen drones, like the Valkyrie (X-58) and the Mako, for contested airspaces. Gremlin drones as a concept seems the most plausible ones. Lockheed Martin is also reportedly developing the SR-72, a hypersonic UAV for ISR roles. A small cargo delivery UAV, the MMIST CQ-10 Snowgoose—using parafoil and autogyro concepts, and capable of being launched from the air as well as surface—are also reportedly under initial operational clearance for point supply to the US armed forces.[47]The cost containment is reported as the main endeavour in these developmental programmes, so that runaway costs—as had happened earlier in case of the B-2 bomber—should not become a hindering factor for the induction of drones in large numbers.[48]

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45 Amy Butler and Bill Sweetman, "Secret New UAS Shows Stealth, Efficiency Advances", *Aviation Week & Space Technology*, 6 December 2013, athttps://aviationweek.com/defense/secret-new-uas-shows-stealth-efficiency-advances, accessed 3 March 2019.

46 Kyle Maxey, "Boeing Introduces Its Newest Drone", engineering.com, 6 September 2018, at https://www.engineering.com/DesignerEdge/DesignerEdgeArticles/ArticleID/17560/Boeing-Introduces-Its-Newest-Drone.aspx, accessed 4 March 2019.

47 Brochure, MMIST Inc., at https://www.mmist.ca/, accessed 6 March 2019.

48 Kyle Mizokami, "How Makers of the B-21 Are Learning Lessons from the B-2 Bomber", *Popular Mechanics*, 22 August 2019, accessed 23 September 2019. Mizokami writes, "At the time of its development the B-2 Spirit was one of the most expensive defense programs ever. The Air Force originally planned to build 132 bombers, but the fall of the Soviet Union and the end of the Cold War, coupled with runaway development and unit costs, caused the Pentagon to trim the number to just 21 B-2s. The entire program cost approximately $83 billion in 2019 dollars, adjusted for inflation—enough to buy 830 F-35A Joint Strike Fighters."

Russia

Although Russia has been often considered lagging behind by about 10–15 years in the development of UAVs as compared to the USA, it has had a history of developing a fairly large variety of UAVs. The Russian UAV program is the most shrouded in secrecy, with often surprising developments getting known through leaks in the media. The status of most of their UAV programmes is still largely unknown. Post-Gulf War 1, though their development of smaller UAVs was seen throughout, the developmental lines of the larger UAVs/UCAVs seem not only to be following, but also catching up with, those of the USA. Russia had revealed the MiG SKAT as a medium-sized stealth UCAV design, but the project was shelved. Some other such military UAVs that later came to light, with some being developed into UCAVs, are: the DOZOR-600, the Altius-M, the Sukhoi Okhotnik-B Hunter (stealth UCAV), the Yak Voron "Raven" UCAV, the Zond -1,2,3 UAVs, among others.

China

China has been pronounced by many to have overtaken the USA in drone development. The varieties of Chinese UAVs/UCAVs probably now exceeds those in the USA. The Chinese are alleged to have developed the UAVs on pilfered and reverse engineered technologies; but have subsequently improved upon them to develop the current state-of-the-art ones. Chinese CH-4 UCAVs have already seen employment by the Iraq military in several hundred missions against the militia.[49] Seen together with China's state of the art weapon's development programme, the Chinese UAV fleet is likely to be the most formidable one.

A recent report on South China Morning Post website reads,

> A medium-altitude, long-endurance UAV, the Gongji — which means "attack" in Chinese is a land attack version of the Pterodactyl. It

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[49] Dominic Dudley, "How China is Fuelling the Arms Race in Drones in the Middle East", *Forbes*, 17 December 2018, at https://www.forbes.com/sites/dominicdudley/2018/12/17/china-fueling-drones-arms-race-middle-east/#3eb55f2e4bb4, accessed 7 March 2019.

> has a range of 4,000km and a maximum endurance of 20 hours. Similar to the US Predator, this drone can carry at least 10 types of precision weapons, including air-to-ground missiles, precision-guided rockets and precision-guided bombs. It has an optical turret, infrared and photoelectric sensors, and laser target pointers, and can guide the targeting of anti-tank missiles as well as provide targeting instructions for other aircraft or ground weapons. It is known for its integrated reconnaissance and strike capabilities, but can also be used for electronic warfare, to guide targeting, or as an anti-radiation missile.[50]

While there may be some hyperbole in the text, it gives a fair idea as to the UCAV capabilities the Chinese have been able to develop. This kind of capability utilization is possible with some level of AI incorporated in the systems onboard.

On its 70th anniversary parade on 1 October 2019, China showcased its stealth GJ-11 UCAV along with a number of others, pronouncing that the UCAV was capable of attacking strategic targets, and that all the systems paraded had already been in active service with the armed forces.[51]

There are reportedly anywhere between 75 and 100 UAV-related companies in China, both private and state-owned, which are building UAVs or related items.[52] Much of China's current drone programme has been to develop

50 Kristin Huang, "The drones that have become part of China's military strategy", *South China Morning Post*, 26 August 2018, at https://www.scmp.com/news/china/diplomacy-defence/article/2161354/drones-have-become-part-chinas-military-strategy, accessed 10 March 2019.

51 Yang Sheng and Liu Xuanzun, "Chinese military commissions GJ-11 stealth attack drone", *Global Times*, 1 October 2019, at http://www.globaltimes.cn/content/1165939.shtml, accessed 1 October 2019.

52 Adam Rawnsley, "Meet China's Killer Drones", *Foreign Policy Magazine*, 14 January 2016, at https://foreignpolicy.com/2016/01/14/meet-chinas-killer-drones/, accessed 10 March 2019.

the UAVs laced with AI for autonomous operations.[53] China had developed the AV-601 series of UCAV proof of concept aircraft based on the US X-47 UCAVs. In June 2018, China unveiled its 'Dark Sword' supersonic stealth UCAV. This was earlier shown only as a model in air shows.[54]

China's EA-03 high-altitude, long-endurance drone is publicised to have a range of 7,000km, a maximum endurance of 36 hours, advanced command communications, and electronic warfare systems.[55]In October 2018, China demonstrated the TW-365 heavy lift cargo drone, and successfully tested the world's largest unmanned transport drone capable of carrying up to 1.5 tons of load.[56] China's drone swarming capability has reportedly exceeded 1000 drones.[57]

Others

Among other nations, projects in European Union nations are in advanced stages of development, and are towing the line of the USA with some advanced designs of UAVs/UCAVs, including cargo versions like the Barracuda, the Taranis, the nEURON, the SA-03, the Harfang, the Magma, the Mantis, etc. Israel has so far focused on the development of the ISR,

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53 Will Knight, "China's military is rushing to use artificial intelligence", *MIT Technology Review*, published 07 February 2019, at https://www.technologyreview.com/f/612915/chinas-military-is-rushing-to-use-artificial-intelligence/, accessed 11 March 2019.

54 Harry Pettit, "China unveils its unmanned 'Dark Sword' fighter jet that could fly at supersonic speeds and prove a "nightmare" for US defences", *Daily Mail*, 6 June 2018, at https://www.dailymail.co.uk/sciencetech/article-5811677/China-unveils-unmanned-Dark-Sword-stealth-combat-drone-prove-nightmare-US.html, accessed 12 March 2019.

55 Kristin Huang, n. 50.

56 "China successfully tests world's largest unmanned transport drone", *The Economic Times*, 17 October 2018, available at https://economictimes.indiatimes.com/news/international/world-news/china-successfully-tests-worlds-largest-unmanned-transport-drone/articleshow/66264074.cms, accessed 15 March 2019

57 Jeffrey Lin and P.W. Singer, "China is making 1,000-UAV drone swarms now", *Popular Science*, 8 January 2018, at https://www.popsci.com/china-drone-swarms, accessed 16 March 2019.

target designation, and self-sacrificial models. It has also revealed an underdevelopment small cargo drone called Airmule. Iran has also developed a range of UAVs and UCAVs ranging from small to medium sizes, some of which, it claims, are using advanced design concepts. Pakistan has a fairly developed military drone industry, with a range of UAVs for military. In fact, the list of the nations which are funding the effort to develop UAVs, and have come out with some kind of UAVs, is lengthy. However, most of their current achievements are limited to the development of drones to be used in basic roles such as surveillance, reconnaissance, and experimentation. Other nations which have made significant advances in developing military purpose UAVs are Canada, New Zealand, South Africa, Turkey, Spain, Indonesia, Japan, Brazil, etc.

India

India has had a considerable lag in the development of the military UAVs and UCAVs vis-à-vis other equipollent nations, and also vis-à-vis the funding capability, research facilities, talent, and the scientific temperament available. However, for about the last one decade, some fresh initiative has been seen where the premiere scientific defence research agency, Defence Research and Development Organisation (DRDO), has come out with some new UAV/UCAV development programmes. These include, the Aura (Autonomous Unmanned Research Aircraft, UCAV precursor, stealth, blended wing body design), Rustom, Netra, Pawan, Ghatak (UCAV), etc. In 2018, the DRDO had commenced flight tests of its first combat drone named Rustom-2. There still appears to be a perceptible lag in this field vis-à-vis the levels achieved by other nations. Even in the field of AI, an essential ingredient of future drones, the investment and effort have only recently started. In the field of micro-chips (integrated circuits), the need for indigenous fabrication still does not seem to be appealing to Indian strategists and policy makers. The Indian armed forces are still dependent on the import of UAVs/UCAVs.

Unlike in the western and Chinese endeavours, there has been little participation of the public or private sector companies or institutions in developing UAVs so far. In the past, the sole and credible effort seems to have been only by the DRDO. However, in the last few years, there has been an effort by DRDO to develop UAVs in a joint venture with Israeli Aircraft Industries and the US Air Force Research Laboratory, both swarming drones as well as reusable drones under the Gremlins programme of DARPA under Defense Technology and Trade Initiative (DTTI). Even Indian institutions like the IIT have developed drones like Marlaa (a solar technology demonstrator).

In February 2019, the DRDO had announced working on the drone swarming technology, and conceptualised swarming combat drones called AlFA-S. Even HAL had announced plans to develop subsonic wingman drones[58] (on a low cost attritable drone concept, with costs less than US$ 5 million per unit) which would be integrated with Jaguar Max—an advanced version of the Jaguar that would be developed in the future. The development would be HAL led, with the participation of private sector companies. The concept, however, seems to be relying on a pilot's control of drones, and limited in roles for air-to-surface operations.[59] These may need to be reviewed, considering the likely developments by then.

As far as these efforts are concerned, it seems that the future potential of these machines is yet to sink in fully. The pace at which developmental work is required to be undertaken in the fields of AI and drones does not seem to be achievable by government agencies alone. This is mainly due to the insufficient availability of talent as well as exposure. The situation is now apparently reaching urgency levels vis-à-vis the lag. These will probably be achievable only by involving and engaging private industry in the developmental work.

Gestalt

The era of drones, or unmanned autonomous platforms, is now approaching and probably, by the late 2020s, advanced drones would

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58 Rahul Udoshi, "Aero India 2019: HAL unveils Unmanned Wingman concept", *Janes 360*, 25 February 2019, at https://www.janes.com/article/86831/aero-india-2019-hal-unveils-unmanned-wingman-concept, accessed 1 October 2019.

59 Vishnu Som, "Air Forces Unmanned Indian 'Wingman' Drone Could Redefine Air Warfare", NDTV, 20 February 2019, at https://www.ndtv.com/india-news/indian-air-forces-unmanned-indian-wingman-drone-could-redefine-air-warfare-1996251, accessed 1 October 2019.

start forming a formidable component of many militaries. The drones, as analysed earlier, would be of multiple types, in varied roles, with immense capabilities, and largely autonomously operating. Combat drones would likely be used more as a part of the initial offensive elements in conventional as well as unconventional warfare to impart maximum initial losses to the enemy as well as preventing exposure to the higher initial lethality of battles of one's own personnel. Besides bringing initial advantages, this would also enable combat capability to be retained for a longer period of time.

The concept of aerial drones has started making place in many military doctrines; but the views are still nascent. What is yet to figure in doctrines is their transformative nature in military strategies and warfare which derives mainly from its potential, its varied designs, and its amalgamation with other disruptive technologies like AI and IoT. All these are likely to make drones better than manned combat aircraft in most military operations. When their potential starts receiving appropriate importance in doctrines is when a major transformation of the forces will start. Doctrinal concepts still tend to retain human-in-the-loop at most of the critical places in drone operations. This is mostly due to the ethical issues related to AI. In time, however, the criticality of AI (that is, autonomy) will be understood, especially in its shortening of OODA cycles, gaining advantage by employing fully autonomous systems, and losing the same by keeping a human-in-the-loop.

In some contexts, drones could prove to be much safer and more effective options for target engagement as compared to manned aircraft—like busting terrorist hideouts with the use of sacrificial drones. In fact, it would be unimaginable to balance the security equation between nations without a drone force in the future. The cost disadvantage would be unaffordable in attempting to build capability without a sizeable drone force. Autonomous drones would be the force multipliers due to their insusceptibility to human limitations like exhaustion, G-forces, and other characteristics which have been discussed earlier in the paper.

In air forces particularly, drones could substitute manned aircraft to a large extent, with their share of missions increasing as their numbers build up, and as technology advances. Decoying, the saturation of the enemy's sensors, and countering enemy drone forces with one's own drones would be crucial to the success of future air operations. Their sheer numbers would be a means of political signalling as well a show of capability.

Future battlespaces would see the employment of a large number of autonomous drones not only as combat elements but also in military support roles, like logistics, communication, security, and administrative requirements. In the future, with both land and air forces having overlapping requirements of drones, there would be a need of an independent control and coordinating mechanism—probably a common structure for centrally coordinating/controlling/de-conflicting drone missions, integrating inter-service requirements of drones, and operating some of them centrally. A centralised, data-network based autonomous War Management System would also be a necessity.

A crucial need for future drones would be to reduce their susceptibility to EW and cyber-attacks, for which employing indigenous technology as well as manufacturing the drone hardware would be crucial. The use of AI and pervasive computing would reduce the need for communication, and thus the vulnerability of the drones to EW.[60]

The next decade is likely to see an exponentially burgeoning role for the drones, both in the civil and military sectors. Particularly for the air forces, it would be impossible to maintain their power and capability without the force multiplier advantage that these would bring. In the Indian context, both the hostile Indian neighbours, China and Pakistan, are investing substantially into this capability. China particularly would build a considerable asymmetry based on drone power over the next decade. It will, therefore, be crucial for India to accord high priority to military drone development, along with a charted roadmap for building drone fleets.

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60 See Kris Osborn, n. 32.

Unmanned systems or drones are fast making way into military operations, be it in air, and on land or the sea. Their advantages range from remote operations to reduced response times, scalable responses, reduced costs, and increased effectiveness in almost the entire spectrum of military operations, including unarmed roles and peacetime tasks such as surveillance and humanitarian assistance in disaster relief. Modern disruptive technologies like Artificial Intelligence, Internet of Things, miniaturised electronics, composites, etc., are taking the capabilities of unmanned systems to new highs and increasing autonomy in their usage by turning them into smart and intelligent machines. Aerial drones are the most crucial members of the drone family that are already playing crucial armed and unarmed roles in many militaries. With further advancement of technology, their role in warfare is set to increase exponentially. In future, new generation aerial drones will be at the centre stage of military operations in warfare, in both lethal and non-lethal roles.

In light of the new capabilities of aerial drones, this paper analyses their future evolution. It highlights their centricity and indispensability for future warfare, including their role, while keeping possible challenges and their current developmental trajectory with major global powers in sight. The paper also reflects on India's position vis-à-vis drone development programmes and highlights key takeaways.

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