Emerging Trends in Unmanned Aerial Systems

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Since the first Gulf War in 1991, the use of Unmanned Aerial Vehicles (UAVs) has continued to increase in successive US campaigns across the world. The initial exploitation for target acquisition and Intelligence, Surveillance and Reconnaissance (ISR) missions has expanded to include Electronic Warfare (EW) missions and as decoys. Arming the Predator Unmanned Aerial Vehicles (UAVs) with Hellfire missiles has allowed them to be used in the hunter-killer configuration, greatly reducing the sensor-to-shooter cycle. These Unmanned Combat Air Vehicles (UCAVs) have since seen global employment by US forces against terrorist targets in Afghanistan, Pakistan, Yemen and Somalia.

Removal of the onboard pilot and human support systems has resulted in increased endurance and loiter time and allowed employment of UAVs in high risk situations. Consequently, there has been an ever increasing dependence of the US and coalition forces on these platforms and their expanded role in critical missions in battles where the forces enjoy air superiority. This has further resulted in steady efforts at improving the sophistication of the platforms, their payloads, weapons, communications and Ground Control Systems (GCS) all of which together are being called Unmanned Aerial Systems (UAS). The phenomenon is being observed by other nations and the market for military UAVs as well as development efforts across the globe have picked up. The US, Israel and China, however, continue to dominate the sector, with initiatives in most other countries being in their relative infancy.

Technology advancement and proliferation have allowed private entrepreneurs to develop commercial applications for unmanned systems, many of which were demonstrated last year. The resultant surge in interest in the domain has caused some proponents to label 2014 as "the year of the UAVs". While commercial interest is focussed more towards the smaller UAVs, any technology progression would contribute towards overall development of the sector through technology sharing and overlapping applications. Incremental improvements to the platforms, sensors, propulsive systems, communications and weapon systems would continue. However, those at the forefront are looking at emerging technologies to revolutionise capabilities as well as provide novel applications that, while being cost-effective, would transform the future battlefield. The article strives to discuss some of these innovative concepts.

Autonomy

One of the most important technology drivers for UAV development is autonomy. Unmanned systems initially were primarily remotely piloted aircraft. Subsequent advances allowed UAVs the option of choosing and following defined pre-programmed options. As ever more processing power in smaller packages can be put onto the UAVs, available inputs from multiple sensor systems can be processed onboard to provide better situational awareness and autonomous decision-making ability. Similar capability supplemented through advanced algorithms and advanced machine learning[1] would enable more autonomy in machine response through flight control systems, in-flight mission management, distributed data fusion and automatic target recognition/engagement. Demonstrations of machines responding intelligently and without human interference to simple situations have already taken place. As this capability improves further, human involvement would progressively decrease, thereby reducing bandwidth requirement for communication and data transfer as also reducing the vulnerability of the data link to counter-measures. Thereby, autonomous systems would also overcome limitations related to erratic communications, for example, in areas with obstructions such as dense forests and urban sprawls. The US Department of Defence's (DoD)'s Unmanned Systems Integrated Roadmap released in January 2014 has outlined a variety of goals for air, land, and sea vehicles that include capability to deviate from the pre-planned missions and altering course without a human command.[2]

However, machine response through computer programming tends to be limited in flexibility and is currently prioritised towards safety rather than dynamism, a prerequisite for military operations. Over a period of time, unless regularly updated, this might result in these machines becoming predictive in their responses. Despite the progress, coding required to totally replace all human actions and responses, if possible, is still a long time into the future. Cyber attacks would be more effective on autonomous systems in the absence of response options like physical overrides. These limitations dictate the presence of humans in the loop at all times, especially for lethal missions.

Aerial Refuelling

A major milestone in autonomy was achieved in April this year when the X-47B test UAV of the US Navy undertook the first ever autonomous aerial refuelling from a KC-707 tanker jet, receiving 4,000 pounds of fuel. Aerial refuelling is a highly complex task involving precise position keeping which even humans take time to master. The US Navy claimed that the resultant increase in range would help in extending the carrier power projection.

Ground Control Station (GCS)

Increasing autonomy would also contribute to a reduction in the requirements from GCS. These are already making use of Commercial Off-the-Shelf (COTS) items to harness the latest technology and reduce costs. Additionally, UAV proponents are seeking interoperability among different systems through common hardware and software architecture. This would further lead to common GCS that would be able to control multiple dissimilar machines and communicate with other distant GCS for better air space control and data sharing. GCS forms a major component of the overall costs of the UAS and, thus, any reduction in their numbers would bring down the overheads.

Designing

Faster processing speeds and advanced manufacturing processes are allowing designers to exploit the elimination of a human pilot to enhance the performance and combat power of the machines. For example, such machines can be designed for evasive high g manoeuvres much in excess of what human pilots can endure. Such UAS armed with sophisticated air-to-air weaponry would be able to prevail over manned fighter opposition.

Standardisation of components and payloads in terms of size, weight, shape, power requirements and interfaces would allow the "plug-and-play" concept. Capabilities, thus, would not be dependent on the platform but would be customised at short notice to meet the mission requirements, thereby providing operational flexibility. Further reduction of costs related to platform development and production could be achieved through 3D printing of smaller UAVs with standardised designs and integrated payloads, a concept already under consideration.[3] This would also allow mass production of small UAVs in a reduced timeframe.

Technological advancement have reduced human involvement leading to greater autonomy and operation of UAVs

Swarms

UAV swarms, inspired mainly by the swarms of insects, are groups of small independent unmanned vehicles that coordinate their operations through autonomous communications to accomplish goals as an intelligent group, with or without human supervision. It may be a heterogeneous mix of machines with dissimilar tasks but contributing synergistically to the overall mission objectives. An idea that is almost a decade old is now seeing fruition owing to the advancement in diverse technologies including sensing, digitisation, networking and Artificial Intelligence (AI). Swarms can have myriad applications based on the imagination and capabilities.

Demonstration of swarms using dissimilar UAS[4] for reconnaissance was demonstrated by Boeing in 2011. They communicated with each other autonomously and searched the designated area through self-generating waypoints and terrain mapping, while simultaneously sending information to teams on the ground.[5] In 2012, the same technology was used to control two ScanEagle UAVs using only a laptop and a military radio, demonstrating the ability to do away with the need of a ground control network. Tests continued on terrestrial robots (2D motion) and in August 2014, as part of the US Navy's Low-Cost UAV Swarming Technology (LOCUST) programme, its Office of Naval Research (ONR) demonstrated a swarming configuration of 13 robotic boats that were able to perform a variety of tasks to protect a high-value ship from incoming craft.[6] In April this year, ONR undertook demonstrations of UAV swarming technology at multiple locations, including one where nine UAVs accomplished completely autonomous UAV synchronisation and formation flight.

Swarms of unmanned systems have multiple defensive and offensive applications with the potential to effect disruptive changes to military operations. Swarms of cheap UAVs, through coordinated cooperative efforts, could do the job of a single high-cost multi-mission aircraft. They could enhance both surveillance area and spectrum, resorting to advanced communication and data fusion capabilities. Swarms of robotic systems can bring greater mass, coordination, intelligence, speed, resilience and responsiveness to the battlefield, enhancing the ability of war-fighters to gain a decisive advantage over their adversaries.[7] Autonomous swarms are more suited to undertake more hazardous tasks. Swarms could overwhelm an adversary's defence systems, most of which are designed to respond to a limited number of targets, through sheer numbers. The tactical advantage can be augmented by using a diverse mix of heterogeneous assets to further complicate the enemy's targeting problem. This would allow higher value assets to fly through for mission accomplishment. With advanced autonomous and networking capabilities, swarming UAVs would be able to act in more fluid, flexible, non-linear ways. They could then follow the conventional concept of swarming for lethal and non-lethal missions – small, dispersed, networked severable packages that can spontaneously come together in varied sized groups, coalesce on mission objective from multiple directions, undertake the desired operations and then disperse randomly and recombine. [8]

The concept of swarming can only be successful if the machines employed are cheap enough that their large numbers in sum cost less than the manned machines, especially if they are to be expendable. However, the technology involved is highly complex and, thus, expensive to develop. As the per unit costs rise, it might not be cost-effective to use these in the expendable role, thereby severely limiting their employability and flexibility. The potential of the swarms of drones to provide diverse civilian applications are leading to commercial and academic efforts to refine the technologies and provide cost rationalisation. Such COTS UAS (Unmanned Aerial Systems) could be employed judiciously for military missions.

Swarms are also constrained because of the bandwidth availability necessary for multiple UAVs to talk to each other as well as to the GCS. Further, their communications would be vulnerable to counter-measures. Laser communication offers some solutions for overcoming these limitations related to Radio Frequency (RF) communication.

New launch systems have increased range and endurance of UAVs

As unmanned systems are going to proliferate in the future with ever increasing capabilities, nations would develop anti-technologies against these machines. These would include soft-kill options like electronic counter-measures against the communication links as also lethal measures to damage or destroy the launch systems, GCS or the machines themselves. Defensive swarms offer great potential to fend off other swarms. [9]

Launch Systems

Innovative launch and recovery concepts are equally important for the success of novel concepts. For swarms to be truly effective, all constituent UAVs have to be launched near simultaneously. The US Navy's LOCUST programme uses a launcher consisting of a series of adjacently placed tubes that would allow rapid launch of their one metre-long Coyote drones. A video released by the US ONR of a test conducted on March 27, shows the UAV after launch unfolding its wings and propellers, stabilising and flying away.[10] There are plans for a demonstration of launch of up to 30 synchronised drones within one minute by 2016. The launcher and the UAV are relatively compact to allow the system to be deployed from ships, tactical vehicles, aircraft or other unmanned platforms.

The US DoD's Unmanned Systems Integrated Roadmap also predicts development of a larger unmanned vehicle that would carry smaller drones directly into the theatre of operations and deploying them within range of a target, thereby overcoming their limitations of range and endurance. Towards this, in November last year, the Defence Advanced Research Projects Agency (DARPA) announced that it was seeking ideas for a "mother ship" that could carry and launch swarms, under the programme name Distributed Airborne Capabilities. The initial objective is to use existing military aircraft, such as the C-130 or V-22 Osprey for the mission. As airborne recovery is not as viable as the launch, most air-launched drones would be expendable.[11] In March this year, the US Marines fired Switchblade kamikaze drones[12] out of a V-22's rear ramp as part of their Persistent Close Air Support programme.[13] A similar concept had earlier been tested in 2003 from the ramp of a C-130 via a roll-on/roll-off pneumatic launch system.[14] The US Navy is exploring deployment of a submarine-hunting drone by the US Navy's P-8A Poseidon maritime patrol aircraft's sonobuoy rotary launchers.[15] Boeing is seeking canister launch of a ScanEagle UAV from the F/A-18 Super Hornet that could then provide targeting information to the jet from a stand-off distance. [16] China's Chengdu Aviation Corporation is developing a mini AVIC drone that can be fitted inside an artillery casing and fired from large artillery. The cannon shell will burst open in mid-flight to release the drone, which would then carry out target designation for the parent battery. [17]

System of Systems

The present lot of unmanned systems as well as those expecting to see active operations in the near future do not match the corresponding manned systems in terms of speed, range and firepower and are also highly vulnerable to air defence systems. Their strengths lie in their persistence presence, hunter killer capability and faraway employment. An ideal approach is to use an optimal mix of assets that would exploit their individual strengths and help shield the shortcomings towards creating a more powerful, functional synergised system. Also, a smaller number of high value assets could work in concert with a larger number of cheaper ones for better cost-effectiveness.

There are growing concerns in the US that proliferation of technology and commercial developments are eroding the technological supremacy of its armed forces. Long developmental cycles of military technology costing billions of dollars to the US are ironically allowing adversaries to catch up through exploitation of rapid technological developments in the commercial sector and by progressive system upgrades. Developmental and production costs related to complex platforms and systems have led to a reduction in numbers that can be produced and deployed, resulting in critical gaps.[18]

Through various civilian contracts, DARPA's System of Systems Integration Technology and Experimentation (SoSITE) programme[19] is working at maintaining air superiority through a new, more flexible approach to weapon systems by spreading key capabilities and functions across a variety of interoperable sensors, mission systems and weapons onboard manned and unmanned vehicles. In March, it released a video of the concept which it claims is at a very early stage of design. It shows jet fighters (acting as a command and control platform), expendable drones' swarms launched from the back of C-130 transport plane and inexpensive cruise missiles also fired by the transport aircraft working together to take on the enemy air defence. This being one scenario, these networked systems can be coordinated to provide diverse air defence and ground attack solutions.

Additionally, an open systems architecture approach is being employed that would create common standards and tools for developing interchangeable modules and platforms, so only some components would need replacing or upgrading rather than a whole system. As standards evolve with advancing technology, backward compatibility would ensure that existing systems' capabilities would continue to be harnessed, thus, saving on huge developmental costs. Integration of newer systems would be faster without necessitating any major alterations. Consequently, while the systems would undergo changes regularly, the overall upgrading would be incremental, allowing doctrines, operational philosophies and training to keep pace.

Conclusion

While technology offers newer equipment, its success on the battlefield can only be achieved through effective doctrinal innovations. These concepts related to UAS development have the potential to influence the future battlefield and, thus, need to be followed closely by militaries, analysts, technologists and defence industry around the world. As the Indian armed forces seek enhanced unmanned capabilities and capacities in terms of platforms and payloads, recent governmental initiatives to step up private investments in the sector are encouraging. There is now a requirement to study the relevance of these futuristic concepts to their own battlefield projections and define a developmental roadmap.

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Notes

1. Advance machine learning is a sub-field of computer science that explores construction and study of algorithms that can learn from, and make predictions on, data. These make data driven predictions or decisions rather than following static programme instructions. Machines can, thus, learn from, and respond, based on data rather than respond to static programmes. Already demonstrations have taken place of machines learning basic games on their own or learning cooking from watching videos.
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4. Two ScanEagle and one Procerus Unicorn from the Johns Hopkins University's Applied Physics Laboratory (JHU/APL)

5. "The Mothership – UAV Swarms Inspire Research Into Flying Aircraft Carriers", *Air Force Technology*, February 10, 2015, accessed at http://www.airforce-technology.com/features/featurethe-mothership---uav-swarms-inspire-research-into-flying-aircraft-carriers-4505474/
6. Patrick Tucker, "Inside the Navy's Secret Swarm Robot Experiment", *Defense One*, October 5, 2014, accessed at http://www.defenseone.com/technology/2014/10/inside-navys-secret-swarm-robot-experiment/95813/
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8. John Arquilla, David Ronfeldt, "Swarming -- The Next Face of Battle", Rand Blog, Rand Corporation, September 29, 2003, accessed at http://www.rand.org/blog/2003/09/swarming----the-next-face-of-battle.html
9. Debra Werner, "Drone Swarm: Networks of Small UAVs Offer Big Capabilities", *Defense News*, June 12, 2013 , accessed at http://archive.defensenews.com/article/20130612/C4ISR/306120029/Drone-Swarm-Networks-Small-UAVs-Offer-Big-Capabilities
10. The video, available at https://www.youtube.com/watch?v=AyguXoum3rk also displays the micro UAVs undertaking autonomous formation flying and lighting up multiple targets.
11. n.5.
12. The "Switchblade" drone is the first batch of weaponised drones that is foldable and packs neatly into its launch tube. It has an electric motor that allows it to loiter and suicide bomb a target when commanded. It is similar to the Israeli built Harop, a kind of loitering missile that can be used against high value targets.
13. Kelsey D. Atherton, "Marine V-22 Osprey Shoots Kamikaze Drones Out Its Backside", *Popular Science*, April 21, 2015, accessed at http://www.popsci.com/marine-v-22-shoots-kamikaze-drones-out-its-backside
14. David W. Roberts, Aaron D. Judy, Test Report – "Separation Flight Tests of a Small Unmanned Air Vehicle from a C-130 Transport Aircraft", accessed at http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.214.6239&rep=rep1&type=pdf
15. n.5.
16. Ibid.
17. Jeffrey Lin, P.W. Singer, "China Shows Off Cannon-Fired Drones", January 27, 2015, accessed at http://www.popsci.com/china-shows-drones-fired-cannon
18. David Szondy, "DARPA Looks at 'System of Systems' to Maintain US Air Superiority", *Gizmag*, April 1, 2015, accessed at http://www.gizmag.com/darpa-systems-sosite/36801/
19. John Shaw, "System of Systems Integration Technology and Experimentation (SoSITE)", Defence Advanced Research Projects Agency (DARPA), accessed at http://www.darpa.mil/program/system-of-systems-integration-technology-and-experimentation