Synergistic Applications of Autonomous UCAVs, Swarm Robotics and Cloud Computing in Future Air Warfare

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Unmanned Combat Aerial Vehicles (UCAVs) represent a pivotal advancement in military aviation. They possess the capability to navigate diverse environments and endure harsh weather conditions. Operating in hostile territories, UCAVs eliminate the risk to human pilots. Autonomous UCAVs (A-UCAVs) further elevate this paradigm, operating without direct human intervention and making independent decisions regarding targets, whether on the ground or in the air, across various flight regimes and in coordination with other A-UCAVs. The integration of Swarm Robotics, a manifestation of cloud computing, facilitates the aggregation and processing of vast amounts of data from multiple machines within a singular cognitive framework. This collective intelligence enables multiple A-UCAVs to coexist in the same airspace, with their shared data and flight control systems orchestrated seamlessly within a common cloud infrastructure. If precisely tailored to the operational roles and topography where a particular military operates, this capability has the potential to significantly enhance the potency across the air, ground and seas.

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Changing Air Power Doctrine: Development, Deployment and Effectiveness of UAVs

The chances of winning are the highest, when the stakes are low.

The contemporary manifestation of air power has attained a level of unparalleled potency, rapidity and, at times, versatility in the theatre of warfare. Nations have developed a tendency for manipulating certain international laws to gain an advantage by cunningly exploiting the lacunae in the prevailing international conflict laws through the adept use of Unmanned Aerial Systems (UASs) that go across international borders without being picked up by radar or by visual means. UASs, colloquially known as drones, represent a paradigm shift in aviation, denoting a class of aircraft devoid of onboard human operators. These systems integrate sophisticated technologies, including remote control and autonomous capabilities, facilitating a myriad of applications ranging from surveillance and reconnaissance to environmental monitoring and logistics. The quintessence of UASs lies in their unmanned nature, heralding enhanced efficiency, cost-effectiveness and risk mitigation. Their multifaceted utility extends across diverse sectors, exemplifying a synthesis of cutting-edge aeronautics and advanced data acquisition. As transformative agents, UASs propel the frontiers of innovation, embodying a synthesis of aerial mobility and technological prowess. The US Air Force's Skyborg Program[1] is an initiative to develop Autonomous Unmanned Combat Aerial Vehicles (A-UCAVs) capable of performing a variety of missions from surveillance to air-to-air combat. The goal is to develop a fleet of low-cost, expendable A-UCAVs that can support manned aircraft and provide additional firepower.

The explicit utilisation of traditional air power, such as manned combat aircraft and firepower, is indicative of the intention to prosecute a full-scale war, while the surreptitious implementation of unmanned aerial vehicles (UAVs), which operate clandestinely to infiltrate the enemy's lines and launch strikes on tactical targets, represents one form of sub-conventional warfare. Following the conclusion of the Kargil conflict, India's aerial supremacy has encountered new-fangled predicaments that have rigorously tested its capability to sustain its dominance in the skies. These predicaments are multifaceted and necessitate a refined approach to confront them comprehensively.

Arguably, one of the most formidable predicaments confronting India's air power is the rapidly evolving technological landscape. The pervasive dissemination of advanced technologies, such as stealth, hypersonic missiles and UAVs in warfare has rendered it arduous for traditional air forces to retain their superiority. India, however, has fallen behind in the development of some of these technologies, which puts it at a technological deficit vis-à-vis adversaries who have operationalised them. Further, another predicament that India's air power confronts is the mutating nature of warfare. The emphasis has shifted from large-scale, conventional hostilities to smaller, asymmetric ones, where non-state actors and militant organisations play a destabilising role. This transformation necessitates the Indian Air Force (IAF) to adjust, formulate and operationalise new capabilities that can efficiently function in such environments. For instance, the IAF has been developing UAVs and armed drones that can launch precision strikes against targets in urban settings without imperilling pilots' lives.

China's belligerent posturing and swift military modernisation have propelled India to reassess its defence posture and invest in new capabilities. China's development of long-range missiles and fighter jets with advanced firepower and electronic warfare capabilities, combined with its assertive stance in territorial disputes, has raised concerns regarding India's ability to safeguard its borders.

India today is confronting challenges with regards to resource allocation and infrastructure development. The IAF has been grappling with a dearth of aircraft and equipment for some time, which has restricted its operational capabilities. The slow pace of infrastructure development has also hindered the IAF's capability to project power efficiently. For instance, India's inadequacy of airfield infrastructure and air defence systems in the northeast has been a long-standing concern, given the region's proximity to China.

Unmanned systems provide for an array of operational requirements and nations today are cognisant that development and deployment of such systems in disturbed or peace times may keep them in the lead. Military R&D of Unmanned Combat Aerial Vehicles (UCAVs) focuses on inculcating state-of-the-art technologies that will increase the flexibility of usage, firepower and autonomous decision-making capabilities while decreasing dependency, flight limitations and radar visibility.

Cloud Robotics is a field that uses Cloud Computing (CC) to create Seamless Communication Networks (SCNs) between autonomous robotic systems. If a Robot/ UCAV enters a disturbed area and learns about the presence of uniquely dressed civilians and how to differentiate them from armed/un-armed combatants, the data is instantaneously sent to other robots/ systems that are connected to a network via cloud. The same can be done for aerial targets and can be accessed by Airborne Warning & Control System (AWACS) aircraft and fighters in the area as well as the operators on the ground. Counter-drone measures use UAV jamming as their paramount weapon. Fully Autonomous UAVs cannot be jammed by such measures. The systems on board ensure complete autonomous flight and almost nil to zero radar visibility during different regimes of the flight. The LiDAR sensors on board provide for high-res pictures and Obstacle-Detection in Air (ODiA). The Inertial Navigation Systems (INS) permits a GPS-denied navigation for achieving the objective. For an autonomously operating group of UCAVs, SWARM Robotics (SR) gives a blend of Cloud Computation and Swarm Management that is tailor-made for multiple UAVs operating as one. Artificial Intelligence (AI)/ Machine Learning (ML)-enabled UCAV swarms can be custom-made for meeting the Indian Operational Requirements while keeping in mind the spectrum of operations and terrain features that Indian air power has to deal with. Cloud Robotics paired with swarms will strengthen data sharing, centralised command system, Machine to Machine (M2M), Machine to Cloud (M2C) communication and prevent unnecessary damage while conducting Operations in Built-Up Areas (OBUA), Deep Penetration Strike (DPS), Close-Air Support (CAS) or border patrol.

With an amplified use of aircraft in armed conflicts, air power became a quicker, easier and a more flexible way of fighting a war. The only liability that emerged was the 'human factor' because in an advent of counterfire there was either loss of life or capture of the pilot. This was clearly evident during the Balakot conflict, when the Pakistani forces captured an IAF pilot, possibly leading to limitations in our response. The human factor led to the idea of flying a Remotely Piloted Aircraft (RPA) in wars. RPAs were operationalised when radio transmitters became successful in controlling flight surfaces throughout the various regimes of the flight. The applications of RPAs are infinite but the most common use in the initial years of their operations was that of surveillance, reconnaissance and Geographical Intelligence (Geo-Int).

Development of A-UCAVs and Operationalisation in Warfare

The journey towards the development of A-UCAVs has been an uphill battle, fraught with challenges that have taken decades to overcome. From humble beginnings in the early 1970s, when remotely piloted aircraft were used as targets in anti-aircraft training exercises, to the sophisticated autonomous drones and UCAVs of today, the evolution of unmanned systems has been a marvel of technological innovation. Driven by the need for improved military capabilities and a desire to minimise the risks to human life in combat situations, the development of A-UCAVs has been fuelled by incredible advancements in aviation and electronics, as well as technologies such as AI and ML. Equipped with advanced sensors and on-board computers, these systems use algorithms to analyse data, make decisions and carry out missions with precision and accuracy. Additionally, advanced communication systems have enabled these vehicles to operate in coordinated swarms, sharing information and executing complex missions with greater efficiency and effectiveness. 'In 2017, a US MQ-9 Reaper UCAV destroyed a Russian-made T-72 tank in Syria. This was the first time an autonomous drone had destroyed a tank in combat.'[2]

The development of A-UCAVs has been a true test of human ingenuity, paving the way for a new era of military operations that promises to revolutionise the way we conduct warfare. The nascent stage of UCAV development witnessed prototypes such as the Radioplane OQ-2, which dates back to World War II and laid the foundation for subsequent advancements.

Over the ensuing decades, UCAVs underwent a paradigm shift from taking on rudimentary reconnaissance roles to possessing sophisticated, autonomous combat capabilities. Pioneering developments, including the General Atomics MQ-1 Predator, marked a watershed moment in the 1990s by combining surveillance and armed capabilities. This paradigm was further refined with the MQ-9 Reaper showcasing improved endurance and payload capacities.

The 21st century witnessed a proliferation of UCAVs with major military powers investing heavily in R&D. Statistics reveal a notable increase in UCAV deployment, with diverse applications ranging from counterterrorism operations to conventional warfare. As of the latest available data, the global UCAV market is projected to continue its upward trajectory, propelled by advancements in AI, sensor technologies and the demand for unmanned platforms in contemporary military strategies. The developmental history of UCAVs epitomises the marriage of innovation and strategic imperatives, reflecting a pivotal chapter in the evolution of aerial warfare.

The Contemporary Deployment of UCAVs in Global Conflict

The utilisation of UCAVs (Non-Autonomous) has proliferated significantly in recent years, emerging as a ubiquitous feature of modern warfare. With technological advancements and escalating global tensions, many nations have gravitated towards UCAVs as their weapon of choice in military operations.

Notably, the employment of UCAVs during the 2020 conflict between Armenia and Azerbaijan[3] proved to be a game changer. Azerbaijan's deployment of Turkish-made Bayraktar TB2 drones proved decisive, raining down like a barrage of bullets on Armenian military positions and propelling Azerbaijan to victory. Equipped with high-resolution cameras, missiles and bombs, these UCAVs proved adept at pinpointing enemy targets. This starkly illustrated the potential of UCAVs in asymmetrical conflicts, where asymmetrical means often require unorthodox tactics.

A further example of UCAV use was witnessed during the 2021 conflict between Israel and Hamas in Gaza,[4] with Israel deploying a range of drones, including the Heron TP and the Harop, to take out Hamas positions and leaders. These UCAVs acted as an extension of Israel's arm, gathering intelligence, conducting surveillance and striking targets with precision like a surgeon's scalpel. This deployment showcased the ability of UCAVs to limit civilian casualties and collateral damage while executing military operations.

Moreover, the United States (US)[5] continues to rely heavily on UCAVs in their Middle Eastern operations, as evidenced by the deployment of MQ-9 Reaper drones during an airstrike in Syria in February 2021, targeting Iranian-backed militia groups. This marked the Biden administration's first military foray, highlighting the ever-growing dependence on UCAVs in US military operations. Recently, GA-ASI has achieved a triumph in showcasing the independent navigation abilities of its MQ-20 Avenger UAS by utilising Low Earth Orbit (LEO) Satellite Communications (SATCOM) datalink.[6] As per GA-ASI, the test flight was conducted in February 2021, where a prototype UAS, equipped with a SATCOM datalink provided by the US Air Force Space and Missile Systems Centre, flew a pre-defined mission and landed autonomously while being controlled through the LEO SATCOM datalink. This feat marks a momentous achievement for GA-ASI's MQ-20 Avenger UAS programme,[7] which aims to develop cutting-edge autonomous capabilities. The use of LEO SATCOM datalink has enabled the UAS to function Beyond the Line of Sight (BLOS) of ground-based control stations, a critical element for specific military operations.

Apart from their usage in active conflict zones, UCAVs have been employed for surveillance and reconnaissance purposes. In March 2021, the Indian Navy obtained its first set of UCAVs, the Sea Guardian, for monitoring the Indian Ocean region. Equipped with cutting-edge surveillance technology, the Sea Guardian acts as the Indian Navy's eyes and ears, watching over the vast expanse of the ocean like a vigilant sentinel.

Nevertheless, the use of UCAVs in warfare has ignited ethical concerns and spawned debates about their legality. Also, use of UCAVs gives rise to apprehensions about the absence of human oversight in the decision-making process, particularly in the case of A-UCAVs. Despite these concerns, the deployment of A-UCAVs in modern warfare is likely to expand. Their precision-strike capability, intelligence-gathering and surveillance operations that minimise risks to human life make them an enticing option for militaries worldwide.

Exploitation of A-UCAVs by the PLA

In recent years, China has emerged as a consequential player in the sphere of A-UCAVs development and deployment. These sophisticated systems are capable of autonomous operation and can execute pinpoint strikes with cutting-edge technology, rendering them ideal for military applications. China's pursuit of A-UCAVs took flight in the early 2000s, as the nation began investing resources into research and development in this sphere. Since then, China has made considerable strides in the development of UCAVs, with a particular focus on stealth and precision strike capabilities. The country has also devoted resources to the advancement of AI and ML technologies, both of which are vital to the development of A-UCAVs.

One of the most prominent examples of China's development of A-UCAVs is the CH-5 Rainbow drone,[8] which was unveiled in 2016. The CH-5 is a long-range, high-altitude drone that can remain airborne for up to 60 hours and has a maximum range of 6,500 kilometres. The drone is outfitted with a range of armaments, including air-to-ground missiles and precision-guided bombs, making it a potent tool for military applications. China has also directed resources towards the development of SWARM robotics technology, which involves the use of multiple robots working together in concert to achieve a common objective.[9] In UCAVs, SWARM robotics can be employed to create a cohort of autonomous drones that can work collaboratively to carry out intricate missions. China has successfully conducted tests of a group of UCAVs, showcasing the potential of this technology for military applications.

The deployment of A-UCAVs by China has raised concerns among its neighbours and the international community. China's maritime disputes with neighbouring countries, such as Japan, Vietnam, Taiwan and the

Philippines, have amplified tensions in the region, and the deployment of UCAVs has compounded these tensions. China's utilisation of UCAVs in the South China Sea, where it has been constructing artificial islands and staking territorial claims, has also been a source of anxiety.

The deployment of A-UCAVs by China has also engendered questions about the role of AI and ML in warfare. While these technologies can provide significant benefits in military operations, they also raise ethical questions regarding the use of autonomous systems in combat. There is a risk that A-UCAVs could be utilised in ways that contravene international law and human rights, necessitating clear guidelines and regulations to govern their use. China's development and deployment of A-UCAVs have also had an impact on the regional balance of power. China's neighbours, including Japan and South Korea, have been bolstering their own military capabilities in response to China's military modernisation. The deployment of UCAVs by China has intensified these concerns, as it signifies a marked increase in China's military capabilities.

A-UCAVs: The Technology Behind Their Autonomy

A-UCAVs are able to fly on their own thanks to a combination of advanced technologies and programming. These vehicles are designed to operate without human intervention, which allows them to execute complex missions in remote or hazardous environments.

The first key technology used in A-UCAVs is Global Positioning System (GPS). GPS allows the UCAV to determine its precise location in three dimensions, which is crucial for navigation and guidance. The UCAV uses this information to plan its flight path and adjust its speed and altitude as necessary to avoid obstacles and stay on course. GPS is also used for mission planning, allowing the UCAV to follow a pre-determined flight plan or respond to real-time changes in the mission objectives. In addition, A-UCAVs use INS with low degradation factor to be able to operate in a GPS denied environment.

The second key technology used in A-UCAVs is computer vision. Computer vision involves the use of cameras and other sensors to allow the UCAV to perceive its environment and make decisions based on that perception. The UCAV can use computer vision to detect, track and identify obstacles, targets and terrain features, and avoid collisions. Computer vision algorithms are also used for autonomous landing and takeoff, allowing the UCAV to operate from remote locations without a human pilot.

The third technology used in A-UCAVs is AI. AI algorithms allow the UCAV to learn from its experiences and make decisions based on gathered data. For example, the UCAV can learn to recognise patterns in enemy behaviour or adjust its flight path based on real-time weather data. AI also allows the UCAV to make decisions in complex and unpredictable situations, such as responding to unexpected obstacles or changes in the mission objectives.

Fourthly, the UCAV's Flight Control System (FCS) is programmed to execute the mission objectives autonomously. The flight control system is responsible for coordinating the various sensors and algorithms used by the UCAV, as well as controlling its propulsion system and other mechanical components. The flight control system can adjust the UCAV's speed, altitude, and direction in real time, and can also respond to emergencies or system failures.

Finally, UCAVs have on-board weapons with precision capability that are fed with a multitude of algorithms to achieve precise targeting. The decision to launch the weapon can be done either autonomously based on AI decision matrix or remotely by a human in the loop.

The military applications of A-UCAVs are vast and varied. These vehicles can be used for surveillance, reconnaissance, target identification and strike missions, among other things. They can operate in a range of environments, from urban settings to remote wilderness areas, and can be deployed from a variety of platforms, including land-based vehicles, ships and aircraft. As the technology continues to evolve, it will be important to address the ethical, legal and practical issues that arise from the use of autonomous systems in both military and civilian contexts.

Applications of Cloud Robotics in A-UCAVs

The potential applications of cloud robotics in A-UCAVs are manifold. Some of the domains where cloud robotics can be game-changing are precision agriculture and meteorological study for military operations. A-UCAVs equipped with sensors and cameras can capture real-time data on crops, soil and weather conditions. This data can be sent to a cloud-based infrastructure, where it can be analysed using machine learning algorithms to provide farmers with insights on crop growth, pest infestations and other crucial factors. This can enable farmers to optimise their crop yields, reduce resource usage and increase efficiency. Another promising application of cloud robotics in UAVs is in disaster response and management. In the aftermath of natural disasters such as earthquakes, floods and hurricanes, UCAVs can be used to gather critical information on the extent of damage and identify areas that need immediate assistance. These UCAVs can be used to assess weather conditions around an airbase, check for bird flocks and survey the winds and flying conditions. If there are low clouds over the airfield, the UCAVs can be safer and cheaper way to perform a 'weather check overshoot' over the runway to see if aircrafts can get a safe approach while landing. This information can be transmitted to a cloud-based infrastructure, where it can be analysed to develop response strategies and allocate resources efficiently.

Cloud Robotics to SWARM Robotics

SWARM robotics refers to the use of multiple robots working together to achieve a common goal. In UCAVs, SWARM robotics can be used to create a group of autonomous drones that can work together to carry out complex missions. These drones can communicate with each other, coordinate their actions and operate as a single entity, significantly increasing their effectiveness.

One of the most significant advantages of SWARM robotics in UCAVs is their ability to conduct coordinated attacks. A group of UCAVs can work together to conduct simultaneous strikes on multiple targets, overwhelming the enemy's defences. Additionally, UCAV swarms can be used to perform search and rescue operations, where the group can cover a more extensive area and locate targets more quickly. Another critical application of UCAV swarms is in reconnaissance missions. The group can survey a vast area and provide real-time intelligence to ground forces. The drones can work together to create a 3D map of the terrain and identify potential threats, providing valuable information for military planners.

UCAV swarms can also be used in urban warfare, where the environment is complex and challenging for human troops. The drones can operate in narrow spaces, identify threats and neutralise them without putting human lives at risk.

Several countries have already begun exploring the use of UCAV swarms. The US has been working on the Gremlins programme, which aims to develop a group of UCAVs that can be launched and retrieved from a mothership in-flight.[10] China has also been investing in SWARM robotics technology and has conducted successful tests of a group of UCAVs.

Fostering Synergy Between Cloud Robotics and A-UCAVs: A Cutting Edge Technological Integration

Cloud robotics is a burgeoning technology that has the potential to revolutionise the field of robotics. This advanced technology entails connecting robots to a cloud-based infrastructure that provides access to powerful computational resources, storage and a plethora of other services. In recent times, the idea of integrating cloud robotics in UAVs has gained significant traction. This has been driven by the desire to enhance the capabilities and performance of UAVs by leveraging advanced technological capabilities. This ensuing paragraph aims to examine the myriad benefits of inculcating cloud robotics in UAVs, the challenges involved and the potential applications of this cutting-edge technology.

Some of the biggest things that this integration and the system's operationalisation will provide is the flexibility of usage while keeping the stakes low. The cloud-based swarm will operate while all its heavy computation will be on the cloud and not on individual machines. An amazing thing about SWARM robotics is that it works on the 'one learns-all learn' capability. If a drone enters into a hostile airspace and detects enemy ground buildup it can instantaneously share the images and intelligence with other UCAVs and operators elsewhere. The M2M and M2C communication will be instantaneous, which will at all times be working, and the information online would continuously increase, making the swarm smarter every second.

Undoubtedly, one of the most significant benefits of incorporating cloud robotics in UAVs is the ability to offload computation and data storage to a cloud-based infrastructure. As is often the case, UAVs are limited by their meagre computational resources and storage capacity, which can hamper their capabilities. However, by connecting UAVs to a cloud-based infrastructure, they can access powerful computing resources and storage capacity, enabling them to perform more complex tasks and process larger amounts of data. This can significantly enhance the UAVs' ability to perform tasks such as real-time data analysis, object recognition and navigation. Another notable advantage of using cloud robotics in UAVs is the ability to leverage the power of ML and AI. ML algorithms can be trained on extensive datasets to enhance the UAVs' ability to recognise objects, detect anomalies and make decisions. By connecting UAVs to a cloud-based infrastructure, they can access powerful ML algorithms and AI services that can be used to augment their performance. This can enable UAVs to perform tasks such as autonomous navigation, obstacle avoidance[11] and surveillance with greater ease and efficiency.

Incorporating cloud robotics in UAVs also opens up avenues for seamless collaboration and information exchange. Cloud-based infrastructure facilitates real-time information sharing and communication between UAVs, enabling them to work together in unison to accomplish complex tasks. This can be instrumental in domains such as search and rescue, reconnaissance and surveillance, where multiple UAVs need to work together to cover a large area or gather diverse types of data. Moreover, cloud robotics can facilitate remote control and monitoring of UAVs, enabling operators to supervise and intervene in the UAVs' operations from a distance.

Shielding Autonomous Drones: Strategies to Counter Electronic Warfare (EW) Jamming

A-UCAVs have become an indispensable instrument in modern warfare due to their exceptional efficacy and versatility. However, they are highly susceptible to Electronic Warfare (EW) jamming, which can render them helpless and even jeopardise their security. Therefore, it is imperative to undertake measures to preclude A-UCAVs from being jammed.

The first step in averting A-UCAVs from getting jammed is to utilise secure communication systems. Conventional communication systems are vulnerable to jamming since they rely on radio frequencies that can be effortlessly disrupted. However, implementing encrypted communication systems can make it more difficult for jamming signals to interfere with A-UCAVs' communication systems. This can be accomplished by employing sophisticated encryption algorithms that are challenging to decode and by limiting access to the communication systems to only authorised personnel.

Another technique to thwart A-UCAVs from getting jammed is to use frequency-hopping methods. Frequency hopping necessitates quickly altering the frequency of the communication signal, making it arduous for jamming signals to interfere with the communication. This tactic is effective since it is hard for jamming signals to match the frequency of the communication signal. Nevertheless, this technique requires sophisticated communication equipment, which can be expensive. Using directional antennas can also aid in preventing A-UCAVs from getting jammed. Directional antennas can focus the communication signal in a specific direction, making it difficult for jamming signals to interfere with the signal. This strategy is effective as it lessens A-UCAVs' susceptibility to jamming signals from multiple directions. However, directional antennas require precise targeting, which can be challenging in rapidly moving and dynamic environments.

Furthermore, integrating AI into A-UCAVs can also help protect them from being jammed. AI algorithms can detect jamming signals and adjust UCAVs' communication frequency, power and routing to avoid interference or just switch off receiving during jamming to survive. This technique can also assist A-UCAVs in identifying and evading other threats such as enemy radar and anti-aircraft missiles. Preventing UCAVs from being jammed is crucial in modern warfare. By utilising secure communication systems, frequency-hopping methods, directional antennas and integrating AI, we can enhance the A-UCAVs' resistance to jamming signals. These measures can bolster the effectiveness of A-UCAVs and amplify the safety and security of military operations.

Fitting A-UCAVs with Swarm Robotics into India's Operational Requirements

1. **Operations in Built Up Areas:** The convoluted urban, rural and semi-urban planning in the Indian subcontinent, including Pakistan, poses a perplexing challenge to differentiate individual houses, not only for humans but also for AI. However, the amalgamated learning capacity of drone swarms can streamline the process. As each drone's AI and the centralised cloud analyse the area, the quick learning ability of the swarm as a whole will make the task manageable. In densely populated areas, such as built-up regions, the utmost precision is crucial in the event of an air strike. To achieve this, rapid communication among A-UCAVs can be pivotal. AI enabled sensors on a A-UCAV will be able to analyse different people on the ground and distinguish armed and unarmed combatants from civilians. This can be very useful in remote areas with a low population density where infiltration and insurgency are high, the A-UCAVs flying autonomous patrol missions can detect hostile people and can transmit the data instantaneously to the commanders at base for a quick fire/ no fire decision.
2. **Surveillance Operations in Rural/Semi Rural Areas:** Sub-conventional warfare, off the charts of global eyes, requires quiet and swift operations. A lot of these operations take place in rural and/or semi-rural areas and that too mostly at night. A-UCAVs mostly provide an aerial over watch to on-foot operators but with recent trends A-UCAVs are becoming the main instruments of these operations. Several A-UCAVs need to carry strikes or surveillance and have to work in tandem. For this synchronised control is required and Remotely Piloted Aircraft (RPAs), which the

IAF currently operates, cannot undertake these complex tasks in close formation as the human fatigue factor and un-synchronised flying render the task nearly impossible. With SWARM robotics, these A-UCAVs can fly in sync with each other as a single mind is controlling its multiple bodies.

3. **Operations in Hilly/ High Altitude Areas:** The Indian military typically deals with three theatres where hills challenge its operations. These are the Kashmir valley (western Himalayas in Jammu and Kashmir and Line of Control [LOC] area), Ladakh (eastern Himalayas near Line of Actual Control [LOAC] and Leh) and the northeastern Himalayas (Arunachal Pradesh and Sikkim). Flying above the peaks and below them in the valleys for gathering GEO-INT or for ground attack missions require taking notice of an adversary's movement on the ground and in the airspace as well. A-UCAV swarms with a divided workload and different responsibilities can make it easier for the forces to accomplish the objective. A cloud-based swarm in such situations can have drones specialising in reconnaissance, ground imagery, counter air and radar operation, ground attack and aerial surveillance.
4. **Offensive Ops:** The use of A-UCAV swarms offers several advantages, including heightened endurance, redundancy and improved tactical flexibility. It is pertinent that the IAF explores the applicability of A-UCAV swarms in ground attack and strike roles. Primarily, A-UCAV swarms display a heightened endurance compared to single A-UCAVs due to the swarm's coordination and unitary operation. This allows for the delegation of duties and workload within the swarm. Furthermore, A-UCAVs can operate as a network, sharing information and synchronising attacks. Secondly, the redundancy of A-UCAV swarms is an advantage in combat situations. The failure of any component in a single A-UCAV system could result in a mission failure. Conversely, in a swarm, the loss of a single A-UCAV may not significantly impact the mission, as the others can compensate.[12] Thirdly, A-UCAV swarms offer improved tactical flexibility. In a swarm, each A-UCAV can play a unique role, such as ground attack, reconnaissance or air defence suppression. This allows the swarm to adapt to different situations and execute multiple objectives simultaneously, achieving parallel operations in small time frames. One potential application of A-UCAV swarms is in ground attack and strike roles. A swarm of A-UCAVs can precisely target enemy ground forces using guided munitions, providing a proficient way of suppressing the enemy. Furthermore, A-UCAV swarms can be used

to neutralise enemy air defences, allowing manned aircraft to penetrate deeper into enemy territory. The Turkish military demonstrated this capability during the recent conflict in Nagorno–Karabakh,[13] where they destroyed enemy air defence systems and provided close air support to ground forces using UCAV swarms.

5. **Air Defence (AD) Ops:** One notable example of the successful deployment of A-CAVs in air defence roles is the Israeli Iron Dome system. The Iron Dome uses A-UCAVs to intercept incoming rockets and missiles in real time. The system's UCAVs operate in swarms and are designed to detect, track and engage incoming threats autonomously, without human intervention. The Iron Dome system has been successful in intercepting incoming missiles and protecting Israeli citizens from harm.[14] Another example of the use of A-CAVs in air defence roles is the Chinese CH-901 drone. The CH-901 is a lightweight UCAV designed to be deployed in high-risk environments to engage enemy air threats. The drone has a range of up to 15 kilometres and can be equipped with various sensors and weapons, including electro-optical sensors, laser designators and precision-guided missiles.[15] A-UCAVs offer several advantages over traditional manned platforms in AD roles, including increased endurance, improved tactical flexibility and reduced risk to human pilots.

Transforming Phased Out Fighters into Autonomous UCAVs

Nations have begun to integrate AI and ML into their aged fighter fleets in order to completely remove risk of pilot's life and adding more wings to their air power. The United States Air Force (USAF) has been exploring the integration of AI into their F-16 fighter jets to make them autonomous. The aim of the project is to create a software suite that would allow the F-16 to autonomously navigate and engage targets, thereby increasing the survivability and lethality of the aircraft in contested environments. The development of autonomous capabilities for the F-16 is being carried out in partnership with the Defence Advanced Research Projects Agency (DARPA), which is responsible for developing cutting-edge technologies for the US military. DARPA's Air Combat Evolution (ACE) programme is focused on developing AI algorithms that can learn from human pilots to improve the performance of autonomous systems. 'The F-16 was modified and upgraded to an all-new configuration that came to be known as the X-62A Variable In-flight Simulation Test Aircraft or VISTA. It was reportedly flown by an artificial intelligence agent for more than 17 hours recently, representing the first time AI engaged on a tactical aircraft.'[16]

The IAF has launched the CATS OMCA programme[17] to enhance its capabilities in UAVs and autonomous systems. The aim of the CATS OMCA programme is to develop and integrate advanced technologies such as AI, ML and computer vision into the IAF's aged fighter aircraft to make them fly autonomously or remotely. This will enable the IAF to operate unmanned systems more effectively and efficiently, with increased autonomy and reduced reliance on human operators. Reportedly the programme has already flown the Kiran MK-2 aircraft autonomously and may also aim to test the phased out MiG-21 variants and the MiG-27s. 'Hindustan Aeronautics Limited (HAL) had earlier unveiled its Combined Air Teaming System (CATS) which involved a mothership operating distantly with an autonomous unmanned aerial vehicle known as CATS Warrior to strike inside enemy territory. The unmanned aircraft concept may look like a futuristic project but HAL seems to have made rapid strides in the last few years.'[18]

China has been developing and testing technologies to convert its old fighter jets into autonomous drones. The project, which is known as the 'loyal wingman'[19] programme, aims to increase the Chinese military's unmanned aerial capabilities, particularly in the area of combat drones. The loyal wingman programme involves retrofitting old fighter jets, such as the J-6 and J-7 models,[20] with new hardware and software to enable them to fly autonomously. The converted drones will be able to fly alongside manned fighter jets, performing a range of missions such as surveillance, reconnaissance and electronic warfare. One of the key advantages of the loyal wingman programme is that it allows China to repurpose its existing fleet of fighter jets, which are becoming obsolete due to advances in technology. By converting them into drones, China can extend the useful life of these aircraft and increase its unmanned aerial capabilities at a relatively low cost. China has been testing the loyal wingman programme in various ways, including conducting test flights and carrying out live-fire exercises. In one test, a converted J-6 fighter jet successfully flew alongside a J-16 fighter jet, demonstrating the ability of the loyal wingman to perform coordinated missions with manned aircraft.

Challenges of the Cloud Robotics Integration in A-UCAVs

However, the incorporation of cloud robotics in UCAVs poses several challenges. One of the primary concerns is data security and privacy. UCAVs generate vast amounts of data, some of which may be sensitive and confidential. The transmission and storage of this data in a cloud-based infrastructure must be safeguarded against cyber-attacks, unauthorised access and data breaches. Another challenge is network connectivity and latency. UCAVs operating in remote or hostile environments may face network connectivity issues, leading to latency and disruption in communication with the cloud-based infrastructure. Additionally, the reliability and availability of the cloud-based infrastructure must be ensured to prevent disruptions in UCAV operations. A study by researchers at the University of Michigan examined the challenges of implementing secure communication protocols between UCAVs and cloud-based infrastructure. They found that traditional encryption methods were not suitable for UAVs operating in dynamic environments and proposed a lightweight encryption protocol that was optimised for UAVs. The researchers demonstrated that their proposed protocol could provide reliable and secure communication between UCAVs and cloud-based resources, mitigating the risks of data breaches and cyber-attacks.[21]

The Dialectic of A-UCAVs in Modern Warfare: Weighing the Advantages and Disadvantages

The ensuing paragraphs will attempt to explore the dual nature of A-UCAVs as a double-edged sword in modern warfare and will try balancing their potent advantages with the potential drawbacks to achieve strategic victory. These aircraft have fundamentally transformed the nature of military conflicts, ushering in a new era of operational capabilities. This discourse will scrutinise the deployment of A-UCAVs in present-day air warfare, deliberating their benefits, drawbacks and ethical considerations.

Primarily, one of the principal advantages of A-UCAVs is their capacity to conduct reconnaissance and surveillance operations without exposing human pilots to risk. These aircraft are outfitted with an assortment of sensors and cameras that can furnish real-time intelligence to commanders on the ground. This enables military forces to observe adversary movements and collect valuable intelligence that can be utilised to design future operations. Additionally, A-UCAVs can be utilised to monitor and trace high-value targets, such as terrorist leaders, without imperilling human lives. Another advantage of A-UCAVs is their capability to execute surgical strikes with pinpoint accuracy. These aircraft can be equipped with a range of weaponry, including missiles, bombs and even laser-guided munitions. In contrast to traditional manned aircraft, A-UCAVs can remain airborne for extended periods, granting them the ability to execute precise and accurate strikes over a prolonged duration. This makes them highly effective in both offensive and defensive operations.

However, the deployment of A-UCAVs is not without its drawbacks. One of the chief concerns regarding these aircraft is their susceptibility to cyber-attacks. A-UCAVs are controlled by software systems that can be vulnerable to hacking or other forms of cyber-attack. If an adversary gains control of an A-UCAV, they could conceivably employ it to launch attacks against friendly forces or civilian targets. As such, it is imperative to ensure that A-UCAVs are engineered with robust cyber security protocols in place. Another concern with the use of A-UCAVs is the risk of collateral damage. Because these aircraft can remain airborne for extended durations, they possess the potential to execute strikes with tremendous precision. However, there is always the hazard of inflicting civilian casualties or damaging infrastructure in the vicinity of the target. This is particularly true when A-UCAVs are deployed in urban environments, where the risk of collateral damage is heightened. Hence, it is crucial to ensure that A-UCAVs are used in a responsible and ethical manner, with appropriate rules of engagement in place. Arguably the most significant apprehension surrounding the deployment of A-UCAVs is the ethical implications of employing autonomous weaponry in warfare. There is an intensifying debate concerning the use of autonomous weaponry, with some experts warning of the potential hazards of using machines that can make decisions without human oversight. While UCAVs are presently operated by human pilots who make decisions about when and where to strike targets, there is a risk that these aircraft could be designed to function autonomously without human intervention. This raises considerable ethical concerns about the use of autonomous weaponry in warfare, particularly in situations where decisions concerning whom to target and when to execute strikes are entrusted to machines.

Conclusion

The symbiosis of A-UCAVs with cloud robotics or swarm robotics heralds a transformative era in the landscape of future warfare, presenting India with a strategic impetus. The amalgamation of A-UCAVs and cloud robotics amplifies computational capabilities, enabling real-time data fusion and decision-making. This synergy equips military forces with unprecedented agility, resilience and precision, essential attributes in the contemporary theatre of conflict.

In the Indian context, envisioning A-UCAVs integrated with cloud or swarm robotics holds manifold advantages. The vast and varied topography of the subcontinent demands a decentralised and adaptable approach to military operations. By leveraging collective intelligence, swarm robotics can facilitate distributed sensing and collaborative manoeuvres, enhancing situational awareness and response times. Cloud robotics, by offloading computational tasks to centralised servers, augments the processing power of A-UCAVs, enabling them to execute complex missions autonomously.

Policy reforms are imperative to harness this potential effectively. Striking a delicate balance between innovation and ethical considerations is paramount. Robust data security protocols must be instituted to safeguard sensitive information processed through cloud-based systems. Furthermore, policy frameworks should address the ethical implications of autonomous decision-making by UCAVs, ensuring accountability and adherence to international norms. Establishing collaboration channels between government, academia and industry can foster innovation while safeguarding national interests. In this paradigm shift, proactive policy adjustments will be the linchpin for India to navigate the evolving dynamics of future warfare seamlessly.

> *Strategy without tactics is the slowest route to victory. Tactics without strategy is the noise before defeat.*
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> — Sun Tzu

Notes

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