EXPLOITATION OF EMERGING AND NICHE TECHNOLOGIES BY THE IAF

ACHU KUZHIYETH

Our vision is to transform the Indian Air Force into a future ready, technology-driven force that is agile, adaptive and fully capable of safeguarding national interests in all domains.

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PRELUDE

In 2024, the Unite States tested the HELIOS laser Directed Energy Weapon (DEW) system with a power output of 60 KW (Kilo Watt) capable of neutralising drones, missiles and fast attack boats. This is in continuation to the operational Laser Weapon Systems (LaWS) installed on its naval assets since 2014.[1] The drone MQ-28 Ghost Bat, which was amongst the first uncrewed loyal wingman systems in the world to be unveiled in 2021, is likely to enter operational service in 2025 in the Royal Australian Air Force (RAAF) after extensive flight testing and is expected to fulfil the

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1. Carter Johnson,"U.S. Navy HELIOS Laser Test Underscores Greater Advancements in Directed Energy Weapons", *Naval News*, January 4, 2025, https://www.navalnews.com/naval-news/2025/02/u-s-navy-helios-laser-test-underscores-greater-advancements-in-directed-energy-weapons/. Accessed on January 25, 2025.

functions of Manned-Unmanned Teaming (MUM-T).[2] China launched its first quantum satellite 'Micius' in 2016[3] and in 2024, Russia and China reportedly established secure quantum communication over a distance of 3,800 km, using secure keys transmitted by China's quantum satellite.[4]

The above examples clearly indicate that such emerging technologies are not figments of science fiction any longer, and are clearly going to influence the conduct of future warfare in general and aerospace warfare in particular. The paper, through its course, intends to analyse the need of exploiting emerging and niche technologies by the Indian Air Force (IAF) towards emerging as a future ready force, and the way ahead for the IAF to adapt these technologies.

INTRODUCTION

The concept of warfare has continued to evolve and has involved the use of force to settle differences. Evolutions and changes in warfare are characterised under generations of warfare, with each generation having different tactics, strategies, and technologies. While the first generation warfare revolved around the use of massed manpower using phalanx, line and column tactics, the present generation warfare or the fifth generation warfare is characterised by non-kinetic military action, such as social engineering, misinformation, and cyber attacks, along with emerging technologies such as Artificial Intelligence (AI) and fully autonomous systems. Fifth generation warfare has been described by Daniel Abbot[5] as a war of "information and perception". Emerging technologies, therefore, play an important role in the present generation warfare and will be essential for every military force to remain competent and relevant in the future.

2. Akhil Kadidal, "Boeing Says on Track with Contracted MQ-28A Production", *Jane's*, November 28, 2024, https://www.janes.com/osint-insights/defence-news/air/boeing-says-on-track-with-contracted-mq-28aproduction#:~:text=Boeing%20Defence%20Australia%20is%20contracted,as%20a%20critical%20force%20multiplier.. Accessed on January 10, 2025.
3. Karen Kwan,"China Reaches New Milestone in Space-Based Quantum Communications", *Scientific American*, June 5, 2020, https://www.scientificamerican.com/article/china-reaches-new-milestone-in-space-based-quantum-communications/. Accessed on February 5, 2025.
4. Matt Swayne,"Report: China and Russia Test Quantum Communication Link", *Quantum Insider*, January 2, 2024, https://thequantuminsider.com/2024/01/02/report-china-and-russia-test-quantum-communication-link/. Accessed on February 5, 2025.
5. Daniel Abott,*The Handbook of Fifth-Generation Warfare* (Nimble Books, 2010), p. 20.

What are Emerging Technologies?

Emerging technology is a term generally used to describe a new technology, but it may also refer to the continuing development of an existing technology. The term commonly refers to technologies that are currently developing, or that are expected to be available within the next five to ten years, and is usually reserved for technologies that are creating, or are expected to create, significant social or economic effects.[6] These technologies are also described as disruptive technologies due to their potential to revolutionise the industries and areas of influence but are, however, still untested and initially limited in reach.

Niche technology, on the other hand, refers to specialised or narrowly focussed technological solutions, tools or innovations that serve a specific, often limited, purpose or a particular industry or segment. These technologies are not mainstream or widely adopted but are designed to address specific needs or problems within a specialised context such as military applications of a technology.

Though armed forces follow the path of adopting sustaining or matured technologies, employing disruptive technologies in the defence sector can alter the symmetry of military capability between adversaries which, in turn, makes doctrines and strategies ineffective. It is the ability to adopt disruptive technologies selectively with a strategic vision that will make the difference in future wars. Emerging technologies, therefore, provide the Indian armed forces with an opportunity to alter existing technological asymmetry in military capabilities with adversaries with their adoption.

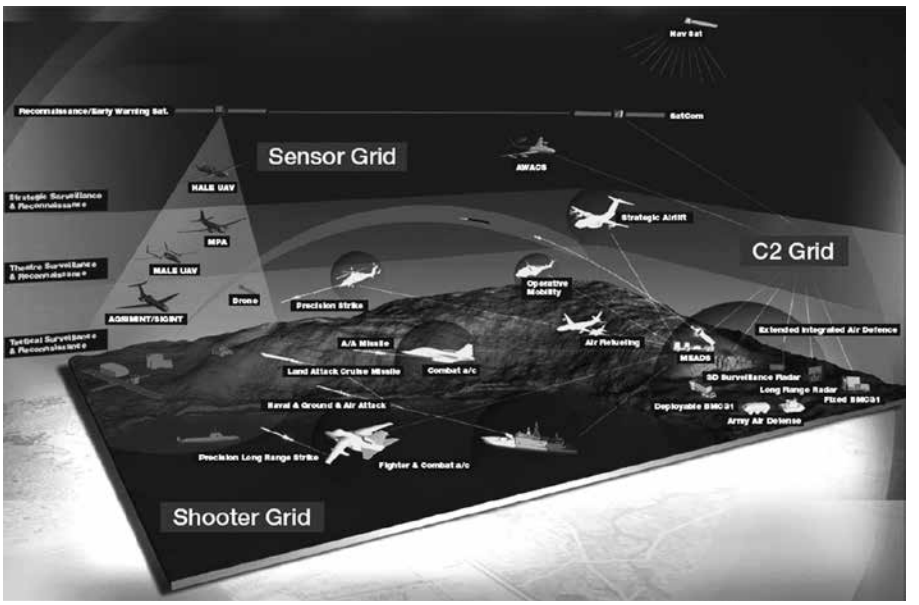
IAF Network-Centric Warfare (NCW) Model

To better understand the implications of emerging technologies, the paper chooses to evaluate an existing concept of warfare and predict changes with the induction of emerging technologies. As an example, the paper uses the IAF Network-Centric Warfare (NCW) model for evaluation.

6. IGI Global Scientific Publishing, https://www.igi-global.com/dictionary/implications-of-knowledge-management-adoption-within-higher-education-institutions/99015#google_vignetteh. Accessed on February 5, 2025.

The IAF conducts its operations under the concept of NCW, while integrating all its ground sensors and weapon systems, along with its aerospace, assets evolving from a platform-centric to a network-centric approach (Fig 1). While the ground sensors and weapon systems are integrated through the Integrated Air Command and Control System (IACCS) network, the Software Defined Radio (SDR) project will facilitate data exchange between airborne and ground platforms. The network enables data exchange through modes of Line of Sight (LOS) communication and satellite communication which allow data from space assets to be integrated into the overall network. The entire network is protected by the cyber domain which translates the network to be a fusion of multi-domain and multi-sensors. However, this concept of warfare would change under the effect of emerging technologies, which would be analysed in the subsequent part of the paper.

Fig 1: IAF Network-Centric Warfare Concept[7]



7. Rambo,"Network-Centric Warfare", The Tacticians Database, June 3, 2014, https://tactdb.blogspot.com/2014/06/network-centric-warfare.html. Accessed on February 3, 2025.

Fourth Industrial Revolution

The rise of emerging technologies, which is also categorised as the fourth industrial revolution[8], comprises a host of critical technologies which hold the power to transform the world as it operates now. The prominent ones being artificial intelligence, internet of things, augmented reality, robotics, cloud computing, three-dimensional (3D) printing, quantum computing, 5G, biotechnology, cyber security, edge computing, cognitive computing, nanotechnology, smart sensors, autonomous systems, cyber-physical systems, directed energy weapons, faster computer processing, block chain, additive manufacturing (3D printing).

The paper has identified a few key technologies with wide reaching military applications and utilisation in recent conflicts to highlight the importance of emerging technologies in aerospace warfare, which are:

(a) Artificial Intelligence (AI).
(b) 3D Printing.
(c) Quantum Computing.
(d) Directed Energy Weapons (DEWs).

ARTIFICIAL INTELLIGENCE (AI)

Artificial Intelligence or AI is a technology that enables machines and computers to simulate human learning, comprehension, problem solving and decision-making.[9] The use of AI to carry out functions in aerospace warfare is multi-fold. With large amounts of multi-sensor and multi-domain data to analyse and the requirement of superior cognitive capabilities to carry out immediate decision-making and analysis functions, the aerospace domain is an apt field for AI and Machine Learning (ML) applications. While the applications are limitless, the paper will organise them under functional headings for better understanding.

8. Nikhil Joshi, " What is Industry 4.0 & the 4th Industrial Revolution", snicssolutions, November 21, 2023, https://snicsolutions.com/blog/fourth-industrial-revolution. Accessed on February 6, 2025.
9. Ellen Glover ,"What Is Artificial Intelligence (AI)?", December 23, 2024, https://builtin.com/artificial-intelligence. Accessed on February 8, 2025.

AI can carry out automatic data analysis of large amounts of data from multiple sensors to glean useful intelligence, while carrying out threat assessment and prediction from these data.

Intelligence

The key to aerospace power and targeting lies in the quality of intelligence available to planners and operators. With AI's ability to learn and improve by analysing large amounts of data using algorithms to identify patterns and relationships in the data to make predictions, recommendations or decisions, intelligence activities involving large amounts of unprocessed datasets can be effectively handled by AI systems while improving the traditional Intelligence, Surveillance, and Reconnaissance (ISR) cycles.

AI can carry out automatic data analysis of large amounts of data from multiple sensors to glean useful intelligence, while carrying out threat assessment and prediction from these data. Analysing target vulnerabilities, identification and prioritisation is another role AI could perform efficiently and was demonstrated by the Gospel and Lavender AI systems in the recent Gaza conflict.[10] AI's capability of machine vision which helps in carrying out pattern recognition, change detection and imagery analysis from vast amounts of real-time image sources and even distorted sensor data can drastically reduce workloads and provide valuable information. ML which helps detect, prevent and respond to cyber attacks could also be useful in intelligence and communication networks to avoid manipulation of intelligence data.

Weapon Platforms

Future warfare is predicted to be revolutionised by the evolution of unmanned systems. AI will be the driving technology which will enable the existing unmanned aerial systems, drones and swarm drone systems to transition from being automated to highly autonomous in the future.

10. Michael N. Schmitt,"Israel – Hamas 2024 Symposium – The Gospel, Lavender, and the Law of Armed Conflict",Liber Institute, June 28, 2024, https://lieber.westpoint.edu/gospel-lavender-law-armed-conflict/. Accessed on February 5, 2025.

The concept of MUM-T will also critically depend on how AI and ML mature in the future. Humans in manned weapon platforms and next generation fighters will be critically assisted by AI enabled machine user interfaces providing data for decision capability in the cockpits and operator stations. This will elevate the roles of pilots and operators to that of decision-makers and enable them to undertake more complex tasks and decision-making with better Situational Awareness (SA).

AI will aid in faster real-time decision-making of command and control systems by optimising multiple sensors and domains, and providing autonomous weapon solutions and tailored decision-making solutions to the commanders and battle managers.

Command and Control Systems

However, AI's critical capability lies in how it assists in transforming command and control roles with its cognitive and comprehension abilities. AI will aid in faster real-time decision-making of command and control systems by optimising multiple sensors and domains, and providing autonomous weapon solutions and tailored decision-making solutions to the commanders and battle managers. AI will also enhance situational awareness through optimised intelligence while protecting commanders from data overload and distorted data. With autonomous weapon solutions and customised decision-making cycles, AI will considerably reduce the sensor-to-shooter time lag.

Training and Planning

AI also has tremendous potential in operational planning and training by enabling war-gaming systems and planning systems which are important niche applications in air campaign planning. With the incorporation of ML, fed with data from operational missions and peace-time exercises, AI will enable planners to efficiently plan missions and campaigns while incorporating the peculiarities of their own platforms and sensors, and provide valuable

lessons to rectify tactics and strategy during peace-time. AI can also be used for developing war-gaming systems at the tactical, operational, strategic and grand strategic levels, depending on the data and environments it is fed with. Complementing AI with augmented reality in the combat and flight simulators can enable the military personnel to be trained efficiently in real-time situations. AI also critically helps in accurate data analysis of combat missions, planning data and in giving an accurate assessment of skill levels at the field units and operator levels and planning staffs, and eradicate shortcomings such as confirmation biases and human errors.

Maintenance and Logistics

IAF operations being a maintenance intensive activity, consisting of multiple weapon platforms, sensors and large spare support and supply chain activities also stand to gain immensely with the induction of AI. AI can significantly assist in daily and periodical maintenance activities by predicting failure rates, analysing snags and system performances and assist in smart warehousing. AI also can help in real-time inventory tracking and generating predictive demands for equipment and spare parts which will help in optimising multiple supply chains to undertake efficient supply and stock-keeping.

3D PRINTING

While AI provides predictive maintenance and spare requirements, these requirements can be fulfilled with the technology of 3D printing in the absence of large manufacturing industries. 3D printing, also known as additive manufacturing, uses materials such as polymers, plastics and metals to create three dimensional structures and products through computer-aided design. In essence, it is a process of joining materials to make parts from 3D model data, usually layer by layer.[11]

3D printing was used by Ukraine to produce prints of the Titan Falcon First Person View (FPV) drones and Candy bombs which basically comprised

11. "Additive Manufacturing Technology", https://www.sciencedirect.com/topics/engineering/additive-manufacturing-technology. Accessed on February 8, 2025.

the 3D printed casings body of polymers and plastics with the same conventional explosive warheads, and Ukraine dropped about 1,000 of these bombs per week.[12] Recently, the Myanmar rebels also used it extensively to create replicas of Liberator swarm drones and hand-held rifles.[13] The Indian armed forces have successfully incorporated 3D printing for a wide range of applications including 3D defence systems which were tested to withstand T-90 tank firing.[14]

However, utilisation of 3D printing for military aircraft parts and munitions is still under development. The IAF can utilise 3D printing for producing aircraft spare parts, radar and weapon systems components, maintenance tools and infrastructure. If could also utilise 3D printing for creating one-way drones and FPV drones, along with weapon systems and munitions for Air Defence (AD) and short range AD systems. 3D printing could also be used in Camouflage, Concealment and Decoy (CCD) measures to create active and passive decoys, radar dome heads and decoy radars. Printing of shelters and infrastructure for operational deployment of troops and equipment on the move even at high altitudes is another imminent application.

QUANTUM TECHNOLOGY

Another emerging technology with immense disruptive effect is quantum technology which uses the quantum properties of superposition, entanglement and interference to provide high processing and computational speeds while storing data in the form of qubits instead of bits, allowing for larger memory storage. However, the major implication of this technology is its ability to render traditional cryptography such as the RSA (Rivest, Shamir, Adleman) encryption method and secure communications that we operate

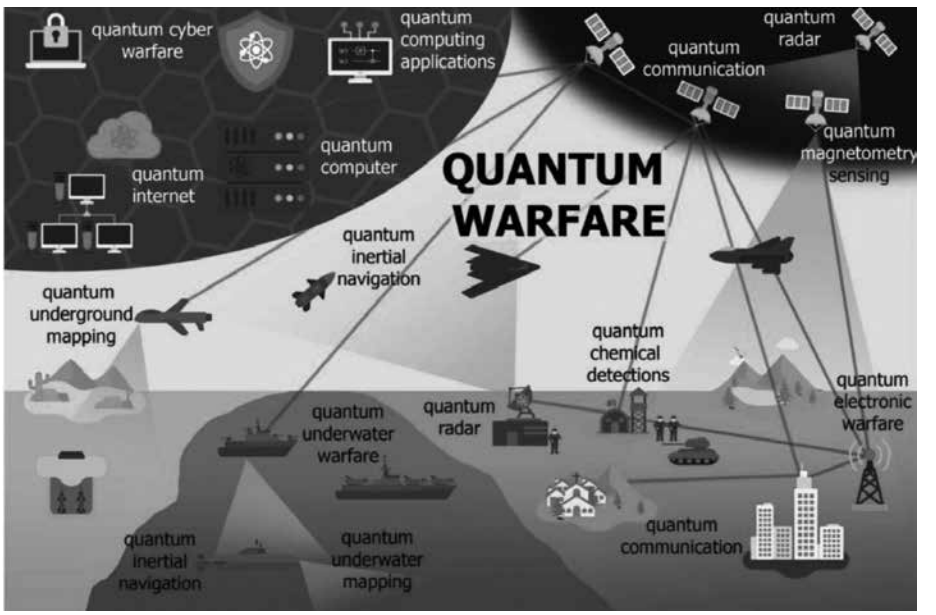
12. Reuben Das, GNET, October 14, 2024, https://gnet-research.org/2024/10/14/3d-printing-in-conflict-zones-a-game-changer/. Accessed on February 9, 2025.
13. Ibid.
14. Lieutenant General, PC Katoch (Retd), "3D Printing in War", *SP's Aviation*, September 28, 2024, https://www.sps-aviation.com/experts-speak/?id=887&h=3D-Printing-in-War#:~:text=3D%20printing%20techniques%20can%20be,tools%20and%20specialised%20job%20aids. Accessed on February 6, 2024.

on presently to be obsolete and vulnerable to breaches.[15] This makes the acquisition of quantum technology a necessity rather than a luxury.

The military applications of this technology are multi-fold and analysts predict that a new form of quantum warfare will replace the existing structures (Fig 2). The major military applications of quantum technology are organised under the following headings:

Quantum Computing: Quantum computing uses the higher processing speeds and large memory capabilities to process large amounts of data, transforming the ways militaries operate. It will also be the backbone on which AI/ML systems will operate in the future, while enhancing decision-making and situational awareness.

Fig 2: Concept of Quantum Warfare[16]



15. Paoloalto Networks, "What Is Quantum Computing's Threat to Cybersecurity?", https://www.paloaltonetworks.com/cyberpedia/what-is-quantum-computings-threat-to-cybersecurity. Accessed on February 3, 2025.
16. Medium," Will Quantum Technology Transform the Nature of Warfare? — A Comprehensive Review of Quantum Tech in Warfare", https://quantumpedia.uk/will-quantum-technology-transform-the-nature-of-warfare-e1d835e5d182. Accessed on January 30, 2025.

Quantum Sensing: Quantum sensing uses quantum technology to detect extremely small changes in physical parameters, such as magnetic and electric fields, and reduces time to detect objects such as enemy submarines or mines. Improved time measurements can be used for applications such as precise atomic clocks, quantum inertial navigation, underground and undersea exploration, more effective radio frequency communication, etc. in the future.

Quantum Cryptography: Quantum cryptography uses principles of quantum mechanics to encode data with the help of Quantum Key Distribution (QKD) in a manner that it is impossible to copy or intercept without changing the state of the system, making it an attractive option for secure and encrypted communications in the future.

Quantum Networks and Communications: Quantum networks and communications aim to transmit quantum information (qubits) across various channels, such as fibre optic lines or free-space communication using satellites, etc., enabling data transmission to be faster and more secure, and accessible from larger areas.

India, having rightly identified these implications, constituted the National Quantum Mission in 2023, with a budget of Rs 6,000 crore[17] to collaborate with private and public players to develop India's quantum capability. In August 2024, India demonstrated its own 6 qubit quantum processor[18] and is reported to have made significant gains in the field of quantum sensing and cryptography.

DIRECTED ENERGY WEAPONS

While the advancements in these emerging technologies guarantee an increased offensive potential in aerospace power, it is equally neutralised by the next technology which is Directed Energy Weapons (DEWs) which

17 Press Information Bureau, India, https://pib.gov.in/PressReleasePage.aspx?PRID=2060435. Accessed on February 8, 2025.

18. Press Information Bureau, India, https://pib.gov.in/PressReleasePage.aspx?PRID=2049356#:~:text=Scientists%20from%20DRDO%20Young%20Scientists,based%20on%20superconducting%20circuit%20technology. Accessed on February 10, 2025.

India continues to undertake extensive trials and development in DEW technology and demonstrated a 2 KW weapon in 2024 for countering unmanned aerial systems and drones, while development of more potent DEWs is going on.

use concentrated electromagnetic energy, rather than kinetic energy like conventional weapons, to incapacitate, damage, disable or destroy enemy equipment, facilities, and/or personnel. Different DEWs can be obtained depending on the part of the electromagnetic spectrum being utilised, with the prominent ones being High-Energy Lasers (HELs) and High-Powered Microwave (HPM) weapons. Though other DEWs like particle beams do exist, they are still in the early stages of development.[19]

DEWs have already been employed for a wide range of applications including laser dazzlers, short range AD systems, close-in weapon systems and counter-drone warfare, with a power output of 5-60 KW. However, with further developments, DEWs will be used extensively in future for counter-rocket defences with power of 100 KW and cruise missile defence and ballistic missile defence with 300 KW and 1 MW (Mega Watt) respectively becoming the first layer of AD in the future due to their capability of rapid engagement, multiple targeting capability and low cost per shot capability.[20] Ukraine has claimed to have successfully deployed its laser weapon, the Tryzub, during the recent conflict to shoot down Russian drones and missiles.[21] India continues to undertake extensive trials and development in DEW technology and demonstrated a 2 KW weapon in 2024 for countering unmanned aerial systems and drones, while development of more potent DEWs is going on.[22]

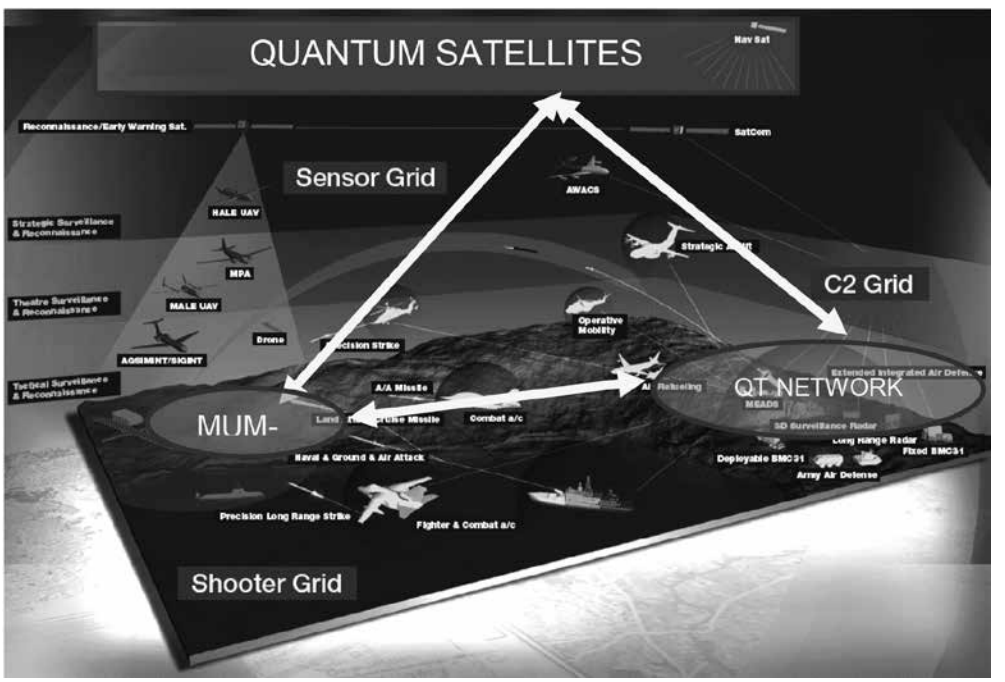
19. Prateek Tripathi," Is the Era of Directed Energy Weapons Finally Here?", Observer Research Foundation (ORF), July 22, 2024, https://www.orfonline.org/english/expert-speak/is-the-era-of-directed-energy-weapons-finally-here#:~:text=Though%20other%20DEWs%20like%20partic. Accessed on January 30, 2025.
20. Ibid.
21. Ibid.
22. Ibid.

FUTURE NCW WITH EMERGING TECHNOLOGIES

Having understood the applicability of emerging technologies in aerospace warfare, the paper now examines the IAF's NCW model which was analysed earlier (Fig 1) for any changes with the induction of the emerging technologies. Crystal gazing into the future, the emerging technologies have the potential to transform NCW into intelligent, highly autonomous and secure network-based warfare in the future (Fig 3).

Satellite communications and line of sight communications could be replaced by quantum satellites and free space quantum communications as the primary means.

Fig 3: Future NCW[23]



23. Rambo, n. 7.

The existing IACCS networks based on the optical fibre network could be replaced by a quantum communication network through optical fibres and free space communication through quantum satellites integrating all ground, airborne and space sensors, while AI, coupled with quantum networks, would be the backbone of replacing the aerial platform operations into highly autonomous combination manned-unmanned teaming operations. Satellite communications and line of sight communications could be replaced by quantum satellites and free space quantum communications as the primary means, while the all five domains as we know them today, would be secured by quantum cryptography encryption methods replacing the cyber domain. In essence, adoption of emerging technologies will be a necessity for the conduct of future warfare.

IMPLICATIONS OF EMERGING TECHNOLOGIES

To understand the exploitation of emerging and niche technologies there are certain implications which need to be understood and are as follows:

Maturing Technology: It is clear that emerging technologies classified under fifth generation warfare will play a role in the success of warfare in the coming years. However, emerging technologies are also in the process of maturing and will take about five to fifteen years to materialise into established infrastructures and usable equipment. The rapid proliferation of demonstrated technological developments in various fields such as AI and directed energy is in an initial phase and will exponentially increase once the technology matures. The lead time envisaged for the technologies to mature is also an opportunity for developing nations with evolving indigenous military industries such as India to heavily invest in, and accrue the advantages of, this new tech revolution future warfare.

India's Potential in Emerging Technologies: India, in fact, has rightly focussed on, and invested in, the Research and Development (R&D) of emerging technologies and has been able to achieve considerable research consolidations. As per a survey from the Australian Strategic Policy Institute on emerging technologies, India is amongst the top five countries in 45 out

of 64 critical technologies and in fast evolving major fields such as AI and ML, advanced integrated circuit design and fabrication, natural language processing, and adversarial AI, behind just China and the US.[24] India has also overtaken the US to claim the second spot in two emerging fields of technological research: biological manufacturing and distributed ledger technology. China, however, has made tremendous progress, leading in 57 of 64 critical technologies.[25]

However, India's achievements comprise contributions from both public sector and private players but at the national level, a collective effort to garner this potential is still absent. Due to the same reasons, only five Indian institutions appear in the top five positions across the 64 technologies despite collectively doing well. The report also predicts that the absence of core research institutions or collective national effort will affect/hamper attracting foreign research talent and also demotivate Indian scientists and technologists to undertake research at India.[26]

Strategic Partnerships: India's diplomatic standing provides a unique opportunity to engage with our strategic partners who are also invested in joint development of emerging and niche technologies. Initiatives such as the Indo-US Initiative on Critical and Emerging Technologies (iCET), India-US Defence Acceleration Ecosystem (INDUS-X), and Technology Security Initiative (TSI) with the UK could be established with more strategic partners to reduce initial investments in R&D, infrastructure and reducing timelines for development. India could also take the lead in initiating the use of regional and international cooperative structures such as the Quadrilateral Security Dialogue (QUAD), and G-20 as platforms for the development of niche technology with multiple partners.

R&D Budgeting and Whole of Nation Approach: The dual use nature of these niche technologies not only benefits national security but the

24. Dr Jennifer Wong Leung, "ASPI's Two-Decade Critical Technology Tracker: The Rewards of Long-Term Research Investment", Australian Strategic Policy Institute, August 28, 2024, https://www.aspi.org.au/report/aspis-two-decade-critical-technology-tracker. Accessed on February 11, 2025.
25. Ibid.
26. Ibid.

Achieving superiority in emerging technologies will need a whole of nation approach, integrating all national resources, and adequate budgeting.

overall national development and national economy. Increased R&D budgeting which will be required to achieve indigenous development of these technologies will also help India to access the global defence markets and boost the national economy in the long run. Achieving superiority in emerging technologies will need a whole of nation approach, integrating all national resources, and adequate budgeting. India will have to learn from the lessons of the past and modify the R&D structure existing in the country. A collaboration of public and private players, Micro, Small, and Medium Enterprises (MSMEs) and the start-up ecosystem in the country will have to be engaged rigorously to focus on the development of these technologies.

A hand-holding approach through easing regulatory and policy frameworks, providing minimum guarantee in terms of assured demands could be measures initiated to encourage MSMEs and start-ups to participate in the development of these technologies. A system of accountability in meeting timelines through contract agreements and methodology has to be ensured with both the public and private sectors to ensure that the development timelines of these technologies are not compromised.

Way Ahead for IAF

The paper puts forward the following as measures for the way forward for the IAF to exploit and embrace emerging technologies:

Aerospace Power – Sensitive to Technology: While it is evident that a whole of nation approach is inevitable for the development of emerging technologies, with aerospace power being sensitive to technology, development of these technologies for future wars will be a necessity for the IAF. A clear strategy, timelines and a roadmap for development, acquisition and induction of these technologies will have to be formulated by the IAF while identifying the resource talent available at the national level and national initiatives to engage with. This will have to be complemented accordingly with reform

of the IAF's doctrines, structures, roles and missions. Such an approach will have to be translated in the overall perspective planning and increased budget allocation through the Headquarters Integrated Defence Staff (HQ IDS) and Ministry of Defence through the defence budgets or inclusion in national level initiatives.

The IAF will also have to evolve into playing the role of an R&D partner, driver and innovator with the private and public sectors towards core technology development rather than being a capability product customer to exploit emerging technologies effectively.

Partnerships in Core Technology Development and Domain Expertise: The IAF will also have to evolve into playing the role of an R&D partner, driver and innovator with the private and public sectors towards core technology development rather than being a capability product customer to exploit emerging technologies effectively. While initiatives towards development of these technologies would exist at the national level, domain specific research and niche requirements for utilisation of these technologies will have to be put forward by domain experts which, in the case for aerospace power, will have to be the IAF to guide the developers.

Extensive research by the IAF personnel, think-tanks and academia on utilities, capabilities and ways to exploit these technologies will need to emerge from the IAF to act as inputs for the development agencies. For example, the IAF's participation at the National Quantum Mission will enable guiding inputs and feedback for development of quantum technologies essential for aerospace warfare. The IAF will also have to facilitate appropriate courses, masters and doctorate programmes with national universities and colleges in consonance with the Professional Military Education (PME) and Human Resource (HR) policies to build up the expertise level for Service personnel involved in organisations undertaking R&D.

Development Cycles, Refining Standard Operating Procedure (SOPs) and Infrastructures: Involvement in the technology development process will also help the IAF to continuously adapt its operational procedures and

infrastructure in consonance with future technology development for a longer timeline. For instance, adapting to a quantum communication network in 15 years will need setting up the infrastructure and modifying operating procedures starting two years from now. This will also help in prioritising or disregarding procurement of existing technologies which could turn redundant with the induction of these emerging technologies.

Participation as a testing partner will help reduce the development cycle and lead times for the developmental agencies. For example, efficiency of AI and ML applications in warfare will depend on the quality of data, large language model and standardised data format that the systems are fed with. Joint development of AI systems will enable the armed forces to standardise and improve the quality of data being archived and provided which, in turn, will ensure efficient development.

Expanding Scope of iDEX and Directorate of Aerospace Design (DAD): Niche military technologies with limited economic and dual use utility will also force the IAF to engage directly with MSMEs and private players for core level technology development for niche technologies. While the IAF has existing structures such as the Directorate of Aerospace Design (DAD), Unit for Digitisation, Automation, Artificial Intelligence and Application Networking (UDAAN) and measures to coordinate development of niche applications with MSMEs and start-ups, their scope is limited due to the budgeting and scope of Innovations for Defence Excellence (iDEX), Technology Development Fund (TDF) and integral service financial powers. The budgeting and scope of initiatives of these organisations will have to be expanded to help them focus from an innovation methodology to fostering core technology level development with private players and start-ups.

CONCLUSION

Emerging technologies will play a pivotal role in future wars and will be an essential part of the operational potential of air forces around the world. These technologies also provide an opportunity for the IAF to bridge the technological asymmetry prevailing with the larger and technologically

superior air forces. As a mature air force with deeper understanding of aerospace power, doctrinal knowledge and vast operational and combat experience, the future demands that the IAF evolve and play a larger role as a research and development partner in the defence industrial ecosystem of the country to accelerate the development of these capabilities for the military and for the country.

While initial investment in terms of research potential does exist, this would have no consequence if not effectively translated into matured technologies, infrastructures and usable equipment while learning from lessons of the past. The IAF should also lead a whole of nation approach, combining national agencies, private enterprises and start-up ecosystems with sufficient budgeting in terms of R&D to achieve these goals. Monitoring of progress and ensuring accountability of entities to ensure that the requisite technologies are delivered on time so as to derive the advantages of being a lead nation in technology development was aptly alluded to by the Chief of the Air Staff (CAS), IAF, in January 2025 when he stated, "Technology delayed is technology denied".