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THE FUTURE AIR DEFENCE CHALLENGES AND WAY FORWARD

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ABSTRACT

The rapid technological advancements of the 21st century have strengthened offensive options and brought significant challenges to traditional Air Defence paradigms. Central to these challenges is the proliferation of stealth technology, which has significantly impaired the detection capabilities of many existing radar systems. Concurrently, the advent and deployment of hypersonic weapons have drastically reduced the reaction window for defensive counteractions. Another pivotal concern is the proliferation of drone technology. With integrated air Defence systems relying heavily on network-centric operations, they have increasingly become susceptible to cyber-attacks. Furthermore, with nations expanding their operations into space, the potential for space-based threats is real.

In navigating these challenges, there is a need for a multifaceted approach. Suitable surveillance sensors, a potent interceptor fleet with preferably first-shot capability, effective missile Defence systems, cost-effective intercept means against low-cost intelligent UCAVs, and robust command and control centres to withstand cyber and EW attacks are some of the most compelling air Defence requirements.

This research paper investigates modern-day technological advancements and offensive concepts, studies the impact and nature of challenges that are posed to the efficacy of the Air Defence system, and, in the end, proposes options and measures to strengthen the Air Defence response.

Keywords: Air Defence, Evolving Technologies, Changing Character of War, Centralised Command, Unconventional Air Defence Solutions.

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1 INTRODUCTION

Air Defence is “all measures designed to nullify or reduce the effectiveness of hostile air action”.[1] In essence, Air Defence protects a country's airspace from various aerial threats to its assets within its territorial boundaries. Air Defence and Aerospace Defence are often used interchangeably, but the latter also encompasses the Defence of space assets. Air Defence operations are carried out in four stages: Surveillance/Detection, Identification, Interception, and Destruction. To accomplish these four stages, the ‘Air Defence Environment’ comprises sensors capable of detecting air threats, networked C4I Centres for threat identification and tactical response, and a shooter force comprising a combination of airborne and surface-based weapons. Ideally, an Air Defence arrangement should have such a deterrent effect that no one should dare challenge the country's air sovereignty. If someone does, there should be several response options so that the cost-benefit calculus for misadventure is heavily tilted towards cost, and the benefits are minimised.

For a deeper academic understanding, it is important to examine the place of Air Defence in the airpower operational hierarchy. The fundamental application of airpower is centred on gaining control of the air. To achieve and maintain the desired level of control, Counter-air operations play a critical role. These operations include both offensive and defensive air operations. Both offensive counter-air operations (OCAO) and defensive counter-air operations (DCAO) are closely intertwined and have a common purpose. Consequently, Air Defence is an integral mission of the Air Force in the quest for air control. OCAO and DCAO are not mutually exclusive but require coordinated planning and execution.

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[1] JWP 3-63, Joint Air Defence, 2nd Edition (Shrivenham: DCDC, 2003) 1-1

2 THE INTRICATE BALANCE BETWEEN OFFENCE AND DEFENCE

Air Defence systems have undergone continual evolution to address a broad spectrum of airborne threats, ranging from conventional aircraft and ballistic missiles to emerging challenges such as drones and hypersonic weapons. The core of Air Defence, however, remains reactionary, with the term "reactionary" bearing connotations for both operational and technological responses. Operationally, the offensive side holds the initiative, executing a carefully deliberated plan that accounts for every detail and variation. The Air Defence response is reactive, as it waits for a threat to materialise before taking action. This reaction must occur within mere seconds, even before fully understanding the extent of the threat. In technology, there is always a delay before an effective defence is developed for each new offensive technology. As opponents create weapons that are faster, stealthier, or more agile; defences are constantly playing catch-up. This delay in reacting to new threats means that Air Defence systems may sometimes be inadequate against emerging dangers. One example of this is the lack of a credible and dependable defence against hypersonic weapons so far.

The issue of cost disparity between defensive and offensive weapons is a persistent problem. It is often observed that the cost of defending against a weapon far exceeds the cost of the weapon itself. Adversaries can exploit this economic imbalance to induce cost-imposing strategies against cheaper offensive tools. For small air forces, the challenge lies in adopting new Air Defence technology that may become ineffective against an evolving threat even before its operational cycle is complete.

3 CHANGING CHARACTER OF WAR AND ITS EFFECT ON AIR DEFENCE OPERATIONS

The nature of war has evolved, driven by various factors such as technology and geopolitics. This evolution has had a profound impact on Air Defence operations, particularly at the conceptual level. In the past, the battlespace was confined to traditional domains such as land, sea, and air. However, with new technologies, cyber and space have become equally important and have expanded the battlespace. Therefore, Air Defence operations must integrate capabilities across all these domains, ensuring resilience and redundancy. Furthermore, traditional large-scale battles between state actors have given way to conflicts involving non-state actors, insurgents, or proxy forces. To tackle these ever-evolving threats, defensive operations must now account for threats like guerrilla warfare and terrorist attacks. In addition, adversaries have developed long-range effective Anti-Access/Area Denial (A2/AD) capabilities designed to prevent or constrain the deployment of enemy Air Defence forces, such as radars and missile batteries, into a particular region or to limit their freedom of action. Therefore, defensive strategies must consider how to counter these capabilities, ensure force mobility, and guarantee freedom of action when needed. Moreover, the rise of AI, drones, and automated systems means that future conflicts might involve machine-on-machine engagements. To deal with these new threats, Air Defence operations will need robust electronic warfare capabilities, anti-drone systems, and cyber defences. The emergence of cyber operations has also put the Air Defence operations in a state of perpetual engagement, and there's no clear distinction between peace and conflict. In essence, the evolving nature of warfare demands a more holistic, adaptable, and integrated approach to air defence, one that recognises and can swiftly respond to a vast array of threats across multiple domains.

4 THE CONTEMPORARY AERIAL THREATS

The onset of the 21st century brought about rapid technological advancements and diversification in nature and sources of aerial threats. The following paragraphs discuss the most significant challenges that Air Defence will face today and in the future with increased potency.

4.1 Stealth Technology and Its Implications

Stealth technology was once the exclusive domain of a few powerful nations, but today, it has become more widespread among smaller global powers. This technology is primarily used on fighter and bomber aircraft such as the F-22, F-35, and B-2, as well as on cruise missiles like the AGM-158 JASSM (Joint Air-to-Surface Standoff Missile)[2] and the Kh-101 air-launched cruise missiles (ALCM).[3] The main objective of stealth technology is to reduce the detectability of aircraft, which poses a significant challenge to Air Defence forces. To achieve this goal, various design, structural, and material innovations have been introduced. This includes a reduction in radar cross-section area, use of radar-absorbing material, IR signature reduction, reduction in electromagnetic emissions, and use of internal weapon bay, etc.[4] However, there are two prominent challenges to stealth. One is the layered deployment of 'Mobile Observer Units', which nations like Pakistan still maintain, and

[2] "AGM-158 JASSM," *Wikipedia*, November 12, 2023, https://en.wikipedia.org/wiki/AGM-158_JASSM#:~:text=.

[3] "KH-101 / KH-102," *Missile Threat*, July 31, 2021, https://missilethreat.csis.org/missile/kh-101-kh-102.

[4] Michael Parker, *Digital Signal Processing 101: Everything You Need to Know to Get Started*, 2nd ed. (Newnes, 2017).

the second is the use of Passive radars that can pick up any electronic emission from stealth aircraft.

4.2 Intelligent Unmanned Combat Aerial Vehicles

"Competition in AI and unmanned aerial vehicles (UAVs) marks the onset of the '7th Military Revolution,' and the states that integrate these advances first will have a prodigious military advantage."[5] Unmanned Combat Aerial Vehicles (UCAVs) equipped with Artificial Intelligence (AI) provide significant advantages to offensive operations. They can identify enemy radar and anti-aircraft systems and navigate sophisticated air defences. They can engage a wide range of surface targets based on pre-defined rules. They can jam communications, intercept signals, and deploy cyber weapons against enemy networks. They can even coordinate assembly of massive fleets of UCAVs for swarm operations, effectively defeating and puzzling adversary defences. Additionally, they can collaborate with manned aircraft to share the workload. The more intriguing concept is a gradual shift towards an inhabited 'mother ship' controlling several semi-autonomous vehicles in all the major air power roles. In a nutshell, they offer the advantages of persistence and risk reduction, along with real-time processing and decision-making abilities.

4.3 Miniaturised, Micro or Nano Drone

These drones offer new methods for offensive applications and present distinct difficulties due to their small size, agility, and ability for mass deployment. The relatively larger Micro-UAVs can fly at altitudes of up to 125 meters and speeds of 180 km per hour.[6] Very small Micro-UAVs generally resemble flying insects or

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[5] F.G. Hoffman, "Will War's Nature Change in the Seventh Military Revolution?" *Parameters* 47, no. 4 (November 1, 2017): 19-31, https://doi.org/10.55540/0031-1723.3101.

[6] Sidney E. Dean, "Micro-Drones: Miniature Reconnaissance Assets for the Modern Battlefield," *European Security and Defence* (blog), May 24, 2023, https://euro-

birds. A good example of a micro-UAV is the Norwegian Black Hornet, which provides autonomous mission-critical situational awareness to soldiers.[7] They can blend into ground clutter or use terrain features for concealment. They are small and quiet, perfect for intelligence gathering behind enemy lines and monitoring troop movements in real time. Drone swarms can overwhelm, confuse, or distract enemy Air Defences, enabling larger assets to operate with reduced threat. Precision strikes against high-value targets such as command posts, radar installations, or individual personnel could be carried out by miniaturised drones equipped with small explosive charges. Additionally, some miniaturized drones can be equipped with electronic warfare tools for jamming and intercepting crucial information.

4.4 Hypersonic Missiles

Flying and changing directions at speeds exceeding Mach 5, hypersonic weapons offer a significant challenge to air defence. These weapons are likely to be used against targets that carry politico-military importance greater than the weapon cost and are relatively well-defended to cause painful attrition to non-hypersonic strikes. These weapons are perfect for fast, decisive preemptive strikes that aim to cripple the enemy's decision-making capabilities, such as command and control centres. Hypersonic missiles can pose a significant threat to naval vessels, including aircraft carriers. With hypersonic weapons, the credibility of a second strike is enhanced, further bolstering deterrence.

At the same time, some analysts say that "hypersonics present an evolution rather than a revolution of warfare." While they do decrease decision-making time

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sd.com/2023/05/articles/31330/micro-drones-miniature-reconnaissance-assets-for-the-modern-battlefield/.

[7] Sidney E. Dean, “Micro-Drones: Miniature Reconnaissance Assets for the Modern Battlefield,” *European Security and Defence* (blog), May 24, 2023, https://euro-sd.com/2023/05/articles/31330/micro-drones-miniature-reconnaissance-assets-for-the-modern-battlefield/.

and challenge the capacities of current missile Defence systems, all changes are matters of degree, not kind."[8] A report published by the Center for Strategic and International Studies (CSIS) in February 2022 makes a more pragmatic assertion that "Defending against hypersonic missiles is strategically necessary, technologically possible, and fiscally affordable, but it will not be easy."[9]

4.5 Ballistic Missiles & Multiple Independently Targetable Reentry Vehicles (MIRVs)

Ballistic missiles, including ICBMs, can travel at hypersonic speeds, leaving only a short window for Defence systems to detect, track, and engage. During their mid-course phase, ballistic missiles travel beyond the Earth's atmosphere, making interception in space difficult. Engaging a missile in its terminal phase is particularly challenging due to its high velocity and proximity to the intended target. MIRVs are especially challenging because they can saturate a Defence system, making it more difficult to intercept all incoming warheads. According to a report by the Center for Arms Control and Non-Proliferation, a Russian MIRVed missile under development may carry up to 16 warheads, each in a separate re-entry vehicle. Warheads on MIRVed missiles can be released at different speeds and directions. Some MIRVed missiles can hit targets as far as 1,500 kilometres apart.[10] Indian SRBM Agni-P is

[8] Maj Jonathan P. Dial, Rebecca "Fräu" Nortz, Maj Brandon D. Jay, and Maj James B. Johnson, "HYPERsonic Missiles: The Path of Temptation," *Wild Blue Yonder*, July 15, 2022, https://www.airuniversity.af.edu/Wild-Blue-Yonder/Article-Display/Article/3063666/hypersonic-missiles-the-path-of-temptation/.

[9] Peter Felstead, "High-End Threat: The Accelerating Pace of Hypersonic Weapons," *Asian Military Review*, November 29, 2023, https://www.asianmilitaryreview.com/2023/11/high-end-threat-the-accelerating-pace-of-hypersonic-weapons/.

[10] "Multiple Independently-Targetable Reentry Vehicle (MIRV)," an MIRV fact sheet by *The Center for Arms Control and Non-Proliferation*, https://armscontrolcenter.org/wp-content/uploads/2017/08/MIRV-Factsheet.pdf.

also believed to be capable of delivering MIRVs.[11] Pakistan has also developed a medium-range ballistic missile, Ababeel, which carries MIRVs.

4.6 Loitering Munitions

"Loitering munitions are one-time-use weapons designed to find a target and crash into it, giving it its kamikaze nickname."[12] It is possible to retrieve certain loitering munitions if they are not utilised during an attack. Unlike traditional missiles, loitering munitions can remain airborne for several hours while scanning for targets instead of following a pre-planned path. Operators can make real-time decisions about target engagement, but advanced loitering munitions such as the Israeli Harop can also engage targets autonomously using predefined parameters. Some common homing devices carried by loitering munitions include GPS, IR sensors, electro-optical sensors, Automatic Target Recognition (ATR) algorithms, laser designators, radiation seekers, radio frequency seekers, and acoustic sensors. Depending upon the warhead and nature of the explosive, they can target troops, infrastructure, armored vehicles, artillery positions, aircraft in the open, supply convoys, and Air Defence systems such as radar installations, missile launchers, and command and control centres. "Israel is the leading developer and producer of loitering munitions, with 40 percent of the systems identified, with the United States and China following, both accounting for 12.5 percent."[13]

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[11] Harsh V. Pant and Kartik Bommakanti, "India's Nuclear Arsenal Recently Went up the Sophistication Curve," *Observer Research Foundation*, January 11, 2022, http://20.244.136.131/research/indias-nuclear-arsenal-recently-went-up-the-sophistication-curve.

[12] Brennan Devaraux, "Loitering Munitions in Ukraine and beyond - War on the Rocks," *War on the Rocks*, April 22, 2022, https://warontherocks.com/2022/04/loitering-munitions-in-ukraine-and-beyond/.

[13] Norine MacDonald and George Howell, "Killing Me Softly: Competition in Artificial Intelligence and Unmanned Aerial Vehicles," *Prism* 8, no. 3 (January 10, 2020): 103–26, https://ndupress.ndu.edu/Media/News/News-Article-View/Article/2053617/killing-me-softly-competition-in-artificial-intelligence-and-unmanned-aerial-ve/.

4.7 Cyber Warfare

Military operations are now increasingly integrating cyber strategies with traditional kinetic operations. Before any kinetic engagement, cyber espionage and reconnaissance activities are conducted to gather intelligence on adversaries, find vulnerabilities, and prepare for the cyber battlefield. Emphasis is on developing offensive cyber capabilities that can disable enemy networks, degrade their command-and-control systems, or disrupt their infrastructure. Similarly, the security of satellites, both from kinetic and cyber threats, is paramount. Cyber attackers can also attack indirectly by targeting the support systems and rendering the main systems dysfunctional. For example, missile systems might be secure, but the logistical, communication, or power infrastructures supporting them might be vulnerable. With the support of automation and AI tools, cyber can scan for vulnerabilities and carry out attacks more efficiently than human operators. Reportedly, in the recent Russian-Ukraine conflict, "cyberattacks targeted the power grids, financial markets, and government computer systems, all with potential consequences that are as devastating as any bullets or bombs."[14]

4.8 Situation Attacks and Swarm Tactics

Drones are developed and “utilised by over 100 countries and non-state actors.”[15] These can be employed in a saturation attack, i.e. large-force drone employment and swarm tactics against a specific target or group of targets. Even the most sophisticated Air Defence systems have a target limit to track and engage simultaneously, and a saturation attack seeks to exceed this limit. In a decoy role, drones can lead a strike mission, generate a radar signature of any fighter aircraft,

[14] Cecil Su, “Understanding the Rising Cyber Warfare Trends in the World - BDO,” April 19, 2022, https://www.bdo.com.sg/en-gb/blogs/bdo-cyberdigest/april-2022/understanding-the-rising-cyber-warfare-trends-in-the-world.

[15] “Combat Drones: We Are in a New Era of Warfare - Here’s Why,” *BBC News*, February 4, 2022, https://www.bbc.com/news/world-60047328.

and thus persuade the adversary to launch its costly missiles on decoys. Also, "Swarms flying lead can detect adversarial electronic signatures and thus Air Defence locations. This enables the aerial vehicles flying behind the swarms to know where not to fly and where and when to turn off their radar."[16] Therefore, saturation attacks can potentially overwhelm even the most advanced Air Defence systems.

5 CHALLENGE OF SPACE WEAPONS TO AD SYSTEMS

Currently, there are no known weapon systems deployed in space; however, many transit space to reach their intended targets. Space-based systems support military functions such as surveillance, reconnaissance, communication, and navigation. Broadly speaking, the following are a few challenges that Air Defence forces would face from weapons employed from or through space:

a) Weapons launched from or through space can achieve hypersonic speeds, making them difficult to intercept.

b) Space weapons can strike from any location and from any direction, rendering the conventional 'arc of threat' concept obsolete.

c) Traditional surveillance systems cannot track space-based threats until they re-enter the Earth's atmosphere, giving limited time for reaction.

d) As and when weapons are deployed in space orbit, it will complicate the Defence readiness.

[16] Ryan Bridley and Scott Pastor, "Military Drone Swarms and the Options to Combat Them," *Small Wars Journal*, August 19, 2022, https://smallwarsjournal.com/jrnl/art/military-drone-swarms-and-options-combat-them#:~:text=There%20are%20several%20options%20that,machine%20guns%20air%20defense%20systems.

6 WHY IS THE CENTRALITY OF COMMAND CRITICAL FOR AIR DEFENCE MISSIONS?

The proliferation of long-range Air Defence weapons across different Services has led to an alarming increase in challenges related to command, control, and coordination. It is imperative to understand that Air Defence is a centralised mission that includes both aircraft and ground-based Air Defence systems (GBADS). GBADS is a critical component of Counter Air Operations. Any attempt to segregate offence and defence can severely undermine the unity of command and the efficiency of the counter-air campaign, which could lead to disastrous consequences. Therefore, it is vital to have one unified Air Defence plan for the entire country, overseen by a single commander responsible for all air operations. In 2016, the Russian Aerospace Defence Forces merged with the Russian Air Force to form the unified Russian Aerospace Forces. This merger has resulted in the elimination of redundant systems, streamlined command and control structures, and enhanced operational efficiency.

7 CHALLENGES OF LONG-RANGE WEAPONS WITH OTHER SERVICES

Given the increasingly longer ranges of SAMs and BVR missiles, the establishment of Joint Engagement Zones has become necessary for the concurrent employment of both fighters and GBADS to maximise Air Defence effectiveness. Under such an environment, there are genuine fratricide concerns over the possession of long-range GBADS by other Services. The coordination issues with diverse agencies, especially in the Electronic Warfare (EW) environment, and with destroyed or degraded communication means, would increase the possibility of accidentally engaging friendly aircraft or simultaneously engaging a threat with more than one weapon. Intercepting the target with fighter aircraft and GBADS is a single activity, and it is inefficient for one-half of this activity to be handled by one service and a different service managing the other. For obvious reasons of safety as well as operational freedom, both shooters should be manned by operators from one service (e.g., the Air Force) that can make coordinated decisions under time compression.

8 WAY FORWARD: TECHNOLOGICAL INNOVATIONS SUPPORTING AIR DEFENCE SYSTEMS

Technological advancements have led to the creation of capabilities and solutions that can enhance Air Defence potency and overcome the aforementioned challenges. The preceding paragraphs elaborate on some of these technologies.

8.1 Detection against Stealth

While stealth technology offers a formidable challenge to conventional Air Defence systems, it's not invincible. A few radar technologies can counter stealth, such as Quantum radar. This is a novel radar concept that capitalises on the principles of quantum mechanics. Quantum radar could detect “the faintest of signals, even if it consists of a single photon.”[17] Also, multi-static radar systems, where receivers are situated away from the transmitter, can detect stealth aircraft by capturing scattered radar reflections from various angles, thereby increasing the chances of detection. It is known that Stealth designs are not very efficient at

[17] Andrey Feldman, “Harnessing Entanglement and Curved Spacetime to Make Quantum Radar a Reality,” *Advanced Science News*, September 27, 2023, https://www.advancedsiciencenews.com/harnessing-entanglement-and-curved-spacetime-to-make-quantum-radar-a-reality/.

deflecting lower frequencies. Therefore, VHF and UHF radars have the potential to detect stealth aircraft but with lower accuracy. Then, there are Passive systems that detect electromagnetic emissions from stealth aircraft, such as radio or data link transmissions, to track them without relying on returned radar reflections.

8.2 Artificial Intelligence and Predictive Defence

The induction of artificial intelligence (AI) in Air Defence can help reduce the challenge for human operators by fast processing and analyzing vast amounts of data presented by radars, satellites, electronic intelligence (ELINT), and signals intelligence (SIGINT). By analysing this data, AI can predict enemy options, suggest threat vectors, and optimise response mechanisms. It can even automate certain responses, thus aiding decision-makers.

8.3 Directed Energy Weapons (DEWs)

Directed Energy Weapons (DEWs), such as lasers and high-powered microwaves, are the future of intercepting and neutralizing threats. DEWs are the most cost-effective solution for tackling aerial threats and drone swarms. Their unmatched accuracy and reduced logistical footprint make them an ideal choice for layered Defence. The US Army has reportedly acquired the Leonidas system, a high-powered microwave (HPM) weapon against drone swarms.[18]

8.4 Close-In-Weapon System (CIWS)

The Close-In Weapon System (CIWS) is most effective against aircraft, drones, anti-ship missiles (ASMs), and surface-to-surface missiles (SSMs) when integrated into a multi-layered Defence strategy. The increasing use of long-range missiles by fighter aircraft has highlighted the importance of CIWS as a terminal interceptor. To maintain

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[18] Jen Judson, "Army Gets First High-Power Microwave Prototype to Counter Drone Swarms," *C4ISRNET*, November 1, 2023, https://www.c4isrnet.com/battlefield-tech/2023/11/01/army-gets-first-high-power-microwave-prototype-to-counter-drone-swarms/.

its effectiveness, it is essential to integrate CIWS with advanced sensors, electronic warfare systems, and other defensive measures.

8.5 Use of Rail Gun Against Hypersonic Missiles

Japan successfully test-fired an electromagnetic railgun from a ship on 17 October 2023. In its 2018 test, it achieved a speed of Mach 6.5.[19] The railgun's endurance is over 120 rounds, and it can fire a projectile weighing 320 grams. No further details are available on its range or guidance, but reportedly, it can be used to attack ships and ground targets and intercept hypersonic weapons.

9 UNCONVENTIONAL SOLUTIONS FOR SMALL AIR FORCES

Small Air Forces confronting larger adversaries must brainstorm unconventional solutions to disrupt or destroy multiple aircraft a/c through a single weapon. One such example is the use of a Non-Nuclear Electromagnetic Pulse Weapon (NNEMP) that generates a powerful electromagnetic pulse capable of disrupting, damaging, or destroying electronic systems and avionics of an entire package. Currently, NNEMP weapons are used against ground targets, but they could also be used in an air-to-air role. A preferred weapon against UAV operations could be a pulsed-power, airborne high-power microwave (HPM) system. This weapon can disrupt or destroy electrical components in and around the target area by generating variable magnitude HPM fields. One must also look at developing means to jam terminal guidance of guided weapons, just like the use of Russian GPS jammers during the Iraq war. Besides

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[19] Kosuke Takahashi, "Japan Performs First Ever Railgun Test From Ship at Sea," *Naval News*, October 19, 2023, https://www.navalnews.com/naval-news/2023/10/japan-performs-first-ever-railgun-test-from-ship-at-sea/#:~:text=The%20test%20was%20conducted%20with,%2DDefense%20Force%20(JMSDF).&text=ATLA%20released%20video%20footage%20on,the%20ocean%20from%20a%20vessel.

unconventional systems and weapons, other areas of interest in the unconventional domain could be asymmetric strategies, such as subversive or destructive activities against the adversary during war, through Special Forces or non-state actors inside enemy territory, for which a necessary foothold may have to be established during peacetime.

Gen. Chang Guan-Chung, Taiwan's Vice Minister of Defence for armaments, in an address to the US Defence Industry Conference in 2020, spoke about the development of innovative and asymmetric capabilities said, "We are developing systems that are small, numerous, smart, stealthy, fast, mobile, low-cost, survivable, effective, easy to develop, maintain and preserve, and difficult to detect and counter."[20]

10UNORTHODOX IDEAS FOR AIR DEFENCE

There are a few unorthodox Air Defence concepts that have the potential to be considered for further evaluation:

10.1 Aerial Mines or Mini Interceptor Drones

The idea of deploying mines in the air to neutralize enemy aircraft or deny them access to a particular area is worth exploring. Electro-mechanical solutions can be studied to suspend the mines in the air until they explode on impact or in proximity to an aerial target. A potential modification of this concept is using mini-interceptor drones flying in swarms. As drones are controllable, they can be assembled at the 3-D coordinates provided by detection radars to create a mined airspace. With the integration of AI systems, these drones can autonomously detect

[20] James Timbie and James O. Ellis, "A Large Number of Small Things: A Porcupine Strategy for Taiwan," *Texas National Security Review* 5, no. 1 (2021): 84–93, https://doi.org/10.15781/gkaw-3709.

and intercept hostile drones/aircraft in the future. A Defence analyst, Paul Scharre, said, "Swarms of $10,000 loitering munitions might 'mine' the airspace, lying in wait to collide with $100 million aircraft.[21] China has demonstrated such capability by using a set of 48 drones in loitering munition's role. These drones carried warheads with high explosives.[22]

10.2 A Cost-Effective Anti-Missile System

The Royal Air Force's wartime strategy of deploying gas-filled balloons around London during World War II helped lift steel strings/nets to 15,000 feet, presented a physical barrier against bomber planes of that era. Similarly, a solution is proposed to protect static vital points against cruise, ballistic, and hypersonic missiles using this approach. The proposed solution involves strategically positioning large steel nets suspended by gas-filled balloons at various altitudes near the vital point. The steel nets will act as a wall against incoming missiles and protect the vital points. By placing these steel nets with the help of balloons, missile trajectories can be disrupted. The placement of these steel nets hung with the help of balloons can be conceived as per missile trajectory. The missile will either explode on impact or go off course. In planning, a replacement set of balloons will have to be catered for. Since the airspace is vast, it could be challenging to correctly place the nets in the air. Additionally, adverse weather conditions could impact the performance of the balloons. Despite these challenges, the concept appears workable and viable, particularly for air forces that cannot afford expensive anti-missile systems.

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[21] Col. Maximillian K. Bremer and Kelly A. Grieco, "Assumption Testing: Airpower Is Inherently Offensive," *Stimson Center*, January 25, 2023, https://www.stimson.org/2023/assumption-testing-is-airpower-inherently-offensive/.

[22] Col. Maximillian K. Bremer and Kelly A. Grieco, "Assumption Testing: Airpower Is Inherently Offensive," *Stimson Center*, January 25, 2023, https://www.stimson.org/2023/assumption-testing-is-airpower-inherently-offensive/.

10.3 Disposable Jammers Across the Fence

While the idea is primarily offensive in nature, offence and defence complement each other. This idea aims to drop disposable multi-function, multi-band jammer boxes in desired enemy operational areas, bases, etc., preferably in plain areas or on heights to enhance effective ranges. The dropping could be via airborne platforms using small parachutes or using artillery fire, which today has ranges over 120 km. The jammers would be battery-operated with days of backup. The technical composition of the jammer box (ELINT/COMINT/ESM/Propaganda) is open to ideas. This capability will supplement, if not save, stand-off jammer sorties, extend EW ranges, create chaos, and disrupt military operations. The electronic signals may provide a ‘Fix,’ but the enemy will not find it easy to locate and neutralize all.

11RECOMMENDATIONS FOR PAKISTAN AIR DEFENCE

In light of emerging challenges driven by technology and the changing nature of war, the following are a few recommendations for the PAF Air Defence.

11.1 Air Defence Plan of Pakistan

One cohesive and well-integrated National AD Plan should be implemented, which comprises the induction, deployment, and employment of all AD assets. This should be centrally orchestrated under the AD Commander of Pakistan in coordination with all stakeholders.

11.2 Possession of HIMADS by PAF

Interception by interceptor aircraft and GBADS is a single activity, and it is inefficient for one-half of this activity to be handled by one service while a different service manages the other. Therefore, it is recommended that ownership of all

HIMADS be given to PAF. If other Services do not agree upon possession, then at least its manning by PAF personnel should be agreed upon.

11.3 Efficacy of AWACS in War

Given the increased ranges of BVR and Anti-AWACS specialist missiles, there should be a moderate expectation from AWACS in a high-intensity conflict, and the same should be catered to in planning. However, AWACS will retain its usefulness in heightened tension periods, especially against surgical strikes.

11.4 Review the Employment Concept for GBADS

The extra-ordinary standoff ranges and hypersonic speeds of air-to-surface weapons merit an overhaul of the decade-old employment concepts of GBADS. It is recommended that CIWS systems be given some preference as point Defence weapons over SHORADS. SHORADS should be used as an asymmetric warfare tool, deployed randomly at different forward locations to present surprise. The LOMADS and HIMADS can also be deployed in a manner that provides area Defence to critical VPs while concurrently giving protection to each other. The usefulness of 20-40 KM missile batteries deployed within the heart of the VPs has become questionable in the face of emerging threats.

11.5 Cost-Effective Anti-UAV Solutions

The present and future wars will witness extensive UAV applications, small or big, in mass or otherwise. The solution lies not in AAMs or GBADS but in disruptive technologies such as EW and HPM. The technologies should be harnessed for their multiple utilities.

11.6 Master the EMP Technology in an Air-to-Air Role

Everything that operates or passes through the air or space has its core in electronics. If electronics is destroyed or disrupted, the mission will not succeed. This is why mastering EMP technology has so many military dividends, both in offence and defence. While the technology has already been tested against surface targets, its air-to-air application is still a challenge that needs to be conquered.

12CONCLUSION

The aerial threats have drastically evolved from the stealth technologies to the rise of unmanned aerial vehicles and the use of cyber warfare. There is an increased argument that the traditional paradigm of waiting for threats to manifest and then countering them is becoming increasingly untenable. Instead, proactive measures, including preemptive cyber operations to disrupt adversaries' launch capabilities, intelligence-driven operations to neutralise emerging threats, and diplomatic efforts to regulate the proliferation of advanced weapon technologies, are imperative.

PAF Air Defence has always stood tall in testing times. Its credibility is one of many other factors that contributed to attaining nuclear capability. There are some capability gaps against present and futuristic threats. Space is one area where Pakistan has lagged. So, the PAF must focus selectively on measures to deny the enemy offensive use of its space capabilities. While ANTI-SAT capability is futuristic, PAF can consider an indirect strategy to attack space C2 structures on the ground or target space links through disruptive technologies. Another prominent area concerns the quantitative inadequacy of missile batteries to defend the declared number of VPs against cruise and ballistic missiles. The recent induction of HQ-9 HIMADS is certainly a big boost, but the number of LOMADS and SHORADS will only find employment in critical sectors. Joint Air Defence Doctrine, the efficacy of Air Defence Committee decisions, coordinated planning for deployments and employment of all Air Defence assets, are a few other areas vital for strengthening the national Air

Defence. NASTP is an excellent project carrying out R&D in many emerging technologies that are most relevant for PAF Air Defence. Therefore, PAF should conceive, plan, and raise Air Staff Requirements to induct these technologies. Being a resource-constrained country, PAF Air Defence must also focus on unorthodox ideas and innovative solutions to negotiate challenges, some of which are given in the study.

The future defensive campaign will have to be fought more offensively than ever. The economic constraints, however, demand that we rationalise and prioritise our requirements and counter the adversary's superiority in numbers through innovative concepts, synergy, and, more importantly, winning strategies.

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