AIR POWER

Journal of Air Power and Space Studies

Vol. 17 No. 2 • Summer 2022
(April-June)

Contributors

Air Marshal Daljit Singh • Air Marshal Diptendu Choudhury
• Dr Joshy M Paul • Group Captain TH Anand Rao
• Mr Abhishek Saxena • Air Marshal Sukhchain Singh

CENTRE FOR AIR POWER STUDIES, NEW DELHI

DEVELOPMENTS IN AIR DEFENCE SURVEILLANCE SYSTEMS

DALJIT SINGH

We must be prepared to control the air above the earth's surface or to be buried beneath it.

General Charles Horner, Desert Storm, CFACC[1]

INTRODUCTION

Recent air strikes around the world show the effectiveness of offensive aerial weapons in inflicting prohibitive damage, despite deployment of proven air defence systems. In March 2021, Houthi militants launched Unmanned Aerial Vehicles (UAVs) and cruise missiles, and successfully struck the oil facilities of Saudi Arabia's state-owned oil company, Saudi Aramco. In January 2022, the Houthis launched ballistic missiles, UAVs, and cruise missiles to strike targets in Saudi Arabia, during which most of the ballistic missiles were well intercepted, but, the UAVs and cruise missiles evaded the deployed air defences. Air surveillance sensors that were conceived to detect intruding fast aircraft and missiles are now faced with low speed low Radar Cross Section (RCS), low flying objects that fly in swarms.

Air Marshal **Daljit Singh** was commissioned in the fighter stream of the Indian Air Force, in June 1976. During his illustrious career of 38 years, he commanded a Mirage 2000 squadron and the Air Force Station, Gwalior. At Air Headquarters, he has held key staff appointments of Director, EW Operations, Assistant Chief of Air Staff (Air Defence) and Director General (Air Operations). He retired in October 2014 as Air Officer Commanding-in-Chief SWAC.

1. Doctrine Update for JP 3-01, Countering Air and Missile Threats March 23, 2012, Air University, US Air Force (USAF).

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Israel has been experiencing massive rocket attacks on its population centres, which have resulted in the development and employment of effective but costly counter-measures. Stealth technology is now applied to almost all airborne objects, including attack aircraft, cruise missiles, UAVs, and munitions, that substantially degrade the detection capability of radars. Present generation fighters can launch Precision-Guided Munitions (PGMs) from much further standoff ranges, during which the mother aircraft may remain outside the 'kill zone' of the Air Defence (AD) weapons. The attack profiles of attacking forces have become more flexible and exploit the gaps in the AD set-up. The attacking forces have been using many types of active and passive decoys that saturate and stimulate the AD network. The AD infrastructure is now required to detect and intercept such low RCS projectiles before they cause any harm to the target being defended. Combat support elements like offensive jammers and anti-radiation missiles which were effectively employed to neutralise the Iraqi AD during the first Gulf War, have acquired more capability and lethality to counter air defences. Hypersonic weapons are being developed at a fast pace by many major powers, against which the present air surveillance systems would be mainly ineffective, to provide engagement solutions. Under such operational scenarios, each country needs to envision the future operational environment and review its AD structure.

The air surveillance systems have also been improving with technological developments, and integrated air defence systems provide much better resilience against counter-measures. Mission specific radars have been developed to detect small UAVs and low RCS cruise missiles. Multi-functional radars are now capable of undertaking mission-tailored surveillance and target tracking capabilities simultaneously. The technological advances have facilitated software defined radars to optimise air surveillance against different types of threat. Digitisation and computer technology have facilitated exploitation of diverse electromagnetic spectra for multi-spectral and passive air surveillance, which do not generate any warning to the intruders.

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China has fielded the People's Liberation Army Rocket Force (PLARF) with a massive arsenal of nuclear and conventional missiles, stealth fighters, and a large variety of armed and unarmed UAVs.[2] Pakistan has also been modernising its air force by inducting fourth generation fighters and advanced weapons. It is, therefore, important to analyse the developments in air surveillance assets and consider the optimum option for India to provide effective air surveillance against the potential capabilities of adversaries.

DEVELOPMENT OF SENSORS

Radars

While research on radar development took place in many countries like the US, UK, Germany, Netherlands, and Soviet Union, well before World War II, the patent for the concept of the radar was granted as early as April 30, 1904, to a German inventor, Christian Hulsmeyer.[3] The first employment of a military radar was on board the naval ships to detect other ships during poor visibility conditions. In 1936, such systems were installed on board major naval units of the United States.[4] Major and rapid developments in radar technology took place during World War II. The Royal Air Force

2. US Department of Defence, "Military and Security Developments Involving, the People's Republic of China, 2021".
3. Alfred Price, *Instruments of Darkness: The History of Electronic Warfare* (New York: Charles Scribner's Sons, 1977), pp. 55-56.
4. Abdul Karim Baram, *Technology in Warfare: Electronic Dimension* (The Emirates Centre for Strategic Studies and Research), p. 79.

(RAF) deployed the 'Chain Home' series of radars in 1937, operating in the HF band and the Germans deployed the 'Freya' radar operating at a radio frequency range of 120-130 Mhz, on a fixed frequency. This radar was easily jammed by the British jammer 'Mandrel'. The Germans then employed a new tracking radar, the 'Wurzburg', operating at 565 Mhz, which was beyond the capability of the British jammers, and it also provided target height information.[5] This competition between radars and jammers led to rapid developments in radar technology. Multi-frequency radars were developed, followed by radars with doppler processing to eliminate clutter from 'chaff'. During the same period, the Germans had developed radars capable of providing three-dimensional information on the target, viz: height, speed, and direction. The Germans had also operationalised an airborne intercept radar named the Liechtenstein BC, installed on board night fighters. In fact, the Germans established the first Integrated Air Defence System (IADS) by integrating one Freya early warning radar, two Wurzburg tracking radars, searchlights, an operational control room and a communication post. The anti-aircraft artillery, and airborne night fighters provided multi-layered weapon systems integrated with IADS to destroy incoming bombers. The RAF had also established a similar IADS which functioned quite efficiently with 'sector fighter controllers' guiding the fighter interceptors.

Post World War II, the Cold War period saw rapid development in radar technology as the opposing countries developed radar guided surface-to-air missiles that were required to track the target with sharper electronic beams and provide more accurate target data. Higher frequency bands of the 'S band' (2000-4000 MHz) provided better range and azimuth resolutions. Technically, radars operating at lower frequencies can achieve longer range detection capabilities as they can generate higher power and can have larger antennae for generating better gain output. On the other hand, the radars operating at higher frequency ranges provide better range and angular resolutions due to the narrower beam antenna.[6]

5. Ibid., p. 111.
6. Marill Skolnik, *Radar Handbook* (McGrew Hill, 2008), pp. 1-14.

The Cold War period also saw reconnaissance spy planes like the U-2 flying at very high altitudes of one hundred thousand feet. This necessitated long range surveillance radars with better height accuracy. The advent of nuclear armed ballistic missiles gave another push for more powerful long-range radars. The first missile defence early warning radars, the AN/FPS-17s, were deployed in Greenland and East Turkey.[7] During this period, the USA and the erstwhile Soviet Union were also in the race for space exploration. This required monitoring of the space satellites of the adversaries. The Lincoln Laboratory of the USA developed and produced the ALCOR and ALTAIR series of radars for space surveillance. The manufacturer demonstrated the first high-resolution range-doppler imaging of satellites. The ALTAIR now has a space-surveillance mission as well as the ballistic missile defence role.[8] The performance of all systems employing electromagnetic waves (emw) is governed by the laws of physics. Therefore, the attacking forces have been resorting to low level attack profiles to remain below the radar line of sight and avoid detection. Low level tracking radars were, therefore, developed to improve target detection capabilities through dense surface clutter and multi-path reflections. The Pakistan Air Force (PAF) had deployed such a network of radars called the SILLACS (Siemens Integrated Low Level Aircraft Systems). These were low power L band (1000-2000 Mhz) 2 D radars that were networked to detect only low-level threats up to 3 km altitude. To provide effective early warning against low flying targets, development of Airborne Early Warning (AEW) radars was initiated and with technological improvements, these radars have matured into very capable airborne surveillance, command and control and communication nodes.

TECHNOLOGY DEVELOPMENTS

Radars deployed during World War II were simple: they lacked technical capability to pick up weak returns and clutter rejection capabilities. Those

7. William P. Delaney, "Radar Development at Lincoln Laboratory: An Overview of the First Fifty Years", *Lincoln Laboratory Journal*, vol. 12, no. 2, 2000, p. 152. https://www.ll.mit.edu/publications/journal/pdf/vol12_no2/12_2radardevelopment.pdf
8. Ibid., p. 154.

Earlier, radars had a mechanically rotating antenna which rotated at a fixed rate and could scan only the fixed space ahead. Due to the inherent antenna design deficiency, the radar beams were not sharp and there was significant spillover of transmission energy into the sidelobes and backlobes.

early radar systems were tube-based and mechanically steered, and involved Radio Frequency (RF) transmitters, RF receivers, analogue signal processing, and a video display.[9] With technological advances in solid state technology, digital signal processing and computing capabilities, the processing power of radars has ensured more sensitive receivers, better Analogue to Digital (A-D) converters and Digital to Analogue (D-A) converters, and fast processors.[10] This has improved the radar detection capability in terms of range, resolution, target discrimination and clutter rejection. Another major technological breakthrough has been the development of the Active Electronically Scanned Array (AESA) that has pushed the capability of radars to much higher levels. Earlier, radars had a mechanically rotating antenna which rotated at a fixed rate and could scan only the fixed space ahead. Due to the inherent antenna design deficiency, the radar beams were not sharp and there was significant spillover of transmission energy into the sidelobes and backlobes. It also made the radars more vulnerable to jamming through the sidelobes. The AESA comprises a phased array system, which consists of an array of antennae which form a beam of radio waves that can be aimed in different directions without physically moving the antennae themselves. The AESA uses many transmitter/receiver modules which are interfaced with the antennae elements and can produce multiple, simultaneous radar beams at different frequencies. AESA radars can control and shape scan patterns and undertake high priority scan revisits for tracking priority targets. The Active Phased Array Radars (APARs) are more resistant to jamming,

9. https://www.militaryaerospace.com/communications/article/16706819/radar-technology-looks-to-the-future
10. Ibid.

have low probability of interception and better Size, Weight, And Power (SWAP) specifications. Multiple Transit/Receive (T/R) modules ensure graceful degradation in performance as even 10 per cent unserviceability of T/R modules does not significantly degrade the radar's performance. New semiconductor materials like Gallium Nitride (GaN) have improved system efficiency and reduced power and weight requirements. The main challenge facing the GaN module had been heat dissipation in an enclosed area. This challenge has been resolved successfully.

ANTI-STEALTH RADARS

Simply explained, a radar sends out em waves that get reflected by a flying object and the radar receives these reflections back to detect the flying object. The reflected wave's energy is dependent on the RCS of the object. The RCS is a measure of a target's ability to reflect radar signals in the direction of the radar receiver. Stealth technology, or more correctly, low observable technology, includes various methods to hide or make assets less detectable (ideally less visible) by a radar, infrared or other sensors. This technology provides the user a significant advantage over the adversary by delaying the detection of a hostile flying object, and enables the user to conduct surprise attacks without being detected.[11] During the 1980s, the US Air Force (USAF) chose stealth technology over standoff jammers, which resulted in the first stealth fighter, the F 117 Nighthawk, being developed during that period. This was followed in the Nineties by the venerable B-2A 'Spirit Bomber', and later, the F-22 A, and now, the F-35 variants. The F-117 and the B-2A were effective in evading detection by radars and successfully carried out their missions during the first Gulf War, without any loss. Russia and China have also developed their own stealth fighters like the T-50 PAKFA and J-20, FC-31 respectively. However, stealth technology has some limitations as the stealth design is effective against limited frequency ranges, mainly from the X to the Ku band. Also, the stealth design is mainly

11. Cadirci Sadar, *RF Stealth (or low observable) and Counter-RF Stealth Technologies: Implications of Counter-RF Stealth Solutions for Turkish Air Force* (Monterey, California: Naval Postgraduate School, 2009), p. 93.

The present generation stealth fighters have 'compromised stealth designs' to enhance manoeuvring and weapons carriage capabilities. Russia and China have been developing anti-stealth radars, especially operating in multiple bands to facilitate detection and improve tracking.

effective in frontal quarters and not at other aspects. The present generation stealth fighters have 'compromised stealth designs' to enhance manoeuvring and weapons carriage capabilities. Russia and China have been developing anti-stealth radars, especially operating in multiple bands to facilitate detection and improve tracking. These Very High Frequency/Ultra High Frequency (VHF/UHF) bands radars are operationally deployed by the Russians. The known Russian counter-stealth radar effort is the digital 55Zh6M Nebo M radar system. This design is a genuine three-dimensional AESA or active array radar system, with three individual networked radars on three separate high mobility BAZ-6909 8×8 vehicles, and a fourth vehicle which performs data fusion from the three radars, and target tracking. One radar operates in the VHF band, one in the L band, and one in the S or C band. The VHF band RLM-M radar is the largest mobile 3D VHF band radar ever built. The design could accommodate configurations with different mixes of radars such as replacing the C or S band RLM-S component with an L band RLM-D or VHF band RLM-M. The use of networked data fusion permits this system to cue the RLM-S and RLM-D components to stealth targets detected initially by the RLM-M component.[12] Another Russian example is the Rezonans-NE stealth air target early warning radar with coverage range of 1,100 km.[13] Such radars are capable of tracking other low RCS targets like cruise missiles and terminal guided munitions. Most of these radars are highly mobile and easily redeployable. While all airborne platforms including fighters, UAVs, cruise missiles and munitions would continue to have stealth considerations, anti-stealth radars would be able

12. Carlo Kopp, "Advancing Counter Stealth Technology", *Defence Today*, vol. 9, no. 4, 2012.
13. ROSOBORONEXPORT Brochure.

to remove their cloak of invisibility. High costs and limitations of stealth technology are considered as the main reasons for scaling down the production of the F-22A Raptors. The advanced technology of digitisation and microprocessors has enabled even the older V/UHF band radars to be upgraded to anti-stealth radars.

AIRBORNE EARLY WARNING RADARS

Ground-based radars are limited to line-of-sight detection ranges due to the curvature of the Earth. This poses a significant limitation in early detection of the incoming threat. Most of the small UAVs and cruise missiles with low RCS follow a low level profile and delay detection by radars. Airborne Early Warning and Control System (AWACS) aircraft carrying airborne surveillance radars have been employed since the early Fifties. The USAF and US Navy had employed the EC 121 Warning Star aircraft which was replaced by the more formidable E-3A Sentry AWACS. The E-3A was employed by many North Atlantic Treaty Organisation (NATO) countries, Japan, and Saudi Arabia. These platforms provide excellent air surveillance up to ranges of 450 km and can look deep into the enemy territory. As the E-3A aircraft structure is the Boeing 707 which is facing obsolescence issues, new AWACS based on the Boeing 737/767 have been inducted by the Royal Australian Air Force (RAAF), Japan, South Korea, and Turkey. The Swedish Embraer 145 Erieye Airborne Early Warning and Control (AEW&C) aircraft based on the Embraer 145 platform and Ericsson ERIEYE active phased-array pulse-doppler radar, was supplied to the Brazilian Air Force in the year 2002 and many other countries followed suit. The improved version, the Global Eye AEW&C system, based on the Bombardier Global 6000 ultra-long range aircraft and a new airborne Swing Role Surveillance System (SRSS) capable of maritime, air and land surveillance, is operational and has been procured by the United Arab Emirates (UAE). AWACS are force multipliers with air surveillance, signals intelligence, multi-spectral surveillance and command and control capabilities. They would continue to be essential assets for all air forces, especially in a net-centric environment.

Radars with plug and play capability and easy transportation are considered essential for deployment at short notice as their deployment would be threat-based.

COUNTER UAV SENSORS

UAVs of all shapes, sizes and configurations have been extensively employed by both state and non-state actors, to attack and destroy vital installations and military targets. During the 44-day war between Azerbaijan and Armenia in the year 2020, Azerbaijan successfully destroyed more than 80 Surface-to- Air Missile (SAM) systems, armoured tanks, trucks, and artillery systems by employing Turkish armed drones and the Israeli loitering munition. The world has taken note of this asymmetric capability with economic advantage and all nations are reviewing their AD capabilities to effectively counter this type of threat. Thanks to the technological developments, lightweight, highly mobile, and advanced radars have been developed to detect nano UAVs with RCS as low as 0.01 m^2. As these UAVs operate at low speeds and fly at low altitude, software defined AESA radars with exceptional sensitivity and sub-clutter visibility have been developed by many companies. These multi-mission radars can be mounted on any vehicle for mobility and can be man-packed for deployment at difficult terrain. However, multi-spectral sensors like Infra-Red/Electro-Optical (IR/EO) and Communication Intelligence (COMINT) sensors are considered essential to improve the overall detection capability of the system. Interoperability with other sensors, interconnectivity on data links and integration with counter-measures are the essential criteria for such radars. Such systems have been deployed at airports and during major events of national importance. Radars with plug and play capability and easy transportation are considered essential for deployment at short notice as their deployment would be threat-based.

OVER THE HORIZON RADARS

Over The Horizon (OTH) radars utilise the refractive properties of the ionosphere to refract the radiated High Frequency (HF) waves from the

The Russian interest in OTH radars has been revived as hypersonic missiles are being developed by the USA.

ionosphere towards the Earth. When these waves hit a flying object or maritime target, some energy gets reflected to the radar receiver, and computer processing generates the target information, within the radar footprint at very long ranges up to 4,000 km. These radars operate within the frequency range of 05-30 Mhz at which the ionospheric refractivity is considered suitable for effective detection of targets. Initial research on this is known to have taken place in the 1950s. During the Cold War period, the USA had deployed three AN/FPS 118 OTH radars in the Alaska area to detect bombers and cruise missiles.[14] After the Cold War period, some of these radars were employed for narcotics surveillance and other radars were kept on 'warm standby'. Russia has been conducting research on OTH radars since 1949 and these were deployed during the 1970s to monitor missile launches in the Pacific Ocean region. The Russian interest in OTH radars has been revived as hypersonic missiles are being developed by the USA. When hypersonic projectiles and ballistic missiles fly at high altitudes, an ionisation signature gets formed around them in the form of the compression wave in front and an ionisation wake behind. The OTH radars can easily detect these perturbations in the atmosphere to detect the objects. Russia has been able to monitor the Arctic region as well as the Middle East with judicious deployment of OTH radars. China is reported to have developed the OTH radar in 1967 and, presently, it has deployed these radars to monitor aircraft carriers in the South China Sea. Australia's Jindalee Operational Radar Network (JORN) monitors a large oceanic area against air and sea early warning. The radar covers 37,000 sq km of the area for surveillance. These radars are relevant and suitable for Australian security imperatives. The OTH radars employ frequency modulated continuous wave transmissions to enable doppler processing. A major limitation of the radar is that it provides a two-dimensional location of the target, and the range resolutions are of the order of hundreds of

14. https://nuke.fas.org/guide/usa/airdef/an-fps-118.htm. Accessed on February 9, 2022.

metres to kilometres. However, with advanced computational powers and digital processing, the radar can accurately compensate for errors generated by atmospheric ambiguities. The OTH radars are likely to the continue being used in the future, especially against stealth aircraft, ballistic missiles, and hypersonic projectiles as part of the networked and IADS.

During the first Gulf War and Yugoslavia War, the average operation time of radars was 15 to 20 minutes, before they were destroyed by ARMs. Through effective Signals Intelligence (SIGINT) surveillance, the enemy draws out the Electronic Order of Battle (EOB) for mission planning in which active radars get recorded.

PASSIVE SURVEILLANCE SYSTEMS

Emitter Location Systems

Radars, being active RF transmitting systems, always provide warning signals to the intruders of being 'illuminated' by radars. Modern Radar Warning Receivers (RWR) are capable of geolocating the radars through RWRs and can target these radars with precision standoff munition. The active radars are also vulnerable to electronic jamming [Suppression of Enemy Air Defence (SEAD)] and attacks by Anti-Radiation Missiles (ARMs) or the Harpy class of loitering munition. During the first Gulf War and Yugoslavia War, the average operation time of radars was 15 to 20 minutes, before they were destroyed by ARMs. Through effective Signals Intelligence (SIGINT) surveillance, the enemy draws out the Electronic Order of Battle (EOB) for mission planning in which active radars get recorded. All the above limitations of radars get mitigated by employing passive air surveillance systems. These systems monitor RF transmissions from airborne objects and track them in three dimensions like an active RF radar. Typically, a passive surveillance system deploys three or four remote listening stations and a control station. The remote stations pick up RF transmissions like Identification Friend or Foe/Tactical Air

Navigation/Distance Measuring Equipment (IFF/TACAN/DME), radio altimeter, airborne intercept radar transmissions, radio transmissions, data links or jamming signals, and locate the target through the Time Difference of Arrival (TDOA) principle. Even UAVs get easily detected as they are always data linked for control and for payload data transmissions. Stealth aircraft or cruise missiles can be detected through transmissions as detection is independent of RCS. Another major advantage of the system is that it supplements the Electronic Intelligence (ELINT) data base with deep ELINT capability, and can also track naval and ground targets. Such systems are more appropriately called emitter location systems. The Vera NG passive location system produced by Era, a Czech company, has been operational in 25 countries, including the USA, Pakistan, Malaysia, and many NATO countries. While China was interested in buying this system, the USA put pressure on the Czech government to stop the sale to China, as the system is considered an effective counter to stealth fighters. The system can detect, track, and identify targets up to a range of 400 km. The Kolchuga M of the Ukrainian company Topaz has been the other popular system producer. China has also developed its own system, which appears to be a copy of the Vera NG. These systems are perfect gap fillers in the AD surveillance systems that are immune to SEAD or Destruction of Enemy Air Defence (DEAD) attacks.

Passive Radar Systems

The passive radar systems make use of non-cooperative FM radio and TV transmissions and employ many receivers to detect, and track with precision, aircraft, ships and ground vehicles. They are known as multi-static passive radars and have been classified as passive covert radar and parasitic radars. Research on passive radars started along with active radars before World War II. In 1924, two researchers exploited the British Broadcasting Corporation (BBC) station transmissions to detect aircraft. During World War II, German engineers developed the bistatic passive radar 'Klein Heidelberg', a parasitic system that utilised the British 'chain home' as a non-cooperative source of radiation, featuring long range and significant effectiveness against airborne objects.[15] In 1999, the passive radar 'Silent Sentry 2' from Lockheed Martin (USA) was introduced. This system used FM and TV broadcasts (both analogue and digital), providing detection with high precision, while maintaining the ability to track 100 targets up to 220-280 km. It could monitor aircraft, missiles, ships, and surface targets, with an accuracy of 250 m for the horizontal, 1,000 m for the vertical and ±2 m/sec for speed, at acquisition and operating costs lower than those of a conventional radar. BAE Systems, Thales Systems and Selex Systems have developed operational systems which have been used by some air forces.[16] With the spread of low-cost receivers and computational advances, such systems have attracted interest, especially as cell communications provide dense transmissions and such passive systems could counter stealth capabilities. However, these systems can operate only up to medium altitudes as non-cooperative transmissions are restricted to these altitudes.

Passive Electro-Optical Surveillance Sensors

Electro-Optical (EO) sensors had severe limitations in the past, especially during adverse weather conditions. With technological advances and digital technology, the sensors are capable of much better performance and now they can be operationally employed for air surveillance. Being passive sensors, they enjoy the same advantages as mentioned for passive sensors and, in addition, these sensors can literally 'look' at the target. The Rafael Advance Defence System has produced the 'Sky Spotter' EO air surveillance system which is likely to be operational with the Israeli Air Force. The Sky Spotter uses, MWIR, SWIR and Day sensors establishing a passive aerial surveillance over a long range. Advanced algorithms of automation, image processing and Artificial Intelligence (AI) enable many targets being tracked and managed simultaneously. The system also features propriety algorithm for coupling EO and radar inputs into a unified picture,

15. *Journal of Computations & Modelling*, vol. 9, no. 2, 2019, 37-61 ISSN: 1792-7625 (print), 1792-8850 (online) Science Press Ltd, 2019.
16. Ibid.

maximising the synergy between both sensors. This system overcomes the inherent challenges of the active RF sensors and has low life cycle costs.[17]

PREVAILING INDIAN OPERATIONAL ENVIRONMENT

China has been aggressive on the borders and its openness to confrontation is on the rise. Territorial issues and a history of conflict spanning the last 70 years have made India's borders some of the most dangerous flashpoints. India's most critical security threat continues to be state sponsored terrorism from Pakistan and a potential conflict with China. The Line of Actual Control (LAC) continues to remain tense, with heavy deployment of troops by both sides throughout the year. There have been significant numbers of drone incursions across the India-Pakistan borders and there was a serious drone attack at Jammu airfield on the night of June 26-27, 2021. Chinese helicopter incursions across the LAC have been frequent. China has forward deployed modern fighters like the J-20 and reorganised its forces for quick response intervention. With a force that totals approximately two million personnel in the regular forces, the People's Liberation Army (PLA) has sought to modernise its capabilities and improve its proficiencies across all warfare domains, so that as a joint force, it can conduct a range of land, air, and maritime operations as well as space, counter-space, Electronic Warfare (EW), and cyber operations.[18] The PLA Rocket Force (PLARF) continues to increase its inventory of road-mobile DF-26 Intermediate-Range Ballistic Missiles (IRBMs), which can conduct both conventional and nuclear precision strikes against ground targets as well as conventional strikes against naval targets. In 2020, the PLARF began to field its

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17. Rafael Sky Spotter Brochure.
18. n. 2.

Overall, the PLAAF has developed into a modern air force, well networked, capable of simultaneous and synchronised multi-domain operations. The Pakistan Air Force (PAF) has been modernising and upgrading its systems methodically.

first operational hypersonic weapon system, the DF-17 Hypersonic Glide Vehicle (HGV) capable Medium-Range Ballistic Missile (MRBM). The PLA Air Force (PLAAF) and PLA Navy (PLAN) Aviation together constitute the largest aviation forces in the region and the third largest in the world, with over 2,800 aircraft in total, of which, approximately, 2,250 are combat aircraft (including fighters, strategic bombers, tactical bombers, multi-mission tactical, and attack aircraft).[19] The stealth fighter J-20 has been deployed at forward air bases in the Tibet Autonomous Region (TAR), and another formidable stealth fighter, the FC-31 has been developed. Last year, China displayed its first dedicated Electronic Warfare (EW) fighter, the J-16 D, capable of jamming all types of radars and communication nodes. China has also developed the FH-95 high speed EW UAV as a SEAD platform. All the Chinese fighters are well equipped with Electronic Counter-Measure (ECMs) self-protection suites. The PL-16 ARM and another type YJ-91 (derivative of the Russian Kh-31 ARM) are formidable DEAD weapons. Overall, the PLAAF has developed into a modern air force, well networked, capable of simultaneous and synchronised multi-domain operations. The Pakistan Air Force (PAF) has been modernising and upgrading its systems methodically. The PAF has acquired the MAR-1 ARMs from Brazil, and it has the dedicated EW aircraft DA-20, with both communication and non-communication jamming capability. It has inducted the JF-17 fighters and there are plans to induct the JF-17 Block III fighters with advanced avionics and AESA radars. The PAF has shown interest in acquiring the latest Chinese stealth fighter, the FC-31. Being a nuclear weapon state, Pakistan has been continuously developing ballistic and cruise missiles. The Pakistan Aeronautical Complex (PAC) is known to have developed the 'Burraq' Unmanned Combat Aerial

19. Ibid.

Vehicle (UCAV)and is working on many other UAV projects. India can expect proliferation of armed drones in Pakistan which could be used by terrorist groups to strike Indian vital areas.

India does not seem to have any radar capable of detecting micro or mini-UAVs. This is a major gap in air surveillance and UAV engagement.

PRESENT INDIAN AIR SURVEILLANCE CAPABILITY

India has vast and well networked air surveillance radars with a mix of legacy and modern AESA radars. For Ballistic Missile Defence (BMD), India had acquired two 'Green Pine' radars from Israel and subsequently developed the Long Range Tracking Radar (LRTR) indigenously. The Multi-Functional Control Radar (MFCR) complements the LRTR radar BMD system.[20] For air surveillance, the legacy long range surveillance radar THD -1955 continues to operate effectively. The other modern radars inducted and deployed are medium power radars originally procured from Israel, and later indigenised as the Arudhra, LLTR, 3D Central Acquisition Radar (CAR), Low Level Light Weight Radar (LLLWR), indigenised as the Aslesha radar. There are plans to develop and induct high power radars and mountain radars.[21] India had acquired two aerostat based surveillance radars from Israel and they are reported to be functional. The Indian Air Force (IAF) had initiated the project Integrated Air Command and Control System (IACCS) under which all the modern radars are networked to provide a seamless and fused air situation picture. As airborne surveillance and control systems, the IAF has inducted two AWACS from Israel and three indigenously produced Emb 145 AEW&C aircraft. Considering the vast borders of more than 7,500 km, the air assets are considered inadequate for any contingency. Recently, the IAF has ordered four HF band radars, probably to detect stealth aircraft. India does not seem to have any radar capable of detecting micro or mini-UAVs. This is a major gap in

20. https://military-history.fandom.com/wiki/List_of_radars#Land-based_and_airborne. Accessed on February 9, 2022.
21 Ibid.

air surveillance and UAV engagement. All the Indian radars are active RF radars, which are vulnerable to ARM and ECM attacks, even though the IAF would deploy radars to ensure enough overlap coverage and multi-layered radars to cover the entire air space.

SUGGESTED INDIAN AIR SURVEILLANCE STRATEGY

India has a vast expanse of air space requiring continuous air surveillance, especially as air intrusions have been occurring regularly from across the borders of both China and Pakistan. Going by the innovative use of rogue drones to carry out explosive attacks in many countries, India is required to protect some strategic areas and its leadership against drone attacks. India has a vast maritime boundary and many island territories which need to be monitored for anti-national activities. To counter rogue drone attacks, the IAF needs to acquire counter-UAV systems with multi-spectral surveillance capability, including an appropriate mobile and transportable radar, EO/IR and COMINT sensors to detect and track the micro-UAV class of threat. The entire system should be pluggable to the IACCS network and easily deployable at buildings in urban areas. These systems should be deployed during all events of national importance and whenever a threat to any vital area or vital point is imminent. All important air bases and strategic assets like nuclear plants, the president's and prime minister's residences and Parliament must be protected with these systems. The National Capital Region (NCR) and other strategically important metro cities like Mumbai, Guwahati, Kolkata, Chennai, Bangalore, and Hyderabad would require BMD protection in due course of time. The S-400 class of AD systems would also be able to detect and engage ballistic missiles. The Eastern Sector must have more of such systems as deterrence and to counter PLARF missile attacks. Airborne surveillance capability is woefully inadequate to provide early warning of attack build-up, and to support deep strike missions. The IAF may consider procuring additional AWACS from Israel as repeat orders to fill this void fast before the indigenous effort of India for AWACS fructifies. Indian AWACS must have the AESA radar with 360 degrees coverage, unlike the present Netra AEW&C aircraft. India has deployed active radars in multiple tiers, but with all of them being vulnerable to ARM attacks and DEAD weapons, the IAF may consider acquiring passive surveillance systems and passive EO surveillance sensors that would be immune to ARM attacks and provide another layer of redundancy in air surveillance, which does not alert the intruding force. The IAF has many VHF/UHF band radars with enough operating hours available. These radars could be modernised and digitised to provide another layer of AD radars to supplement the passive radars in detecting stealth aircraft. India should develop more Artificial Intelligence (AI) embedded software defined cognitive radars, that could adapt to the operational scenarios and operate autonomously. All army and shore-based surveillance and acquisition radars should be interoperable and networked with the IACCS to improve surveillance at all altitudes. Civil air surveillance radars should be integrated with the AD radars to ensure seamless and maximum gap free surveillance capability of the entire Indian air space. BMD radars should be integrated with the IACCS network and all new SAM systems having early warning radars should also be integrated with the IAACS. This would ensure better BMD surveillance as modern long-range radars can provide inputs for BMD. To counter the cruise missile threat, aerostats and AWACS are the ideal surveillance platforms, along with low level radars. India should consider defence against the hypersonic threat by undertaking research and development of radars on cluster grouped Low Earth Orbit (LEO) satellites, fully networked with space surveillance systems. Effective weapons to counter such hypersonic weapons would be the next step.

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Application of stealth technology and proliferation of modern and manoeuvrable ballistic missiles, cruise missiles and hypersonic weapons have necessitated a review of the air surveillance strategy for India.

CONCLUSION

India has been facing continuous threats from China and Pakistan, and terrorists have copiously used drones to drop material for themselves and to attack vital installations like the IAF bases. Application of stealth technology and proliferation of modern and manoeuvrable ballistic missiles, cruise missiles and hypersonic weapons have necessitated a review of the air surveillance strategy for India. There have been rapid technological advances which have led to more lethal and capable attacking forces which can strike targets accurately and from standoff distances. Multi-layered attack profiles necessitate multi-layered surveillance systems. Computational advances and digitisation have also advanced the capabilities of modern radars. Technology advancements have now made it possible to produce multi-spectral and passive air surveillance systems that enjoy immunity from anti-radiation missiles, electronic jamming and do not alert the attacking forces. Such systems are also capable of detecting stealth aircraft. India must consider bridging the air surveillance gap to detect drones, stealth aircraft, and deploy multi-spectral sensors to ensure surveillance against a hostile EW environment. Deficiency in AWACS assets requires urgent attention to remain effective during any operational contingency. While India has gained proficiency in producing modern surveillance radars, it is important that all these radars are networked and are adaptable to the changing operational environment.