Integrated Air Defense Systems with a Focus on Interception Technology

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Integrated air defense systems (IADS) have been a continuously advancing technology since their introduction in the 1940's. Air defense systems originally depended on radar systems and manual observation, with interception being done by fighter aircraft, barrage balloons, and anti-aircraft artillery. The systems have advanced to incorporate sensors such as radars, infrared technology, and satellites for detection. Interception is carried out by missiles with varying ranges and fighter jets. Along with the technology used, the communication speed between the sensors and the interceptors has increased, allowing for a timelier interception. With the rise in artificial intelligence and advancements in technology, integrated air defense systems will become more precise, accurate, and timely. This paper explores the evolution of integrated air defense systems along with the projected future of the systems.

I. Introduction

Integrated air defense systems (IADS) have been around since WWII, introducing a new defense strategy. The main goal of IADS is to protect assets and populations from attacks. This is done through a form of detection, spotting the threat and then alerting personnel who can then target and eliminate the threat. This united various defense methods into one integrated, rapid system allowing for timely interceptions. As technology has grown into more advanced systems, the detection, communication, and elimination components of IADS have grown as well, and continue to grow.

II. Early Stages

A. First System

The first defense system used was Britain's Dowding System in the 1940's. The Dowding System was broken up into four different geographical regions, which was further divided up into separate sectors making sure every region was covered. The separate regions meant a smaller area was covered by each system, which allowed for more control during upcoming attacks. This system incorporated radar systems along the east and south coasts to detect incoming aircraft and signaled the command. The systems faced away from the inland, which caused an issue: once the aircraft was inland, it could not be detected. To combat this the Observer Corps was developed to help provide additional information of incoming aircraft, made up of volunteers who were self-taught in detecting aircraft models and their altitude. [1] The Observer Corps alerted the Observer Corps Center which passed the information to their respective group and sector stations.

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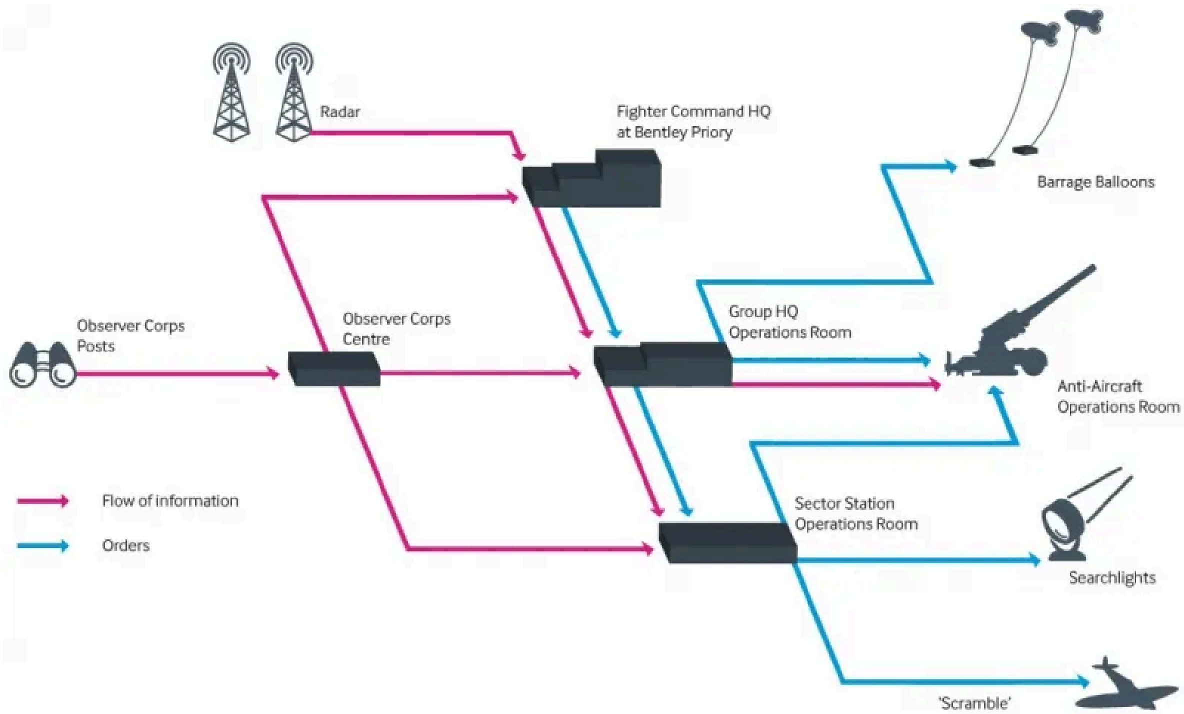

Fig I: Britain's Dowding System Control Flow [1]

From there, information from the radars and Observer Corps were processed by the sector stations. The sector stations were broken up into two groups, plotters who were made up of the Women's Auxiliary Airforce, and operations staff. The plotters worked to track incoming attacks by using wooden blocks on a large table map, with each block named and had the strength and direction of each attack. The operations staff was located on a balcony that oversaw the plotters. Each operation staff member had their own role in communication between different sectors and squadrons to make sure all information was current. Operations staff also consisted of Liaison Officers who were directly in contact with the Observer Corps, ‘Ops A’, and ‘Ops B’ which gave orders to pilots to direct them into attack. [1]

Fig II. Plotters and Operations Staff [2]

Once alerted, separate crews would be called into action to prepare as needed to defend. The defense part of the Dowding System was done by fighter aircraft, anti-aircraft guns, and barrage balloons. Once alerted the crews would carry out their defense operations. Assisting the defense crews on the ground were searchlight operators, engineers, armorers, riggers, and fitters. These ground crews would make sure the defense operations ran smoothly and efficiently, either helping during the attack as needed, preparing planes for flight, or just helping keep the runway clear. The Dowding System united various systems into one integrated system which benefited Britain's air defense by allowing for prompt responses for upcoming enemy attacks which was a major contribution in the Allies' victory during WWII.

B. How Systems evolved

With developing technology, changes were made to the Dowding System to further improve its functionality, with allied forces incorporating similar systems into their defenses. More radar systems were introduced to improve detection at night since visibility at night was an issue for the Observer Corps and spotting enemy attacks. Other countries also started to incorporate IADS into their military defense, with the systems advancing alongside technology, continuously changing.

During the 1950s missile technology continued developing, leading to the creation of heat-seeking missiles which would target threats more effectively. Before seeking missiles were created, missiles had little to no guidance post-fire. Crews would create a set path for the missiles and then launch, with the missile being able to keep itself on the path. However, the Ruhrstahl X-4 Missile was able to be guided post-firing, "fighter pilots guided the missile visually with a small joystick, and thin wires." [3] Without guidance the missiles were mostly inaccurate, with target paths changing from their predicted paths, it was hard to guarantee early missile accuracy. The creation of seeking missiles increased missile accuracy which simultaneously increased defense. This allowed missiles to become fire-and-forget, personnel would lock a missile on to a heat signature from the target and then fire. The missile would then follow their target up until its destination having a more precise attack.

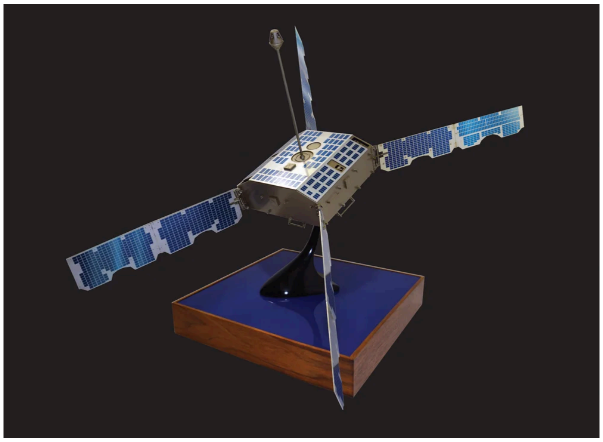

Fig 3. Percase Satellite [4]

Reconnaissance Satellites were developed in the 1960s and played a role in detection of threats. Since the satellites were in space it was difficult for an enemy to shoot them down. Taking down a satellite requires precise technology which was expensive and advanced at the time. The satellites allowed for detection without human risk, orbiting overhead and taking photos of military bases. The photos provided intelligence on enemy weapons allowing militaries to gauge what kind of technology they had and when troops were being deployed. Satellites also improved communication providing a secure reliable source. [5] Due to the space race during the cold war, and also since satellite technology was new, satellite systems kept evolving. By the 1970s satellites had longer lifespans and were equipped to fill more roles. With ground systems advancing to being able to receive data from satellites, satellites were used to detect missiles. [6] Satellites also helped fill a hole in detection: being able to detect enemy naval ships known as the Percase Satellite System. With satellites the signals of ships were able to be recorded and received by ground systems. [4]

III. Current Integrated Air Defense Systems

Current technology creates multi-layer integrated defense systems. Radars and sensors are used to detect and identify upcoming threats, plotting them simultaneously on a map providing a full view of all current threats. Modern detection uses various radar systems such as phase array radars, infrared search and track systems, and electronic support measures. [7] Systems then piece together data from various sources into one place which can contain multiple threats. The system also filters out false attacks to make sure information is reliable. Artificial intelligence is used to suggest defense moves, having an operator approve the move rather than having them fully automated. This helps improve response time, leading to faster interception times.

Surface to air missiles which vary with altitude and range, anti-aircraft artillery, and energy missiles are used for the interception, with surface to air missiles being the most common. [7] Mobility is also a key benefit to current air defense, with weapons being mobile which can be mounted on a vehicle or launched from a naval ship. Unmanned autonomous vehicles (UAVs) are also used. They rely on cameras with an operator controlling them, watching the cameras. High end UAV systems use artificial intelligence for complex environments, allowing them to navigate without human input. [8] UAVs provide various benefits for IADS such as surveillance and combat.

IV. Future of Systems

A. Uncrewed Systems

Fig 4. Future Stealth Combat Drone [9]

Unmanned autonomous vehicles are developing to use artificial intelligence as well as machine learning. With current technology still using operators for performance, it is projected that in the future UAVs will be solely reliant on artificial intelligence, using no human input. The UAVs will be able to learn from their environment and adapt to have more autonomy. [10] This will allow for more coordinated swarm attacks, overwhelming enemy defenses. There will also be an increase in UAVs in the future, "the global UAV market is set to skyrocket from $28.5 billion in 2021 to $58.4 billion by 2028." [10]

Stealth UAVs are also predicted to emerge. Since current UAVs are able to be detected, this will open a new chapter in defense. Allowing for undetected surveillance or attack. Payload size is also estimated to increase for UAVs. Increased payload sizes would allow for larger cameras or sensors to be equipped. Larger weapons could also be carried or essentials could be delivered from base to base. [11]

Sikorsky is also working on autonomous aircraft. In 2022, they had a successful flight with an uncrewed Blackhawk that used Aircrew Labor In-Cockpit Automation System (ALIAS). [12] ALIAS is an automation kit that is simply installed into pre-existing aircraft, with the goal of supporting an autonomous flight from takeoff to landing. [13] The Blackhawk was able to maneuver fully autonomously, flying through a simulated environment where it had to reroute mid-flight. The flight was successful, with the Blackhawk routing successfully and even having a perfect landing.

B. Faster Communication Times

Artificial intelligence will allow for communication speed between systems to increase. A current struggle that defense systems face is gathering data from various sensors and delivering it to ground systems. Defense Operations Grid-Mesh Accelerator (DOGMA) allows for information from various sensors to be combined into one source to get it to the ground systems efficiently. [14] A benefit of this is that DOGMA can be deployed anywhere, using satellite connections. Tests using DOGMA technology monitoring UAVs showed a drastic decrease in decision making time, from 30 seconds to 3 seconds. [15] Fast communication speed is crucial when dealing with active attacks, DOGMA's role in faster communication will allow for faster response times to attacks.

Source: Gorodenkoff/stock.adobe.com.

Fig 5. Laser Communication Satellite [16]

The Department of Defense is also aiming to strengthen satellite communications. Integrating satellites with each other to cut down lines of communication, making them less vulnerable to threats. Satellite communication will also be larger, and more secure, delivering larger sets of data at once. [17] The U.S Space Force is currently working on making new satellites for low Earth orbit to complete this goal using laser technology, since lasers transmit data faster with precision. [18] As of November 2025, the initial satellites with this technology have not proven operational, however the project is still being funded in hopes of it working. Satellites in low Earth orbit will be able to track missiles better as well.

C. Space Systems

Space based missile defense is also predicted to come in the future. A start up based in California, Wardstone, has the goal to provide space interception on missiles. The system works using interceptors to track threats then using particle clouds before impact. [19] Currently the system will be used to counter hypersonic attacks but plans to grow to counter ballistic missiles and other space threats.

D. Laser Weapons

Fig 6. Army Vehicle Equipped with Laser Weapon [20]

Laser weapons work by generating beams of light from converting energy into photons and narrowing the photons into a beam. The beam of photons can reach a high enough power to melt through materials. [20] Laser weapons provide the benefit that they don't have to be reloaded compared to other weapons. They also have a higher speed compared to current technology, being able to lock onto their targets and hitting them at light speed. [21] High energy lasers are becoming more prominent, being used against various defenses. The US Army tested a high power laser against UAVs, the test was successful and provided insight on how lasers can be used in defense and different techniques while using them. [22]

V. Conclusion

Integrated air defense systems have come a long way from their origin in the 1940s. With the continuous advancement of technology, the systems will only advance further. The future promises integrated air defense systems incorporating artificial intelligence and machine learning to have them become self-sufficient. More focus is also being placed on space systems such as satellites to improve communication as well as developing space interception systems. Laser weapons will also have a significant advantage over UAV swarms, since they don't need to be reloaded and fire at the speed of light. Future IADS will be composed of a system of systems, using multiple layers for step in air defense increasing reliability. If one of the systems fails, there are multiple others that can cover its place, for instance if a detection satellite fails, there are still radar systems that can detect a threat. Overall, IADS are continuously improving alongside technological advancements securing air safety.

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