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**Stealth in the Era of Electronic Attack Aircraft, Drones, and Hypersonic Missiles:**

**A Review**

Modern warfare success depends in large part ondominating or controlling enemy air space. World War II was an excellent example, as air superiority was needed for mobilizing troops, maintaining proper logistics supply chains, and neutralizing the enemy's movements. It also played a key psychological role by boosting friendly soldiers' morale while demoralizing enemy morale. After the invention of radar by Royal Air Force scientists to counter German air raids, several countries began researching and developing new radar systems. Based on the ongoing debate on whether stealth aircraft are needed or not and the Russian failure to dominate/control Ukrainian airspace, this article has been written to put a light on the importance of the stealth aircraft. (The Jordan Times, 2022)

The development of radar guided air defences in the 1970s made bombers and fighters increasingly vulnerable. To overcome this issue,in 1974 the Defence Advanced Research Projects Agency and the United States (U.S.) Air Force started working on low radar signature combat aircraft with the capability to enter the enemy's airspace. This concept was not new one. In the 1940s, Jack Northrop developed the experimental aircraft YB-49 with smooth surfaces and rounded edges with no external fuselages or tail. In comparison with other aircraft, the YB-49 generated less Radar Cross Section (RCS) signature (Correll, 2019). Unfortunately, the design was too early for the times, generated no great interest, and was cancelled in 1949. The fundamental principle for creating stealth aircraft is to neutralize command and control of radar-based air defences, and to facilitate the roles and missions of other regular fighter aircraft and bombers. (Kennedy, 1993)

Stealth technology is a combination of different design concepts and material technologies, which all together significantly reduce aircraft detection at longer ranges. In comparison to normal aircraft, stealth technology-embedded aircraft can be detected within only a few kilometres. This drastically reduces the enemy's response time and before reaching this detection zone, stealth aircraft can launch a guided missile/bomb or radar homing missile/bomb and destroy the radar stations and command centres that are tracking them. (Banga, 2017)

To create a stealth-designed aircraft, normal aerodynamic design features are sometimes compromised to reduce radar signatures. For example, the F-117 had tilted tail surfaces, and the B-2 Spirit totally omitted the tail to achieve a near-perfect stealth design. These aircraft also have special coatings/materials consisting of paint-like dielectric composite materials to absorb radar waves. They are more transparent to radar in comparison to electrically-conductive materials such as metals and carbon fibers. Similarly, there should not be any kind of external protrusions from the aircraft such as the weapons, fuel tanks, and other systems that increase radar signatures. Stealth designs reduce weapons and fuel carrying capacity, operational range, and reduce air-to-air combat capability compared to non-stealth combat aircraft.

Even after keeping its weapons, fuel tanks and other systems within the stealth designed framework, the aircraft is still vulnerable to detection when their weapons are used. Since stealth aircraft carry all armaments internally, to deploy missiles, the weapons compartment doors have to be opened thus increasing the aircraft's RCS until the doors close again. During the short span of time weapons doors are open, air defence systems have a fractional chance to detect and engage the aircraft. But this probability is either very remote or not proven as yet.

Since stealth aircraft carry fuel and other systems along with weapons internally, they are capable of carrying only a few laser- or GPS-guided bombs in comparison with a non-stealth attack aircraft. To overcome this problem, countries started deploying specialized radar suppression and electronic counter measure aircraft such as the EA-18 Growler, SU-35S, and J-16D. These specialized electronic attack aircraft can disrupt and suppress air defence systems, making it easier for other non-stealth aircraft to carry out combat missions, the latter of which are comparatively cheaper than stealth aircraft. (Chopra, 2020)

In combat missions, the U.S., Israel, and Russia have employed stealth aircraft. During Operation Just Cause in Panama, the U.S. used the F-117 for the first time in combat to drop one 2,000-pound bomb each within 150 yards of the Panama Defence Force 6th and 7th Rifle Company barracks to stun and confuse the occupants just before Rangers of Task Force Red parachuted into the area. (Wilson, 1989) Later, the F-117 was used in the Iraq war in 1990 alone, again in 2003 in Iraq in tandem with the B-2 Spirit, and in 1999 in Kosovo with B-2. Sikorsky UH-60 Black Hawk helicopters were used in Operation Neptune Spear that resulted in the death of Osama bin Laden in May 2011in Pakistan. The UH-60s used were extensively modified with stealth technology to be less apparent to radar for clandestine missions. In September 2014, the F-22 made its combat debut over Syria as part of a U.S.-led coalition against the Islamic State of Iraq and Syria. Since 2018, Israeli F-35I stealth jets carried out a number of operations in Syria, and in 2018 Russia deployed its SU-57 in Syria. The Chinese introduced their J-20, which has been in service since 2017, and the Chinese FC-31 is still in development, and has yet to demonstrate its true combat worthiness. Currently, the F-35 in many modified versions is the only widely utilized stealth aircraft use by the United States and its allies throughout the world.

Recently, the concept of plasma stealth has been introduced to reduce RCS using ionized gas. In this interaction, electromagnetic radiation (radar) and ionized gas can create a plasma layer or cloud around the platform to deflect or absorb the radar signal. As stealth technologies evolve, research and development programs are underway to counter this technology. Many countries are developing advanced radar systems that are able to detect stealth aircraft, including passive infra-red (IR) sensors, multi-static radars rather than monostatic radars, ultra-low frequency radars simultaneously using various band frequencies in multi-mission mode, and over-the-horizon radars. (Noronha, 2019)

On 27 March 1999, during the NATO bombing of Yugoslavia, a Yugoslav army unit (the 3rd Battalion of the 250th Air Defence Missile Brigade) shot down an F-117 Nighthawk by firing a S-125 Neva/Pechora surface-to-air missile. It was the first time a stealth aircraft was shot down since aircraft stealth technology was introduced. However, there is no conclusive evidence to substantiate the claims and counter claims of both sides regarding how it really happened. Similar missions were carried out by F-117s and B-2s without any losses.

In 2018, the German defence contractor Hensoldt claimed that it had detected and tracked two F-35s with a new type of radar system called TwInvis, nearly 100 miles away. According to Hensoldt, the system can detect aircraft moving through this invisible sea of signals by "reading how the signals bounce off airborne objects" (Whitney, 2018). However, the aircraft may not have been detected if they were not flying in the stealth mode. These type of aircraft have options to switch from stealth to non-stealth and vice versa, depending on their mission. Whenever they operate in their own country for training, or during friendly exercises, they are usually in the non-stealth mode to allow their flights to be monitored. On the other hand, whenever they are on a combat mission or attack mode they will go on stealth mode to avoid radar detection. It was unknown which mode Hensoldt detected the F-35 using the TwInvis radar system.

Similarly, other companies/countries have claimed that their technologies can detect stealth aircraft at significant distances. The Russian Nizhny Novgorod Research Institute of Radio Engineering (NNIIRT), a part of the Almaz-Antey Joint Stock Company that developed the Struna-1/Barrier-E bistatic radar system is one of the companies to make this claim. The Struna-1 is unique among radars in that it is a bistatic radar, which means that the receiver and transmitter of the radar are in separate locations, as opposed to traditional radar technology, in which the receiver and transmitter are in the same monostatic area. The advantage of biostatic technology is that deflected radar waves from stealth aircraft can be detected by other sources of receivers. (Gao, 2020) Russian Resonance-N radars were built with artificial intelligence software to detect and analyze a wide range of targets, including stealth aircraft, mini-drones, and hypersonic gadgets. According to the Zkrytoe Aktsionernoe Obshchestvo (ZAO) company, the Resonance-N radar can detect aerodynamic objects from 373 miles away and ballistic targets from 746 miles away up to an altitude of 62 miles. (Nolan Peterson, 2020) Another radar named Nebo-Malso known as RLM-ME or 55Zh6ME (export version) was also developed by the Nizhny Novgorod Research Institute of Radio Engineering (NNIIRT) for a whole range of targets. Nebo-M is not just “anti-stealth,” but is also capable of covering a huge array of targets, including hypersonic and ballistic, whether stealth or not. (Kay, 2021)

According to the literature and defence experts, the Russian S-400 designed by Almaz-Antey is a surface-to-air missile system capable of tracking stealth aircraft. The company claims that its Active Electronically Scanned Array (AESA) radar is particularly effective at detecting stealth jets. Within a range of 400 km, it can engage all forms of aerial targets, including aircraft, unmanned aerial vehicles, and ballistic and cruise missiles. To counter the flying hostile targets with the range of from 40 to 400 kms, it is capable of firing different types of missiles. (Noronha, 2019, Counter-Stealth Systems)

New concepts called as photonic and quantum radar in which targets can be detected as far away as 800km to 1000km (Memon, 2019; Yirka, 2022; Bassyouni, 2010; Majumdar, 2018) are also evolving. The quantum radars can detect a target with only a little echo, and they can do so with low power transmissions. As a result, they're harder to detect and jam. China has stated its goal of being a global leader in quantum technology by 2030, and it is spending vast sums of money to achieve this goal. It's a safe bet that it will be the first to crack the quantum radar code. (Noronha, 2019)

Another new concept is Terahertz Radiation Radar (TRR). Terahertz radiation wavelengths are halfway between infrared and microwave wavelengths. It has the capacity to pierce the composite materials that make up stealth aircraft skin, exposing the metallic components within. According to the Chinese, their TRR can clearly trace the contour of any stealthy object and identify it as a fighter jet or not. While terahertz radiation is extremely effective at short distances, it decays quickly in the air. (Noronha, 2019)

Countries with modern air defences are using a combination of radar types to create integrated aerial air defence systems. Instead of depending on a single sensor with a particular wavelength, a system receiving data from multiple sensors and varying bands of wave length can fuse data to improve the precision and robustness of target recognition and tracking. This data fusion and subtraction technology helps to improve the capability to distinguish a specific object from other objects by combining different data from different sensors. Note that some of these counter-stealth technologies remain unproven.

Considering the high cost of developing, purchasing, and maintaining stealth jets, some argue that stealth is overrated, and that it is better to buy greater numbers of cheaper, non-stealthy planes. Non-stealth aircraft can be equipped with powerful electronic Suppression of Enemy Air Defences (SEAD) systems that can be used to strike enemy anti-aircraft defences. For example, a fast jet that is well armed and highly maneuverable is the Boeing EA-18G Growler electronic attack aircraft, which has the ability to jam across the entire spectrum. SEAD may be much cheaper than stealth providing a better cost-benefit ratio.

The basic purposes of stealth and non-stealth aircraft are different. The fundamental concept of stealth aircraft is to invade enemy territory without detection and destroy the enemy’s eyes and ears, i.e., neutralize command and control and/or radar equipped air defence nodes without revealing the stealth aircraft’s presence, or not giving the enemy the time to respond. In addition, stealth aircraft can be used undetected in non-permissive countries to accomplish surveillance or other missions without the country's permission or knowledge. On the other hand, electronic attack aircraft are able to suppress, confuse, and spoof enemy radar air defence systems on various bands of wavelength, but they cannot disguise themselves from the enemy. Although the enemy may not be able to accurately locate and acquire them, they will know of the intrusion into their airspace and may send interceptors. Therefore, non-stealth electronic attack aircraft are not useful or suitable for missions requiring plausible deniability. Therefore, these two types of aircraft are complementary to one another.

The recent use of drones and loitering munitions has rapidly changed the nature of battlespace. Even small states and non-state actors started using drones for both surveillance and attack missions. However, in 2019, the shooting down of a U.S. RQ-4A Global Hawk BAMS-D, a high altitude long endurance non-stealthy drone, by Iranian air defence clearly indicates that non-stealth drones are not immune from radar-assisted air defences. Similar to stealth aircraft, hypersonic missiles cannot be detected by radar-assisted air defences and can be used for attack missions or pre-emptive strikes. On the other hand, they are neither useful for surveillance missions nor reusable. Since they are not reusable and cannot be used on multiple targets, their cost-benefit ratio will be unfavorable compared to stealth aircraft.

Recently, Chinese scientists' have claimed that they have developed a new surveillance drone named WZ-8 with hypersonic capability. (Military Watch, 2019) If this is true, stealth technology might be incorporated in the design of hypersonic drones making them undetectable. Some may argue that satellites can fulfil surveillance and mapping needs. While satellites can perform surveillance, they cannot provide real-time data until their orbit arrives over the target location, or until they can be redirected to the target location. On the other hand, stealth aircraft can be more responsive if they are within range of the target area, thus satisfying the need for timely data.

Thus far, stealth aircraft have been used only in minor conflicts like Syria and Afghanistan where advanced air defence systems were not present. The effectiveness of stealth versus anti-stealth technology will only be proven in major conflicts between countries that claim to possess advanced aircraft, radars, and anti-aircraft missiles. Modern warfare success depends on dominating and controlling airspace. This can be achieved through a combination of stealth aircraft, electronic attack aircraft, electronic warfare systems, and missiles. Using stealth aircraft against small states or non-state players may be costly, but maintaining a nation's edge over peer adversaries is unquestionably required until anti-stealth technology proves its supremacy over manned or unmanned stealth aircraft.

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