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Stealth Technology and Evolution of Stealth

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ABSTRACT: This paper will focus on Stealth technology with evolution of stealth and modern-day stealth aircrafts. This paper also, discuss the Areas of improvement for stealth aircraft, various techniques use to make aircraft stealthy and Reasons why an Indian air force need stealth technology.

KEYWORDS: Stealth technology, Evolution of stealth, Plasma active stealth, RCS reduction, Modern-day stealth, Infrared Stealth, Acoustic stealth.

I. INTRODUCTION

The concept use for stealth design is totally based on the principle of reflection and absorption that makes aircrafts stealthy. One of the ways is that deflecting the incoming radar waves into another direction and another is to absorb the incoming radar waves totally and to redirect the absorbed electromagnetic energy in another direction. Whatever may be the method used, the level of stealth an aircraft can achieve depends totally on the design and the substance with which it is manufactured.

Stealth Design use for reducing transmitted and reflected energies like heat, light, sound, electric potentials to deny an opponent to locate, track, identify and attack its target. In simple terms, stealth design allows an aircraft to be partially invisible to Radar or any other means of detection. It reduces the detection range. This gives a clear and safe striking distance.

To make aircraft stealthy there are many techniques and by the use of these techniques any aircraft gain ability to avoid radar system without any trace. Some of these techniques are Reduce Radar Cross Section with Complex Shape and Design, Infrared Stealth, Acoustic stealth, Radar Absorbent Surface using RAM or Stealth Material, Active cancellation technique, Passive cancellation technique and Plasma active stealth.

II. LITERATURE REVIEW

All military platforms have visual, radar, thermal (infrared), and acoustic signatures. Stealth reduces these signatures and there are several methods used to accomplish this reduction [2]. This thesis discusses all of these but mainly focuses on radar (RF) signatures.

Stealth technology has been refined and evaluated for nearly half a century. It has been used operationally for more than twenty years. However, stealth technology is still a sensitive subject. Due to its secrecy, this technology is typically protected under black programs [3]. This is done, to secure the technology from exploitation by enemy and to make sure dominance of the technology.

To achieve RCS reduction, four approaches are used. The first one applies shaping features. In a conventional radar configuration, the transmitter and receiver are collocated, so the stealth platform is shaped to reflect the incoming radar signal in a direction other than directly back to the radar. The second approach seeks to absorb, cancel or scatter the incoming radar transmitter signals so as not to reflect them to the radar receivers. This is accomplished by the application of special coatings to the platform's body or using special composites or materials in platform construction. The third technique implements passive cancellation. Cancellation is achieved by adding a skin to the surface of the platform which acts as a secondary scattered and cancels the reflected field from the primary target [1] one of the techniques is the absorption of RF signals using a plasma active stealth. There are not many applications of this technique; however, some researchers consider it promising for future stealth designs.

The solution to counter stealth is based on using passive receivers. A cell phone network can be used, conceptually, in a fashion similar to a multistatic radar network. This method involves using cell phone transmitter nodes, spread out widely in a defended area, for gathering the different RF signals scattered from a low observable vehicle's surface.

Using high speed computers and processors within an air defence system, the data from the various cell phone base stations can be processed to gain positional and tracking information on the stealth targets [5]. As there is an evolution in stealth technology new techniques, approaches are developed to maintain stealth, there is also an evolution in the counter stealth technology. This will require a deep knowledge of stealth technologies, radar knowledge and electronic warfare principles.

III. EVOLUTION IN STEALTH TECHNOLOGY

III.IHorten IX Flying Wing (1944-1945)

It has never been completely proven that the Horten IX Flying Wing’s unusual shape and airframe characteristics reduced its RCS, even to less advanced radar sensors during the WWII era. However, it is certain that there were many ingenious design specifications of the Horten brothers’ 0.92 Mach, 620 nm., combat-radius, 1930s’ bomber that would inform subsequent low observables’ design priorities [6]. Radical flying-wing airframes with no vertical surfaces, extensions of trailing edges, solid plywood wing skins, steel engines and steel-tube substructures concealed under the absorbent skin of the fuselage and engine exhausts on top of the wing were some of these specifications [7]. It was then manufacture with wood/plastic laminate structure and “...sandwich skin with a material derived from charcoal, sawdust and glue matrix (early RAM) to be used in the core to absorb radar energy [12].”

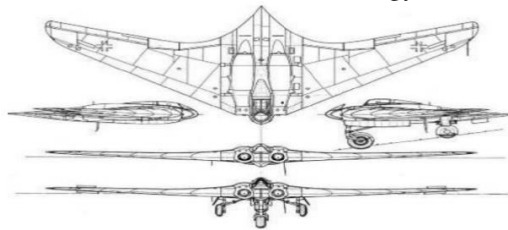


Fig.1 Horten IX Flying Wing(From [4])

III.IILockheed U-2 Dragon Lady (1958-1960)

When the Central Intelligence Agency’s (CIA) U-2 strategic reconnaissance aircraft was designed in the 1950s, the specifications required an aircraft that could fly over Soviet airfield with some operational capabilities to provide minimum risk of being shot down [12]. Low RCS was never proposed as a chief design factor. The main purpose of the program was to build a plane which could fly at an extremely high operational altitude, on the order of 70,000 to 90,000 ft. Soviet radars and weapons systems were considered incapable of reaching such high altitudes. Although particular U-2 models had different service ceilings, aircraft achieved flight at high altitudes with cruise speeds of around 460 mph and a maximum range of 2,200 to 3,500 nm. Furthermore, flying radius could be increased with external fuel [8].



Fig.2U-2 Spy plane (From [4])



Fig.3 Trapeze Modification on U-2s (From [4])

When deployed operationally over Soviet Union airspace, it was discovered that Soviet radars could detect the U-2 and development of a missile which could also reach the aircraft’s service altitude was just a matter of time [12]. As a result, radar absorbent materials were placed on the surface of the aircraft and printed circuits were used to counter S-band radars. Moreover, in order to defeat low frequency (70 MHz) radar signals by cancellation methods, the leading and trailing edges of the wing and tail surfaces of the aircraft were fitted with wires at a distance of quarter wavelength away [12].

These upgrades did not give the desired results since they were effective at only specific frequencies and other frequencies could still be used to detect the aircraft. Even worse, some of these modifications reduced the aircraft’s operating altitude to less than 60,000 ft., which increased the risk of threat missiles. Later U-2 models, such as the U2R and TR-1 variants, were more successful at RCS reduction by employing flat-black iron ball RAM coatings and small,

red, low visibility markings [8]. These efforts taught manufacturers that if an effective low RCS design was desired, the asset should be designed with this purpose from the very beginning of the project [12].

III.III Teledyne Ryan’s RPV Designs (AQM-91A Compass Arrow (1969), Low RCS Vehicle (1973-1974 Design Study), Mini-RPV (1974-1975))

The new approach was provided by Ryan Aeronautical, the producer of several types of Ryan Firebee RPVs, the opportunity to offer the U.S. Air Force (USAF) a new version of its designs which would have low RCS capabilities to accomplish reconnaissance missions. The Ryan Firebee RPVs were air-launched or ground-launched and were used as target drones or unmanned air vehicles from the 1950s to 2000. A wire mesh screen over the inlet and RAM [12] in some parts of the body were used in the BQM-34A, the later version of the Firebee (Q-2A and other versions). By incorporating these design modifications, coupled with the advantage of being smaller than a manned aircraft, the model achieved some RCS reduction. However, it was again demonstrated that significant RCS reduction could not be achieved by manufacturing upgrades, but was only feasible when considered from the base design [12].

Teledyne Ryan’s low RCS vehicle design of 1973-1974 attempted to address these issues. Because conventional wing-body-tail surfaces, up to that date, did not have very low RCS, the new design required flying delta wings with two inward canted vertical tails and “a small metal centre body surrounded by a large amount of lossy dielectric material [12]” with RAM.

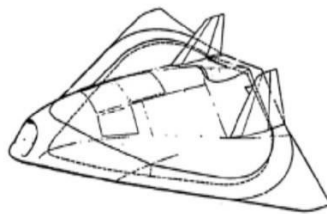


Fig.4 Teledyne Ryan AQM-91A (From [4]) Fig.5 Design of Teledyne Ryan (From [12]) Fig.6 RPV Design of Teledyne Ryan (From [4])

In 1974-1975 another design, having a similar shape but without any reliance on RAM, was introduced. Several versions were designed, each of which represented “trade-offs between radar treatment, countermeasures and overall system cost [12]”. To reduce radar signature, the vehicles had a ducted propeller on the top of the fuselage and wire screens were used at the end sides of this duct and also at the sensor radome beneath the drone. Unfortunately, these designs could not achieve adequate RCS reduction levels to evade detection while operating in a military mission [12].

III.IV Lockheed A-12 (First Flight 1962) and Lockheed D-21 Drone (First Flight 1966)



Fig.7 Lockheed A-12 (From [4])



Fig.8 Lockheed D-21 (From [4])



Fig.9 The D-21 Drones (From [4])

The A-12 was the earlier CIA-funded operational version of the SR-71 Blackbird, with a maximum speed of 3.35 Mach, service ceiling of 95,000 ft, and range of 2,200 nm. It was the first aircraft known that was designed with RCS reduction methods from the beginning of the project. Internal construction methods, which included structures behind the skin of the aircraft, such as re-entrant triangles that trapped or absorbed radar energy, were first used on the A-12. Furthermore, design concepts such as inward canted vertical fins, a slender oval section fuselage blended with a thin delta wing, and special iron ball infrared and radar absorbent paints all combined to reduce its nose and side radar signature. This made possible this aircraft’s survivability against state of the art (especially Soviet) radar and guided missiles [12].

However, there were still some unwanted elements that did not benefit stealth. One of these was the inlet lips of the A-12 which caused diffraction toward the receiver. This design element was necessary to enable the aircraft to reach

extremely high altitude and Mach numbers. Therefore, some compromise to stealth was accepted with the idea that “It was not possible to create an aircraft invisible to early warning or missile guidance radars, but in combination with high speed, high altitude, manoeuvring, and electronic countermeasures, a very high degree of survivability has been obtained in service [12].” Although the A-12 was a successful spy plane, the political tensions of the period required the U.S. to sustain its deep penetrating missions with unmanned vehicles. The plan was to carry a drone as far as possible on an M-21 (specially designed A-12 mother ship), and then to launch the drone at an extremely high speed, boosting it to nearly Mach 4 and around a 100,000 ft altitude. After taking pictures of the target area in the enemy zone, the drone would come back to a safe zone, eject a capsule that contained the data, and terminate itself, while the capsule, gliding with a parachute would be snatched in mid-air by a C-130 plane[4].

The drone, which flew its first test mission in 1966, had a shape very similar to its ancestor the A-12, with a nacelle and two outer wings [7], and fuselage composite. Moreover, the ramjet tailpipe was extended to increase the IR low observable capability of the drone. Low RCS, speed and altitude goals were achieved; however, it was very hard to deploy this drone from the mother ship at the required high speeds. Thus, the configuration was changed to carry the drone under the wings of a B-52 H, by modifying both assets, but the project was cancelled after four operational flights failed to achieve success and the Teledyne Ryan AQM-91A Compass Arrow, high flying, unmanned, photo reconnaissance aircraft, was selected to fulfill the mission[4].

III.VMc Donnell Douglas Quiet Attack Aircraft (1972-1973 Design Study)

There were also some design studies which never resulted in an operational system, but were delivered as technology demonstrators which were successful in promoting the evolution of sophisticated low observable technologies. In 1972-1973 McDonnell Douglas designed the Quiet Attack Aircraft Project, which attempted to achieve lower radar, infrared and acoustic signatures than former attack aircraft, increasing survivability in high threat environments. The design included hidden inlets and a blended shape which avoided all vertical surfaces and contained no straight, leading, or trailing edges. However, the edge returns resulted in a contradiction. Entire curved platform edges produced a flare spot, which resulted in a relatively strong diffracted return from part of the edge, perpendicular to the line-of-sight [12] at nearly every viewing aspect.

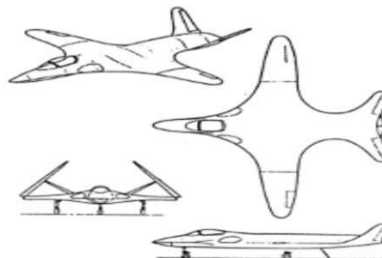


Fig.10 Quiet Attack Aircraft Project (From [12])

III.VIRockwell International B-1B (First Flight 1984)

At the beginning of the 1970s, the U.S. realized that its B-52 squadrons would be vulnerable to advanced Soviet defense radars. Therefore, a faster bomber with more capability to conceal itself from enemy tracking missile systems was vital. The B-1 bombers were designed to meet these requirements with their low altitude, high speed, penetrating bomber capabilities. Its careful design with rounded fuselage shape and RAM applied to key areas, gave it an RCS which was much less than a small fighter [2]. Although its curved engine nacelle upgrade reduced the flight performance and top speed of the B-1B as compared to the B-1A, this design change resulted in a great RCS reduction by means of eliminating and trapping incident radar signals [2].

The electrically conductive tapes prevented discontinuities and travelling waves which contribute to RCS, were eliminated. The aircraft's AN/ALQ 161A defensive avionics also improved survivability by means of its comprehensive electronic counter-measures, such as electronic jamming, dispensing expendable chaff and flares (or towed decoys), in-flight re-programmable design, detecting-counteracting enemy radar threats and missiles even when attacking from the rear [2],[11].

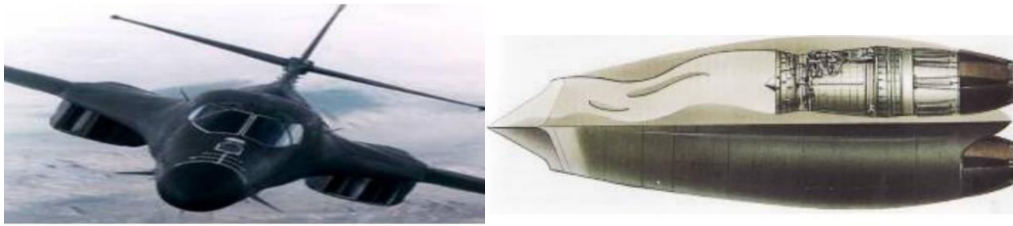


Fig.11 B-1B Lancer (From [4]) Fig.12 The Engine Nacelles of B-1 (From [4])

III.VIIF-117 Nighthawk

The F-117 is considered a second-generation stealth aircraft, and an advancement over first generation variants, like the SR-71 Blackbird and other early low observables. It was the first aircraft designed with a focus on all aspects of stealth, although RCS was the leading concern. In earlier low observable designs, the low observability was either an added feature or a partial consideration to improve survivability. Instead, the F-117 was designed to be stealthy first, and other specifications were aligned to this purpose. This design was based on the Experimental Survivable Testbed (XST), a technology demonstration, also known as the Have Blue project. Although more realistic than the “hopeless diamond” concept, which was aided by sharp surfaces without extended parts, the XST was designed from an electrical engineering perspective rather than an aerodynamic one. The F-117 was deployed as a single pilot, twin-engine powered, stealth, night strike, light bomber with the ability of cruising at high sub-sonic speeds (max. 0.92 Mach), carrying 5000 lbs bombs (usually two, each weighing around 2000 lbs) and having a range of 900 miles, with extension by air-refuelling. The fuselage of the aircraft was produced with straight lines, which was different from the conventional curved approaches. The wings have three flat surfaces, one on the top and two on the underside. The aircraft has outward-canted thermoplastic graphite rudders. Because of its unusual aerodynamic shape, a fly-by wire control system is used for handling. Flight data is taken from four special faceted low observable air pitot probes in the nose of the aircraft. The entire body is coated with RAM. The cockpit panels, as well as other access panels such as weapon bays, have serrated shapes to reflect the incoming signal in directions other than toward the radar receiver. The faceted cockpit glass, has special coatings which prevent radar waves from penetrating into the cockpit, thus eliminating further reflections. The engine intakes have fine mesh grids, which are 2.5 cm by 1.5 cm, to conceal the engine blades that would otherwise contribute to the RCS. The forward-looking IR (FLIR) and downward-looking IR (DLIR) panel apertures are covered with wire mesh. To avoid signal detection by hostile receivers, no radar is deployed on the aircraft. The inertial navigation system is aided by flight computers and a global positioning system (GPS) satellite navigation receiver (this was a later upgrade). For locating target and guiding weapons, IR (FLIR for initial detection and DLIR for close range) and electro-optic laser designator systems are used to take advantage of their passive nature. All of the ordnance is carried internally in centreline weapons bays. If a determination is made that there is a risk of being detected, the aircraft’s automated system blocks the bomb doors from opening [4].



Fig.13 F-117 Nighthawk (From [4])

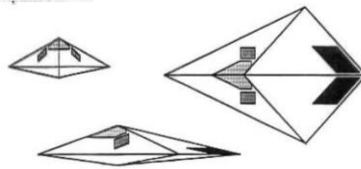


Fig.14 Hopeless Diamond (From [4])



Fig.15 XST or Have Blue (From [4])

Most of the design features are used against radar detection, but some are for IR signal reduction. Together with some IR signal reducing coatings on the surface, a portion of the inhaled air bypasses the engine and is utilized to decrease the temperature of engine efflux by forming a mixture consisting of this air mass and hot engine efflux. This mixture is ejected through narrow-slot exhausts in the rear fuselage and diminishes the aircraft’s jet plume IR signature [2].



Fig.16 Reflection of F-117's Cockpit Coating (From [4])



Fig.17 Thin Mesh Grid, at the Engine Intake of F-117 (From [4])

III.VIIIB-2A Spirit (Stealth Bomber)

The B-2 is a long-range, multi-role, heavy strategic stealth bomber with the capability of carrying both conventional and nuclear payloads. It is piloted by two crew members, with a place for a third flight-member. Because of its nuclear mission, it is radiation hardened. It can carry up to 40,000 pounds of armament: 16 nuclear bombs, 16 to 80 conventional bombs, or 8 to 12 precision guided attack bombs. All of these must be located in its internal bomb bays. If mission requirements dictate, a mixed bomb configuration is also possible. By using a flying wing concept, the B-2 has minimal surfaces contributing to drag, and its four non afterburning turbofan engines within the body-wing blended shape give it a considerable lift factor. This enables the aircraft to carry large payloads with fuel efficiency to intercontinental ranges (nearly 6000 nautical miles at up to a 50,000 ft mission ceiling), that can be extended with refuelling. It has a high subsonic (maximum speed of nearly 0.85 Mach) cruise speed which both provides mission capability and contributes to its low observability [4].



Fig.18 B-2 Spirit Flying Wing Aircraft (From [4])



Fig.19 B-2's Open Bomb Bays (From [4])



Fig.20 B-2's Open Bomb Bays (From [4])

Serrated edges are used extensively in B-2's design and cockpit windows have fine wire mesh for reducing RF signal reflections. Engine nacelles and nozzles (ahead of the trailing edge) are all placed above the wings as a design measure for both RF and IR signal reduction. The four engines are concealed from the reach of direct radar signals by the curved shape of the nacelles. The air intakes have a very complex shape, with a slitlike secondary inlet below the main opening and two extra air supply doors, on the upper surface of each nacelle to increase the performance of the engines at taxi, take-off, while flying at low speeds and under cases of turbulence. The heat of the exhausts is also eliminated by mixing airflow obtained through the boundary layer splitter slot to reduce the IR signature [13].

III.IXF-22A Raptor

Following the success of the stealth F-117A and the B-2A bombers, the U.S. Air Force began work on a new stealthy air superiority fighter project, the Advanced Tactical Fighter (ATF), at the end of 1980s. The YF-22 was selected for this role to replace the aging fleet of F-15s. Thus, it was designed as a one seat, next generation, multi-role, air superiority stealth fighter and after some development changes YF-22 was turned into F-22A Raptor. The mission of the Raptor includes escorting other attack aircraft to their targets, hunting enemy fighters, and destroying air defences such as SAM sites. U.S. forces expect the F-22, to provide air superiority by dominating the increasing capabilities of integrated air defence systems and hostile air forces with its precision ground attack capability and air-to-air sophistication for the next 40 years [14]. The main concept of the F-22 is "first-look, first-shot, first-kill capability [14]" by using its stealth capabilities, advanced sensors and precise air-to-air and air-to ground weapons. It is very manoeuvrable with its large control surfaces and two thrust vectoring engines with a mission ceiling of more than 50,000 ft.



Fig.21 YF-22(From [4])



Fig.22F-22 A Raptor (From [4])

The F-22 uses less RAM and RAS than earlier generation stealth aircraft. Some of the RAM is a sprayed-on type and it covers the edges of doors and control surfaces. RAS is used on the body, wing and tail edges, and its conductive metallic coating prevents radar energy from penetrating the composite skin [15].The F-22, like other stealth aircraft, has a carefully designed shape that contributes to RCS reduction. The forward fuselage is diamond-shaped in cross section and the fuselage has large surfaces. The aircraft has inlet ducts which are both curved inwards and upwards to provide shielding to front faces of the twin engines from direct illumination by hostile radars [2]. The payload of the F-22 can be increased with its four underwing pods, if the mission is suitable for this non-stealthy configuration. The pylons under the wing can be jettisoned after expending ordnance to regain low observability. Furthermore, development of stealthy ordnance is under research [15]. The exact RCS level of the aircraft is confidential; however, it is hypothesized to be -40 dBsm (0.0001 m²) at certain critical angles [15].



Fig.23 F-22 with Two External Fuel TanksPayload (From [4])



Fig.24F-22 with Two External Missile Payload (From [4])

III.XModern UAV and Cruise Missile

Along with manned aircraft, unmanned aerial vehicles (UAVs) or unmanned aerial systems (UAS) and cruise missiles also take advantage of stealth technology. UAVs maintain significant advantage over manned aircraft. They do not put human life at risk, since there is no pilot on board, thus affording them the ability to enter even the riskiest battlefield environments. Additionally, they can stay airborne for extended periods because there are no crew restrictions. Further, they weigh less, cost less, are smaller, have more payload, and more manoeuvring capability than comparable manned aircraft. To increase their survivability, just as in the case of manned aircraft, stealth technologies are now being applied to UAV design.Modern stealth UAVs use similar techniques as manned aircraft to reduce their signatures. Most stealth UAVs are flying wing designs without tails, with sharply canted surfaces, engines located on top of the fuselage and internal payloads. Serrated surfaces and RAM/RAS are also used for further RCS reduction[4]. The RQ-3 DarkStar, Boeing X-45C, Northrop Grumman X-47A, BAE Systems Taranis, and the Dassault nEUROn are some UAV examples which have used stealth technology.



Fig.25 Boeing X-45 C (From [4])



Fig.26 Northrop Grumman X-47A (From [4])



Fig.27 Dassault nEUROn (From [4])

IV. AREA OF IMPROVEMENT FOR STEALTH AIRCRAFT

IV.I Speed and Manoeuvrability

Stealth aircraft unable to fly as fast as standard fighter aircraft nor are these as manoeuvrable.

IV.II Payload

The stealth aircraft is the reduced payload that these can carry because most of the payload is to be carried internally, in order to reduce radar signature.

IV.III Comparative Cost

Stealth aircrafts are comparatively much costlier than their standard fighter aircraft.

V. THE REASONS WHY AN INDIAN AIR FORCE NEED STEALTH TECHNOLOGY

Stealth aircrafts are particularly designed with the features and performance qualities to increase utility, which helps to fulfil the mission objectives. Thus, stealth ability has a crucial role in the battlefield. Further, stealth aircrafts are able to achieve and survive missions where other fighter aircraft cannot. Their functioning gives the capability to attack even the most well defended zones with safety. In battlefield, tracking of enemy assets is crucial for counter attack. While on other side, low observable technology enhances air superiority and the freedom to attack surface targets by means of reducing an aircraft's radar detection range and its infrared, visual and acoustic signatures to degrade the chance and range of detection [9]. Thus, stealth technology assets capable to conduct missions securely, even in the most defended enemy zone. Though it is not possible to become completely stealthy, either delaying the detection or lessening an opponent's ability to track target course after detection provides a major advantage to low observable users [3]. With stealth technology, defenders might not be able to respond at all. If a surface-to-air-missile battery defending a target observes a bomb falling and surmises that there must be stealth aircraft in the vicinity, it is unable to respond if it cannot get a lock on the aircraft in order to feed guidance information to its missiles [10]. To sum up, stealth technologies give an edge in battlefield. They reduce the risks of mission against well defended targets in enemy territory. Further, stealth assets surprise attack will do the heavy damage of enemy in battlefield. Thus, an air force needs stealth technology to neutralize enemy air defences and to destroy high value, strategic targets while improving friendly forces' air superiority. An air force with these capabilities will control the airfields and operate safely while reaching and penetrating into an enemy's deepest territories [9].

VI. FUTURE OF STEALTH TECHNOLOGY

The future of Stealth Technology appears to be brighter than ever because of the fact of significant development in these field of defense. The fact that most countries are investing heavily in Stealth technology and the emerging technologies.

VII. CONCLUSION

The advancement in Stealth Technology plays vital role in any air force forces aiming to achieve superiority. When stealth is implemented effectively, aircrafts can dominate battlefield which increases the mission success possibilities. The Stealth Technology has improved significantly more advanced in the last fifty years or so.

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