INSTITUTE FOR DEFENCE STUDIES & ANALYSES

IDSA ISSUE BRIEF

Evolution of Aerial Combat

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July 8, 2013

Summary

At the dawn of aerial warfare, the weapons as well as the aircrafts were rudimentary. Over the years the advancement of technology led to deployment of guns and canon on aircrafts. The availability of new weapons influenced the nature of aerial warfare and the aircrew were constrained to tailor their tactics to meet weapon considerations. Over the years, guns and cannon gave way to air-to-air missiles, initially with close range and then long range weapons. The modern air-to-air missiles changed the nature of aerial combat, moving it from close in "dogfight" towards energy combat at much longer ranges. Current trends indicate a future of directed energy weapons (DEW), which will further change the nature of aerial combat.

Introduction

Aircrafts entered the battle field in the early years of the twentieth century and immediately made their mark. Thereon great strides have been made in the development of weapons and the conduct of aerial warfare. An examination of the evolution of these weapons is educative and gives pointers towards future developments in the way that aerial combat is likely to be conducted.

Advent of Aerial Weapons and Early Aerial Combat

In World War I (1914-18), emphasis was placed upon aircraft extending the hot air balloon concept of observation of enemy land forces' deployments and movement from the air. Then current aircraft capability did not permit more advanced roles. As the military advantages of better intelligence from aerial observation of opposing land forces became clear, it became desirable to deny the enemy similar information through use of his aircraft, by destroying his aircraft if necessary.

The Advent of Aerial Combat

As early aircraft were not used as weapon platforms, the pilots carried personal firearms, such as revolvers and rifles, which were fired from the cockpit while flying the aircraft. Such weapons were quite expectedly inaccurate, to say the least. In time, personal firearms gave way to flexible gun mountings[1] on two-seater aircraft during World War I. At the time, combat comprised of the pilot manoeuvring his aircraft to get the enemy abeam or slightly behind his own machine[2] to enable the gunner to fire his flexible gun.

Attempts to fix weapons on aircraft, such that these fired from outside the propeller disk, were abandoned till the time aiming problems had been resolved to an acceptable extent.[3] A major breakthrough that spread rapidly was the invention of an interrupter gear[4], which

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1 These involved two-seat aircraft with a gunner positioned in a cockpit behind the pilot's cockpit. This gunner's cockpit housed a machine gun on a mount, which could be traversed by the operator to an extent dependent upon the mechanics of the mounting design; hence the "flexible" tag. This two-seat configuration was adopted because fixing forward firing guns on the fuselage was not possible due to the presence of the propeller at the front of the fuselage.

2 The location of the flexible gun in the gunner's cockpit behind the pilot still did not permit firing forwards due to the propeller and the pilot himself being located in the way.

3 This happened just prior to World War II when many fighters fielded multiple machine guns mounted on their wings, well outside the fuselage-mounted propeller disk. By this time, while sighting remained dependent upon the ring and bead sight, the theory of aerial gunnery and sighting had been fairly well understood.

4 This was a mechanism that was able to track the position of the blades of the propeller as these rotated around their axis. It inhibited the firing of the gun or machine gun fixed to the aircraft fuselage at the moment that a propeller blade was in front of the barrel of the gun, and thus most vulnerable to damage. The interrupter gear enabled fixing of guns close to the fuselage ahead of the cockpit and firing forwards through the propeller disk.

greatly eased problems of aiming. Attention was also devoted to developing sighting systems to deliver accurate firing solutions. Initially, basic ring and bead sights were used. Over time, there was progress in the types of guns used, with machine guns of various calibres being fitted on aircraft. The location of the weapons also varied from the forward fuselage to multiple installations on the wings. Major attention was devoted towards development of better sighting systems in this period.

Nature of Early Air Combat

Fixed forward firing guns on fighter aircraft forced pilots to aim the entire aircraft to aim the weapon. Combat comprised tight manoeuvres by opposing aircraft in very close proximity. As aircraft speeds were very slow at the time, the turning radii of aircraft were small—just a few tens of metres—while effective ranges of the guns were also relatively small. While turning to point one's own aircraft at the correct aim point for a hit on the enemy, a fighter pilot had to keep a sharp lookout for other enemy aircraft coming into position to fire at him. This close proximity tight turning fight led to the coining of the term "dogfight" due to its similarity with a pack of fighting dogs. Combat comprised manoeuvring one's own aircraft to point it entirely at the required point of aim ahead of the enemy. The need to concentrate on this combined with the presence of more enemy aircraft in the area gave birth to a "pair of aircraft" as the basic element in aerial combat. While the leader of a pair engaged the enemy, his "wingman" or "No. 2" scanned the airspace around to spot any attack on the pair by other fighters. Most pilots successful in aerial combat fired from very close ranges to overcome the limitations of sighting systems. Basic rules of aerial combat were derived as early as World War I by an extraordinary German pilot, Captain Oswald Boelcke, in form of his *Boelcke's Dicta*.[5] These *Dicta* remain true even in today's skies that host formidable modern fighters such as the F-22, Rafale, Su-30MKI, MiG-29, F-15, F-16, EF-2000 Typhoon, etc., armed with advanced missiles.

Developments in Sighting Technology

The ring and bead sight remained the mainstay of sighting till the 1940s, with few alterations. Military aviation entered the Second World War with the fixed gun and ring and bead sight as the basic weapon and weapon aiming system in aerial warfare. During World War II, the reflector sight was introduced which, in its earliest avatars, displayed similar symbology to ring and bead sights but on a semi-reflective glass plate. Technical advances then saw the introduction of the first gyro gun sights. These used gyroscope properties to help the pilot obtain required lead angles for deflection shooting through a degree of automation. Technology thus started to move the secrets of accurate aerial shooting from the man towards the machine. Individual skills in deflection shooting now included skills in gyro handling.

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5 "Oswald Boelcke", available at http://usfighter.tripod.com/ww1ace.htm, accessed on 18 June 2013.

In the years after World War II, the advent of the computer led to major advances in gun sight technology. Computers installed in the weapon system were able to rapidly compute more accurate firing solutions than had been possible earlier. The earliest computer-enhanced gun sights required a short period of steady tracking of the target to compute accurate solutions. More advanced digital computers reduced this time requirement considerably. By the 1960s and 1970s, "snap shoot" gun sights were being introduced. These obtained their name from their ability to very rapidly compute and display firing solutions with minimal steady tracking of the target, thus enabling an earlier "first accurate shot" by the aircraft equipped with such gun sights.

The nature of aerial combat in World War II and through the 1950s to the 1970s remained essentially the same as in World War I, as the primary weapon was the gun and sighting was through slightly improved but essentially similar sights as before. The dogfight still dominated; the difference being that with higher speeds, the dogfight occupied more volume than before. Most successful fighter pilots fired from very close ranges to overcome the limitations of sighting accuracy and bullet dispersion. Snapshoot gun sights enabled their lucky operators to get a few very high deflection shots, "impossible" in earlier years, off for quick kills.

The Missile Age

It was during World War II that the search for a technical solution to the problem of more accurate weapon usage in aerial combat led Germany to develop the world's first guided Air-to-Air missile (AAM)—the Kramer X-4 (also known as the RK-344), which in its earliest versions was wire guided with a maximum range limited by the length of wire to about 3.5 km.[6] Another German AAM—the Hs-298—used both radio command guidance and wire guidance in different versions. The radio command guidance variant had a maximum range of close to 9 km. These guided missiles solved the problems of accurate attack with the projectile itself being able to modify its flight path towards the target based upon command inputs; however, these developments came far too late to affect the outcome of the war.

The advantages of a projectile that could manoeuvre towards the target in flight after being fired were self-evident, and major research effort was devoted towards development of such weapons to make aerial engagements more lethal for the enemy. As is usually true for any new technology, its champions tended to overestimate its capability in the early years. Some sections thought that advent of the air-to-air missile meant the end of the airborne gun/cannon. In the US, the McDonnell Douglas F-4 "Phantom-II" fighter

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[6] Emmanuel Gustin, "German Secret Weapons of WWII", available at http://www.warbirdsresourcegroup.org/LRG/Secweap.htm, accessed on 31 May 2013.

bomber was built without an integral gun/cannon.[7] Its designers put their faith in the new air-to-air missiles as its sole air-to-air armament and this was accepted in full by the F-4's first operators, the US Navy and Air Force. American aviators realised the folly of elimination of the gun/cannon when they met MiG-19 and MiG-21 aircraft over Vietnam and their rudimentary air-to-air missiles—the Air Intercept Missile (AIM)-7A/B "Sparrow" and the AIM-9A/B "Sidewinder"—proved far less effective than expected. Left unarmed while engaged in mortal combat after firing their missiles, the US aircrews rued the lack of a gun/cannon on the aircraft. During this war, an add-on gun pack in a blister fitting (or gondola) installed on the lower fuselage was developed for the F-4. Since then every fighter aircraft has carried a gun/cannon. Even the world's first in-operation Stealth fighter—the F-22 "Raptor" —carries an internally mounted cannon.[8]

AAMs usually have firing ranges measured in kilometres as compared to the few hundred metres of guns. The ability to hit from further away removed the need for close-in manoeuvring. Early missiles still required a position in the target's rear quarters for success. This position is similar to that needed for gun firing in the earlier years. Early AAMs just opened out the "dogfight" to larger ranges while the essential manoeuvres remained the same as before. Early AAMs, such as the AIM-9A/B and Russian K-13, did not change the nature of aerial combat in a major way. These missiles required similar manoeuvring as guns did, to achieve a position in the target's rear quarters for a successful shot. Their affect was limited to open out the ranges of firing and freeing the attacker, to an extent, from the tyranny of steady tracking and accurate gun aiming.

AAMs have come a long way since the Vietnam War. Today's missiles are several orders of magnitude more capable than their fore bearers. Cutting-edge modern AAMs designed for close combat boast large "no escape zones".[9] A few All Aspect Air-to-Air Missiles (A4Ms) that fall into this modern lethal A4M category are the Israeli Python-4 and Python-5, the US AIM-9X "Sidewinder", the Russian R-73E RDM-1 and R-73E RDM-2, and the European Iris-T. Several of these missiles boast Imaging Infra Red (IIR) seekers in place of the earlier pure IR spot seekers. IIR helps the missile look for and track the typical IR band "shape" (locking on to the hot parts of the friction heated airframe which displays a distinctive aircraft like shape) of its intended target, and thus offers much better resistance

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7 A gun is differentiated from a canon from the fact that the former fires solid projectiles that cause damage through kinetic impact alone. A canon, on the other hand, is able to fire projectiles that carry an explosive charge and cause damage through a combination of kinetic impact and explosive affect on the target.

8 The F-22 is fitted with an internally mounted 20 millimetre M61A2 Vulcan Gatling *cannon. See Lockheed Martin's website, http:// www. lockheedmartin.com/us/products/f22.html.*

9 A "no escape zone" refers to the superb kinematics performance of the missile and signifies that once a target aircraft has been introduced into the missile's "no escape zone" and the missile fired, the probability of the target being able to escape intact through manoeuvre is infinitesimally small.

to IR countermeasures as compared with earlier IR missiles that tracked a heat source sans shape.

A4Ms freed the launch aircraft from having to fire from the target's rear quarters only. The nature of manoeuvres changed considerably, with the dogfight being replaced by high speed slashing attacks from almost any aspect to the target. The combat arena opened up considerably as most A4Ms boasted ranges of more than 10–20 km. Modern A4Ms made the first move towards freeing aerial combat from the "dogfight". Large ranges coupled with ability to launch from any aspect changed the very nature of aerial engagements, with emphasis now being placed more on spotting the enemy first and getting in the first short than on manoeuvring agility. Energy agility came to replace manoeuvre agility as an important fighter design feature.

Development of other AAM guidance systems was based on the use of radar to guide missiles. The larger range obtainable through use of radar[10] led to development of radar-guided missiles for Beyond Visual Range (BVR) weapons. The earliest examples of such missiles were the AIM-7A/B "Sparrow" semi-active radar guided BVR missiles. Current generation BVR missiles include the US AIM-120 Advanced Medium Range Air-to-Air Missile (AMRAAM), the Russian R-77, the Israeli Derby, the French MICA, and the British Meteor. While earlier BVR radar missiles were semi-active[11], newer missiles are usually active[12] missiles that give their launch aircraft a "fire-and-forget" capability.

Semi-active missiles required launch aircraft support throughout their flight. This has two possiblly unpleasant consequences. Firstly, while carrying out its semi-active missile

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10 IR energy suffers high attenuation in its passage through the air. Radar energy suffers appreciably lesser attenuation in similar conditions due to its much larger wavelength. Thus, radar is able to deliver much better range performance than IR.

11 A semi-active radar guided missile is dependent upon its launch aircraft till target impact. The launch aircraft has, on board, a powerful airborne radar. It locks on to and tracks its target with this onboard radar. The missile itself carried on board a radar receiver only, in addition to antennae designed to receive radio command instructions from its launch platform, apart from other normal components such as its guidance computers, proximity and impact fuses, warhead and motor. After launch, the semi-active missile is directed in the general direction of its target through command signals from its launch aircraft's radar computer. At closer ranges, its own radar receiver picks up the radar energy of its launch aircraft reflected from the target and then it homes on to this reflected energy till impact. The launch aircraft is thus constrained to retain radar lock on the target till the missile's flight time elapses. As the radar on fighters is mounted in the nose section, the fighter has to continue flying towards the target for the duration of the engagement.

12 An active radar guided missile such as the R-77 or AIM-120 carries not just a radar receiver but its own radar transmitter as well. After launch at a range called the "self lock on range", the missile's own on-board radar acquires and locks on to the target and thereafter guides itself till target destruction.

attack on the target it is possible that other enemy aircraft in the area may be able to shoot down the fighter, which is constrained to continue on a fairly rigid and fixed path. On the other hand, as the fighter continues to close in on its intended victim throughout the engagement, there is a possibility that the doomed target subject to semi-active missile attack may be able to acquire the fighter and launch its own fire-and-forget IR guided A4M at the fighter taking it out of the sky before or concurrent with its own demise. In contrast, from the time of "self lock on" of an active missile, the fighter is free to carry out any manoeuvre in any direction without jeopardising the attack. These active missiles are more lethal and provide greater survivability to their launch aircraft platforms.

Semi-active missiles, while constraining the launch aircraft's manoeuvres during its time of flight, helped open up the combat arena even more than the A4M had done. Semi-active BVR missiles had ranges typically of more than 25–30 km, and were not constrained in requiring to be launched from any particular position with respect to the target. Semi-active BVR missiles sounded the final death knell of the classical "dogfight", which had dominated aerial engagements from World War II till the A4M era. The active BVR missile has taken this trend further in granting the missile launch platform the freedom to manoeuvre while the missile is still in flight. This freedom enabled better survival probability in actual combat.

The recent shifting of the sighting system from the windshield to the pilot's helmet has resulted in freeing the pilot from needing to bring the target into his windshield in order to engage him. In concert with high "off bore sight" capability[13] missiles, the pilot can now fire at a target which is not in front of him but off to any side, all the while being within the azimuth and elevation limitations of his helmet-mounted sighting system and of his missile. Such a situation has made it more difficult to judge one's vulnerability to an opposing aircraft as well as made aerial combat more lethal.

Future Developments in Weapons and in Aerial Combat

BVR or A4M missiles are not the last word in aerial armament. Today, research is heading towards the development of Directed Energy Weapons (DEWs) to replace the legacy projectile (unguided or guided) weapons. DEW has opened up the aerial weapons field to include solid state lasers, particle beam weapons, and directed high power microwave

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13 Even to fire missiles—as these weapons are fixed on pylons aligned with the fore and aft axis of the fighter and the missile seekers look directly ahead within a small cone—pilots needed to point the aircraft axis and hence the missile seeker at the target to obtain a "lock on" to launch. Some missiles have slew able seekers that can scan angles in excess of 45–60 degrees about their fore and aft axis. Such missiles, while remaining fixed on the aircraft axis, can detect and lock on to targets well beyond the bore sight (fore and aft vector) of the fighter. Thus fighters with these missiles can launch at targets that are off to one side.

weapons. Research is in progress on these new weapons in technologically-advanced countries that aim to lead and not follow. The US is carrying out flight trials of its Airborne High Energy Laser (AHEL), currently mounted on a Boeing 747 aircraft. It is clear that over the next few decades there will be ever increasing progress in development of DEW for use in aerial warfare, as the current problems of provision of the high energy required for operating these is resolved. DEW with their high energy, near-instant impact on targets[14], and selectable calibrated energy output offer a sea change in the way warfare is conducted.

DEW weapons deployment on aircraft is likely to be constrained by the need of very high electrical energy for these to function. Due to the speed of travel of energy, DEW are unlikely to require any deflection in sighting, thus vastly simplifying their use. The near instantaneous arrival of the DEW from launcher to target is likely to lead to a major time compression in aerial combat. The need for tight manoeuvre has progressively reduced from the initial aerial dogfights in World War I, through World War II to the modern missile age. DEWs are likely to remove tight high 'g' manoeuvre altogether from the design requirements of fighter aircraft as well as combat tactics. This is going to be a major change.

Till date, the introduction of better weapons and sighting systems have reduced the need for tight manoeuvre and opened up the ranges at which combat is conducted. However, even in modern aerial warfare, purely BVR combat agility and manoeuvre play a prominent part. The advent of DEW is likely to change that paradigm. A parallel can be seen here with land warfare where the short sword, long sword, lance, etc., opened up the combat distance and later the rifle changed the very manner of fighting. In a DEW era, detection of the enemy at large ranges and firing one's own DEW at him first is likely to be decisive with tight manoeuvres being relegated to the dustbin of history. However, it is unlikely that anyone is likely to abandon guns and AAMs in a hurry until DEW technology is fully mature and battle proven.

Conclusion

The first weapons to be used in aerial warfare were the personal side arms of the pilots. Since then, aerial weapons have evolved through fixed and flexibly mounted guns and machine guns, through cannons to A4M and BVR missiles. Aerial combat has essentially remained the same since its advent in World War I. Weapon developments have been progressive and evolutionary over the past century; thus the manner of fighting has essentially remained the same, with distances and a few details changing. Weapons and

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[14] DEW weapons comprise directed electromagnetic (EM) energy. All EM energy travels at the speed of light, hence the near instantaneous impact on the designated target.

their utilisation technology will continue to develop further. Research today is focussing on the development of DEW as the next phase in the evolution of the weapons of aerial warfare. These new developments in weapon technology are likely to have a far-reaching effect on how aerial warfare is conducted.

These changes are likely to be revolutionary in that they could be expected to change the very manner of conducting aerial warfare. Practitioners of aerial warfare must be firmly grounded in the legacy methods of using their weapons and other equipment as, at present, these will comprise the bulk of equipment available in case of war. However, they must keep a sharp eye on the latest developments in their field as it is likely that these will percolate fairly rapidly with game changing effects on the nature of their combat operations. Failure to do so would make them vulnerable to an enemy who has not ignored these new developments.