Post Cold War Air to Air Missile evolution

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THE AIR-TO-AIR MISSILE (AAM) IS THE BACKBONE OF MODERN WEAPON SUITES CARRIED BY FIGHTER AIRCRAFT. THERE HAS BEEN considerable evolution since the first AAMs deployed operationally in the late 1950s, and that evolution continues unabated. The past decade has been especially important, with the shift away from analogue guidance systems to digital, the appearance of Focal Plane Array imaging seekers, the commodification of Gallium Arsenide technology monolithic microwave integrated circuits, and the emergence of solid propellant ramjet engines – all impacting on the capabilities of these missiles.

The matter of AAM effectiveness and lethality remains controversial and steeped in as much mythology as fact, as competing players and Services market the virtues of their favoured designs. Little has changed since the early 1960s when guided missile proponents declared that fighter performance was irrelevant in the face of the then new US AIM-9B Sidewinder missile and its UK sibling, the DH Firestreak. But the Vietnam war proved this prediction to be just fantasy. Today we see the same arguments, now peddled by bureaucratic and industry proponents of aerodynamically or stealth-wise underperforming fighters.

The most widely used Beyond Visual Range missile in the Western world, the US AIM-120A/B/C AMRAAM, has achieved a success rate in real combat of around 50 per cent, but this has been against Third World targets without modern countermeasures, modern warning systems, or indeed pilot evasive skills. While test range claims for the latest AIM-120 variants sit around 85 per cent, these involved shots against QF-4 drones, which are not representative in turning performance of today's targets, such as Sukhoi Flanker fighters.

Achieving a kill with a guided missile is not as simple as many would have us believe. The missile must first be launched within a viable kinematic envelope, usually termed a "Launch Acceptable Region" (LAR), which means in the simplest of terms that the target is near enough that the missile does not run out of energy before it can kill the target. What is less often stated is that the kinematic envelope for an AAM varies greatly with target aspect and thus the closure rate between the missile and its quarry. The distance at launch for a target head-on is much larger than a tail aspect target, since the target is flying into the missile. What is a viable kinematic envelope may not be viable if the opposing aircraft performs even a simple reversal, for which there is plenty of time in many Beyond Visual Range combat situations.

Covering the distance to the target after launch, termed the midcourse flight phase, is relatively straightforward, for most missile designs. Problems may arise if the missile has a datalink to receive target position updates during flight – and the datalink is jammed. Problems may also arise if the target performs a major change in trajectory, which puts it outside of the kinematic envelope while the missile is in transit.

MBDA Meteor.

Once the missile nears the target it will transition from midcourse flight to its terminal homing phase, usually termed the 'endgame'. Most missile failures in combat happen during the endgame.

Playing the endgame successfully requires the missile to overcome defensive manoeuvres by the target, and overcome defensive countermeasures used by the target. The former are constrained by the aerodynamics of the target, which are dramatically different for a contemporary thrust vectoring Su-30MK or Su-35BM, compared to a 1980s MiG-23/27/29 or Su-27S. The latter are determined by capabilities of the flares, expendable jammers, infrared or radio frequency jammers, and infrared and radar signatures of the target. Suffice to say that the towed decoy, laser infrared jammer or Digital RF Memory microwave jammer, which a missile guidance seeker has to overcome today, present far more challenges than the low burn temperature flares, chaff, and basic jammers deployed during the late 1980s.

Developments we have seen over the last two decades reflect in part the availability of new technologies used in the design of missiles, as they reflect the competitive pressures of defeating opponents' designs.

The end of the Cold War is a useful datum point for any discussion of AAM technologies, both Within Visual Range (WVR) and Beyond Visual Range (BVR).

WITHIN VISUAL RANGE AAM EVOLUTION

At the end of the Cold War the standard Western close combat missile was the heatseeking AIM-9L/M, and in some air forces the AIM-9E/P series. This basic missile was an evolution of the 1960s AIM-9 variants, with a gas cooled all aspect InSb detector in a conically scanning seeker, predominantly analogue processing, and a simple short burn motor and canard controls.

The Soviets deployed with the MiG-29 Fulcrum and Su-27 Flanker the revolutionary R-73 Archer missile, which used a large diameter high impulse rocket motor, exhaust thrust vectoring and a complex canard arrangement to provide hitherto unseen G capability for endgame homing, and an agile gimbaled seeker coupled to a helmet mounted sight, allowing the missile significant off-boresight launch capability. The Archer was superior to all of

AIM-9X Sidewinder.

BGT Iris T.

Rafael Python 5.

its Western competitors and used properly could produce devastating effect in close combat.

The Israelis were first to react, developing the superb Rafael Python 4 missile, which also used an agile gimbaled scanning seeker, but combined a long burn duration motor with a double delta wing and dual canard control arrangement to outperform the Russian Archer.

The unusual and unique British ASRAAM followed, generally regarded to be the fastest close combat AAM ever built. It combined an unusually high impulse motor, with an agile imaging InSb Focal Plane Array seeker, and an inertial midcourse guidance package to permit defacto beyond visual range shots, or helmet mounted sight cued 'over the shoulder' shots against rear quarter targets.

The US AIM-9X was a substantial redesign of the baseline AIM-9 series, retaining the rocket motor and warhead, but introducing a new agile gimbaled Focal Plane Array seeker with an inertial midcourse guidance package, a new control arrangement combining thrust vectoring with ganged tail controls, and new energy management algorithms to extract best possible range and turning performance from the impulse provided by the legacy motor.

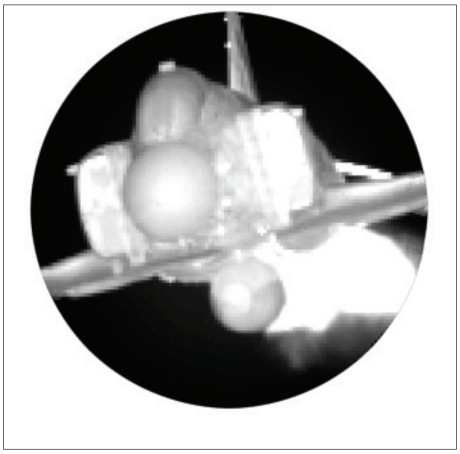
Germany, and its partner Norway, opted to go their own way and developed the Diehl BGT IRIS-T (Infrared Imaging System Tail/Thrust Vector-Controlled). This missile combines mid-body strakes for high turning performance with tail controls and thrust vectoring.

The Russians were not idle and developed a series of incrementally improved Archer variants, with greater off-boresight capability and better ability to reject countermeasures. The most advanced Archer variant is the fully digital R-74E (K-74), disclosed some years ago.

Post cold war missiles are now entering the second generational phase. Rafael are now marketing the Python 5 missile, which is an enhanced Python 4, using a gimbaled Focal Plane Array seeker with an inertial midcourse guidance package. China is currently working on its equivalent to the AIM-9X, a similar tail control thrust vectoring design.

The converging technological trends for close combat missiles relate to the use of imaging agile gimbaled Focal Plane Array seekers with inertial midcourse guidance packages and advanced aerodynamics including thrust vectoring. Motor impulse will progressively but incrementally improve for the foreseeable future.

Such weapons will be capable of sustaining 60 to 90 G in the endgame, and will be resistant to most countermeasures, other than lasers with the power to burn through protective filters and destroy the imaging array.



The advent of FPA imaging seekers means higher sensitivity, better immunity to countermeasures, and intelligent aimpoint selection. Depicted image from AIM-9X trials.

Beyond Visual Range AAM Evolution

At the end of the Cold War BVR missiles shifted away from semi-active radar homing seekers, where the launch aircraft must illuminate to impact, to active radar homing seekers that allow the launch aircraft to break off once the seeker has acquired the target.

The AIM-120 AMRAAM was the first production medium range missile to provide this capability – until then seen only in the very long range Hughes AIM-54 Phoenix carried by the US Navy F-14 Tomcat, and its Russian equivalent, the Vympel R-33 Amos carried only by the MiG-31 Foxbat.

What was revolutionary about the AMRAAM was that it combined a digital autopilot with a strapdown inertial system, a Travelling Wave Tube active radar seeker, and a datalink allowing the radar on the launch aircraft to continuously transmit position updates on the target as the AMRAAM sped away. Once the missile entered the 'acquisition basket' and was near enough to lock on, the seeker would activate, paint the target, then switch to terminal homing.

The thinking behind the AMRAAM was to provide the US F-15C in the Central European Theatre, with the capability to simultaneously attack up to eight incoming Soviet strike aircraft, these comprising typically the MiG-23BM, MiG-27, Su-7BM, Su-17/22 and Su-24 Fencer. A secondary role for the AMRAAM was long range shots against Russian Flankers and Fulcrums to deny them the opportunity to use the lethal Archer at close range. At that time marketing literature for the AMRAAM even proposed that it be used as a 'one size fits all' air combat missile, replacing the AIM-9 Sidewinder, launched directly off the rail in active transmit mode.

Whereas the Soviets had the clear advantage in 1991 in WVR missile technology, the US held the advantage in BVR technology with the AMRAAM.

At that time most Western fighters were equipped with variants of the semi-active homing AIM-7 Sparrow, such as the monopulse seeker equipped AIM-7M or BAe Skyflash or older conically scanning variants including the Selenia Aspide, which was reverse engineered by the Chinese and remains in production.

When the AMRAAM arrived, the best medium range BVR missile the Soviets had were variants of the Vympel R-27 Alamo. While the Alamo predates the AMRAAM in design, it postdates the Sparrow. The monopulse semi-active radar homing short burn Alamo variant, the R-27R, indeed compares closely to the AIM-7M in performance and capabilities.

The Soviet strategy for defeating the AMRAAM was twofold. The near term measure was the 'long burn' Alamo, with a longer and larger diameter rocket motor casing carrying a lot more propellant. The long term measure was the RVV-AE or 'AMRAAM-ski' deployed in Russian service during the 1990s as the R-77 or AA-12 Adder. With much better range than the early AMRAAM variants, the long burn R-27 provided Russian customers with the first shot in a BVR engagement.

The RVV-AE AMRAAM-ski entered the market during the late 1990s, and combined AMRAAM-like guidance using the Agat 9B1348E datalink/inertial/active radar seeker, with a radically different straked airframe and lattice tail controls. Like early AMRAAMs, early Adders did not live up to expectations in range performance and, like the AMRAAM, the Adder has since gained a dual pulse extended burn rocket motor.

While most Russian effort post Cold War has been in the area of medium range missiles, they have also developed the Vympel R-37 / AA-13 Arrow and are developing the Novator R-172/K-100 'counter-AWACS' or 'counter-ISR' missiles in the 300 km to 400 km range class. These weapons provide the ability to kill AEW&C or tanker aircraft from outside the range of defending Combat Air Patrols. The 180 km range class AIM-54C Phoenix was withdrawn some years before the F-14Ds were scrapped, and there is no Western equivalent in existence or planned.

The period following the end of the Cold War saw incremental upgrades to the AMRAAM, primarily intended to improve counter-measures resistance and reliability. The latest AIM-120D variant, now in test, is claimed to include a dual pulse motor to extend range, a revised antenna design, a GPS receiver to improve midcourse accuracy, and a two-way datalink channel.

Late Cold War US DoD image of V-PVO Su-27 armed with a mix of short burn R-27T, R-27R and long burn R-27ER Alamo variants.

The other important technological development of this period was the air-breathing throttled rocket ramjet engine. Vympel made the critical breakthrough during the 1990s and widely marketed the RVV-AE-PD or 'ramjet Adder', subsequently licencing the technology to the French, via ONERA, who used it in the MBDA Meteor missile for the Eurofighter Typhoon, Dassault Rafale and SAAB Gripen Eurocanards. While the Russian missile has yet to appear outside mockups, the Meteor is now well into its development with an IOC planned for 2013.

What ramjet missiles provide is not only more range than rocket missiles of equal mass, as the oxidizing agent is the air mass itself, they importantly provide thrust during the endgame phase of the missiles' flight.

This is important because in conventional missile designs once the rocket motor is exhausted the missile's total energy is only that stored in its momentum and altitude. Once the missile has to pull significant G to close with a manoeuvring target, energy is bled off rapidly, with two effects: reduced closure rate and reduced ability to sustain G.

Because the missile is traveling several times faster than the target, it has to pull many times greater G to match the angular rate of the target and hit it, or get near enough for a proximity fuse to trigger detonation of the warhead.

The weakness of all pure rocket BVR missiles, single or dual pulse motor designs, is that typically they are flying on inertia in the endgame. When the Israelis designed the Python 4 they employed a profiled motor burn which quickly accelerated the missile, and then sustained its speed by using a slower burning propellant layer, the intent being to allow 70+ G to be sustained in the endgame.

One highly experienced air combat analyst has raised a very specific concern, which is that dual pulse rocket missiles typically gain additional speed in the latter part of their trajectory resulting in higher closure rates with targets, requiring much higher G to effect an intercept against a manoeuvring target. Conversely, a ramjet with throttle control can actually decelerate when entering the endgame, to reduce the peak G demand to collide with the target, and thus be more effective in the endgame.

Table 1 Russian Post Cold War AAMs

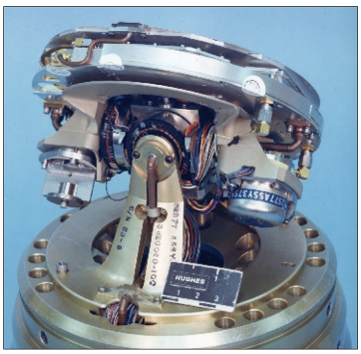
Type	Seeker	Model	Acquisition Range	Kinematic Range	O/B	Target G	Launch G	Length	Dia	Weight	Adaptor
Units	-	-	[NMI]	[NMI]	[deg]	[G]	[G]	[in]	[in]	[lb]	-
R-73	IRH	MK-80	5.4-8.0	16	45	12	8	114.2	7.0	232	APU-73
R-73M	IRH	MK-80M	8.0	21	60	12	8	114.2	7.0	232	APU-73
R-73R	IRH	MK-80M	8.0	5.4-6.5	60	12	8	126.0	7.0	253	APU-73
R-73E	IRH	MK-80E	8.0	16	75	12	8	114.2	7.0	232	APU-73
R-74ME	IRH	MK-80ME	8.0	21	75	12	8	114.2	7.0	232	APU-73
R-27R1	SARH/DL/IMU	9B-1101K	~16.0	43.2	-	8	5	157.5	9.0	560	AKU/APU-470
R-27T1	IRH	36T	5.4-8.0	38.9	-	8	5	145.7	9.0	561	AKU/APU-470
R-27P1	Passive RF	9B-1032	~130	38.9	-	8	5	157.5	9.0	560	AKU/APU-470
R-27A1	ARH/DL/IMU	9B-1103M	10.8-13.5	43.2	-	8	5	157.5	9.0	560	AKU/APU-470
R-27ER1	SARH/DL/IMU	9B-1101K	~16.0	70.2	-	8	5	185.0	9.0	773	AKU/APU-470
R-27ET1	IRH	MK-80/M	5.4-8.0	64.8	45/60	8	5	177.2	9.0	753	AKU/APU-470
R-27EP1	Passive RF	9B-1032	~130	64.8	-	8	5	185.0	9.0	773	AKU/APU-470
R-27EA1	ARH/DL/IMU	9B-1103M	10.8-13.5	70.2	-	8	5	185.0	9.0	773	AKU/APU-470
R-77	ARH/DL/IMU	9B-1348E	8.6	54.0	-	12	8	141.7	7.9	386.3	AAKU/AKU-170
R-77M	ARH/DL/IMU	9B-1348E	8.6	>54.0	-	12	8	141.7	7.9	386.3	AAKU/AKU-170
R-77T	IRH/DL/IMU	MK-80E	8.0	54.0	75	12	8	141.7	7.9	386.3	AAKU/AKU-170
R-77P	Passive RF	9B-1032	~130	54.0	-	12	8	141.7	7.9	386.3	AAKU/AKU-170
R-77M-PD	ARH/DL/IMU	9B-1348E	8.6	86.5	-	12	8	145.7	7.9	496.7	AAKU/AKU-170
R-77T-PD	IRH/DL/IMU	MK-80E	8.0	86.5	75	12	8	145.7	7.9	496.7	AAKU/AKU-170
R-77P-PD	Passive RF	9B-1032	-	86.5		12		145.7	7.9	496.7	AAKU/AKU-170
R-172	ARH/DL/IMU	-	-	215.0	N/A	N/A	N/A	291.3	20.0	1656.0	-
R-37	ARH/DL/IMU	ARGS-PD	-	160.0	N/A	N/A	N/A	161.4	15.0	1100.0	-

Seekers:

IRH Infra-Red Homing O/B Off Boresight Capability
SARH Semi-Active Radar Homing DL datalink
IMU Inertial Measurement Unit
ARH Active Radar Homing
Passive RF-Anti-Radiation Seeker - usually X-band

A short burn heatseeking R-27T and long burn semi-active homing R-27ER1.

Agat AAM seekers. Left to right: 9B-1101K dual plane monopulse semi-active homing seeker used in R-27R1/ER1, 9B-1348E active radar homing seeker used in R-77 variants, and 9B-1103K active radar homing seeker for R-27EA.



Hughes Aircraft Company photo of developmental AIM-120A antenna assembly.

In effect, what ramjet propelled missiles provide is a similar capability to that of the close combat P4 by sustaining thrust into the endgame, with the caveat that the turning performance and agility of a much bigger missile, aerodynamically built for range, will never match a close combat missile. A supercruising thrust vectoring Su-35BM is expected to be able to sustain supersonic 9G turns in the manner of the F-22, making it an extremely difficult target for conventional BVR missiles like the AIM-120 AMRAAM.

It is conceivable that the Russians may have incorporated an automated high speed evasion manoeuvre into the digital flight controls of late model Flankers, initiated either by the Missile Approach Warning System or the pilot, intended to pull high G during the endgame. If so, this is likely to be a well guarded secret.

The US Air Force have not to date actively pursued BVR ramjet missiles for the simple reason that the F-22A's supersonic high altitude launch environment adds around 35 per cent more range to the AIM-120C AMRAAM, or providing much more endgame momentum for conventional launches.

Flanker launching the R-77 / RVV-AE / AA-12 Adder "AMRAAM-ski".

Eurofighter Typhoon being used for carriage trials of the MBDA Meteor ramjet missile.

An MBDA Meteor demonstrator about to impact its target.

The Vympel R-77M-PD RVV-AE-PD (Povyshlenayya Dal'nost') "ramjet Adder" is credited with an A-pole range of around 80 nautical miles. This missile is a direct derivative of the R-77 series.

Conclusions

Missile technology has advanced considerably since the end of the Cold War, with advances in seekers, guidance, propulsion and aerodynamics. Concurrently targets have evolved mostly in performance, and in countermeasures intended to defeat missiles.

The long term outlook is that the 'Kill Probability=1' AAM will remain an illusory goal, as progressive advances in missile capability are systematically countered by aircraft designers. Technologies such as the Digital RF Memory will continue to present genuine problems for designers of active radar missile seekers.

What is clear is that aircraft flying with Cold War era performance, weapons and defensive systems will not survive long if pitted in combat against the current generation of AAMs.