History of the Electro-Optical Guided Missiles

AIM-9M Sidewinder Seeker head

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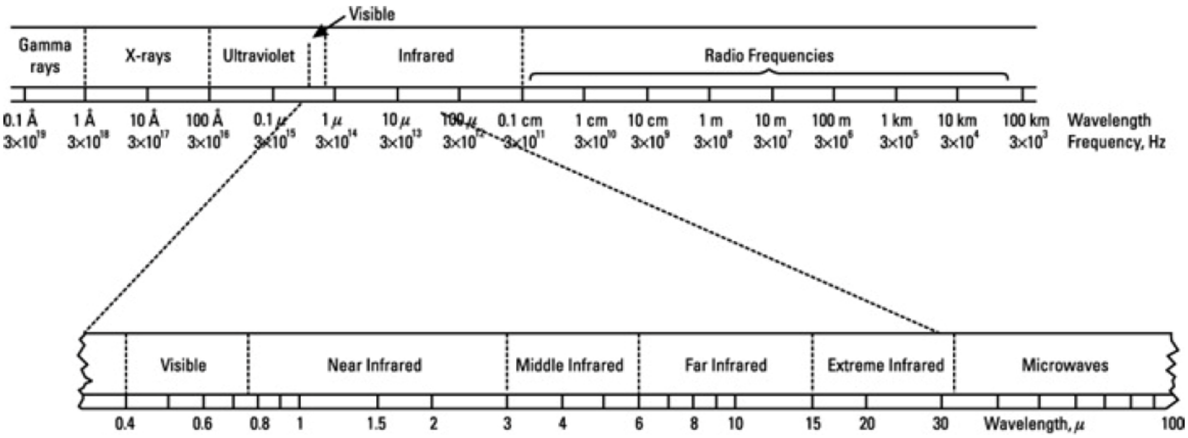
Foreword

Little about IR terms and units is universally agreed.

Different reference books give different names and locations for the sub-bands within IR and sometimes use different terms, and units for the expressions of radiant power.
And often, some of the most important terms and concepts are not mentioned at all.

IR is a contentious part of the spectrum.[1]



Electro-Optical guided missiles are true self-guiding Fire-and-Forget anti-aircraft weapon systems, developed due to the proliferation of fast-jet aircraft, that rendered manually aimed anti-aircraft machine guns ineffective.

Like the development of other military technologies, the history of IR-guided missiles has the usual measure-countermeasure back-and-forth.

1, First IR missiles used uncooled Lead Sulfide (PbS) detectors and Spin Scan optics.
These were very short legged and strictly tail aspect only missiles, they needed to look-at and track the hot metal parts of the target's engine.

2, Cooling the Lead Sulfide (PbS) sensor material, its IR sensitivity, lock-on and tracking range increased, thus with the use of larger rocket motors, their effective range also increased.
These were still strictly tail aspect only missiles, a serious limitation.

3, Onboard thermal jammer could effectively break the Spin Scan missile optical lock, by injecting a modulated heat signal into the tracking head.

4, Seeker using Photo Contrast tracking instead of infra-red, cannot be confused by modulated heat signal.

5, Conical Scanning of the seeker optics effectively negated the thermal jammers, as the missile head is not looking all the time at the target, co-located with the onboard jammer.

[1] Page 15, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures

6, Using cooled Indium Antimonide (InSb) detector, the target engine plume could be tracked, resulting an (almost) all aspect missile.

7, Pyrotechnic Flare is an off-board countermeasure (CM), and could also break the missile optical lock by introducing a hotter target in the tracker field of view.

8, Flare position relative to the target (above or below) could be used as a counter-countermeasure (CCM) technique against flares.

9, Flare energy rise time could be used as a counter-countermeasure (CCM) technique against flares.

10, Narrow instantaneous field of view tracker head could also reject flares by its different angle rate (deceleration) of the flare compared to the target.

11, Dual-band seeker can effectively discriminate between pyrotechnic flares and the target by their different IR energy levels (temperature).

12, Pyrophoric decoy has similar IR energy level as the target, so it cannot be discriminated by dual band sensors.

13, Imaging seeker can discriminate between the pyrophoric decoy, and the target by its energy distribution change.

14, Directed Infrared Countermeasure (DIRCM) can blind and damage the seeker sensor with directed high power laser.

15, Directed Infrared Counter-Countermeasure (DIRCCM) equipped missile seekers are hardened against laser pulses, and can track its source.

As missile seekers incorporating DIRCCM become operational on a larger scale, targets will incorporate anti-DIRCCM techniques, for example a towed DIRCM.
The countermeasure, CCM, C-CCM, DIRCM, DIRCCM game will continue...

9K32 Strela-2 (SA-7 Grail) missile ejected from the launch tube towards a flare target

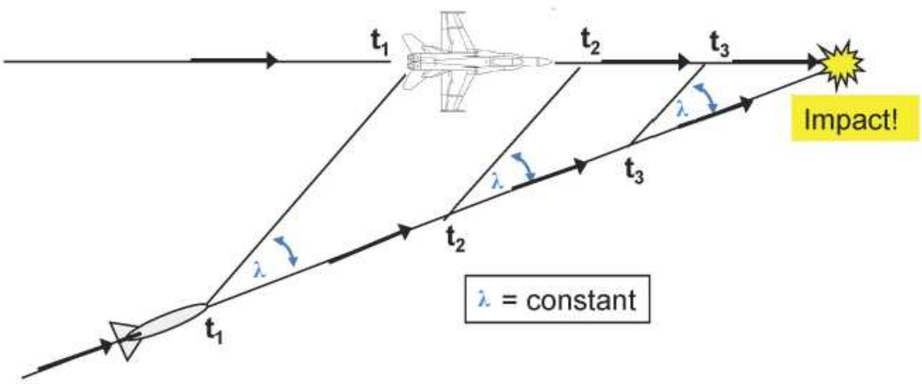
Proportional Navigation

To intercept a target in the shortest time and distance traveled, a missile must navigate toward a point in space ahead of the target aircraft and must time its arrival to be there at the exact instant as the target.[2]

Proportional navigation has nothing to do with navigation. It is purely a guidance law used to guide missiles. The reason for this misnomer is that in the early days of development of guided missiles the vocabulary of guidance literature was somewhat limited, but navigation of ships was a well-known science.

The idea behind proportional navigation guidance initially originated from a certain observation made by sailors. They observed that from a moving ship if another ship appears to be stationary and its size appears to be growing, then the two ships were on a collision course.

Essentially these two conditions imply that the two ships are on a collision course, i.e., there is no relative velocity between the two ships perpendicular to the LOS and the ships are approaching each other. [3]

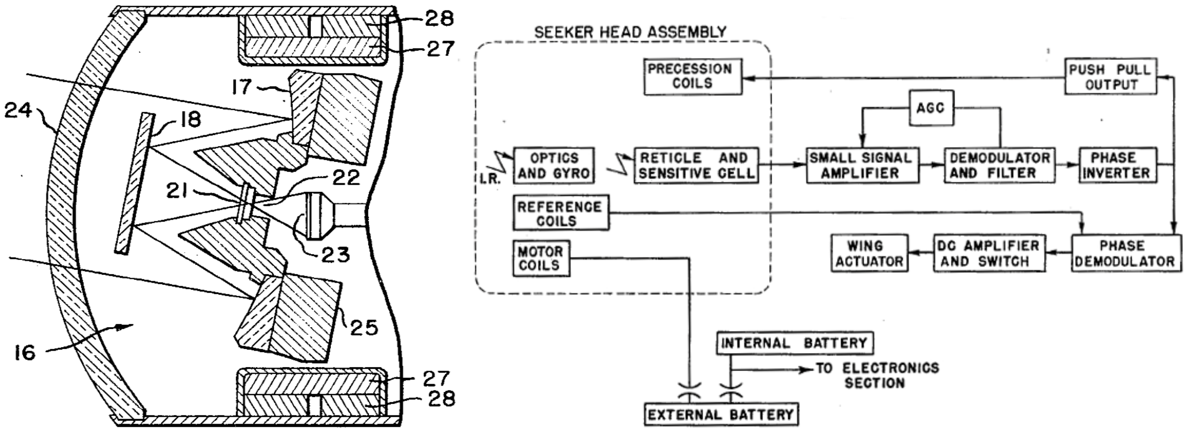


Translated to the language of LOS rate and closing velocity, it implies that the LOS rate is zero and the closing velocity is positive. PN law uses the idea that if the LOS rate at any time is non-zero then the guidance command applied should be such that it annuls the LOS rate.

A rather simple hardware implementation of this guidance law can be found in early AIM-9 Sidewinder missiles. These missiles use a rapidly rotating parabolic mirror as a seeker. Simple electronics detect the directional error the seeker has with its target (an IR source), and apply a moment to this gimballed mirror to keep it pointed at the target. Since the mirror is in fact a gyroscope it will keep pointing at the same direction if no external force or moment is applied, regardless of the movements of the missile. The voltage applied to the mirror while keeping it locked on the target is then also used (although amplified) to deflect the control surfaces that steer the missile, thereby making missile velocity vector rotation proportional to line of sight rotation. Although this does not result in a rotation rate that is always exactly proportional to the LOS-rate (which would require a constant airspeed), this implementation is equally effective.

[2] Page 63, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures
[3] Page 106, Navigation, Guidance and Control

Seeker Hardware



US Patent 3,323,757 submitted by General Dynamics in 1961

Fast spinning **parabolic mirror (17)** together with a **reticle (21)** integrated on a **permanent magnet (25)** used in the **seeker (16)**. Infrared sensitive **photo resistor (23)** and a simple electronics (note the block diagram right) detect the directional error the seeker has with its target, and apply a moment via **precession magnetic coils (27)** to this gimballed mirror, to keep it pointed at the target.

Since the gimballed fast spinning mirrors (17, 18), reticle (21), and **permanent magnet (25)** act like a gyroscope, it will keep pointing at the same direction if no external force or moment is applied, regardless of the movements of the missile.

The voltage applied to the precession magnetic coils (27) while keeping the seeker (16) locked on the target is also used (although amplified) to deflect the control surfaces selected by the **reference coils (28)** based on the gyroscope (17, 18, 21, 25 together) position that steer the missile, thereby making missile velocity vector rotation proportional to line of sight rotation.[4]

Optics

The most common telescope for missiles incorporates reflective optics in a Cassegrain design.

The design uses a donut-shaped objective mirror (17), which collects radiation and directs it to a **secondary mirror (18)** in the center. From the secondary, radiation converges to form a real image centered on the optical axis of the reticle (21). This image contains the target information that will be used for tracking.

For missiles, a Cassegrain has advantages over other telescope designs because it is compact for a given focal length and because the focal point is located on the optical axis, unlike a Newtonian telescope, for example, in which the focus is located to the side. The whole telescope assembly is protected by a curved window called an **IR dome (24)**.[5]

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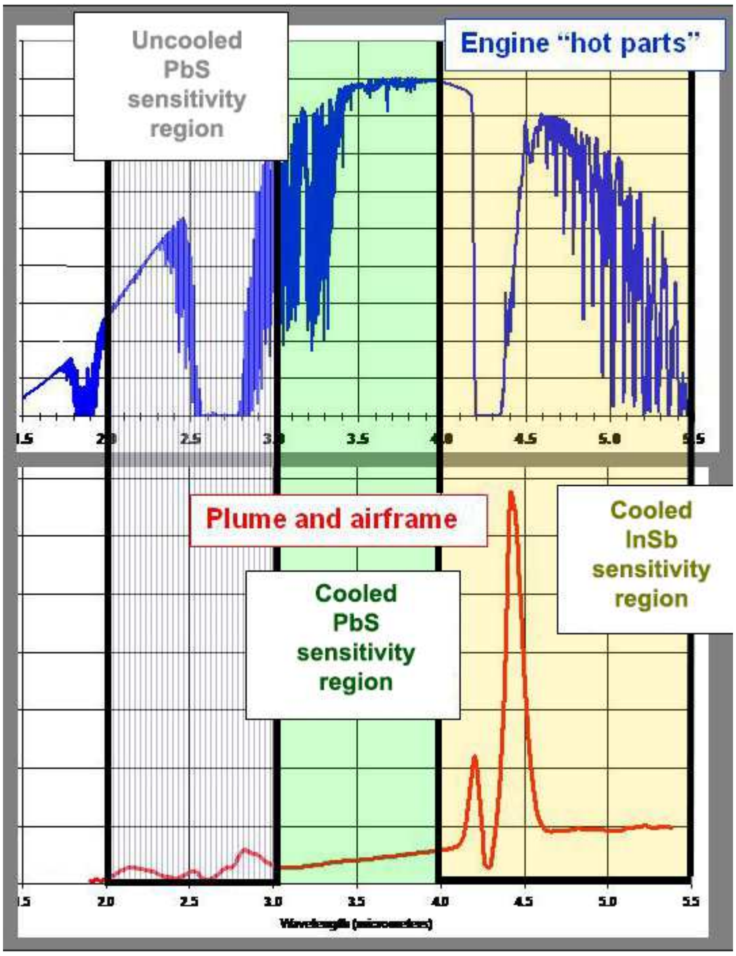
[4] US Patent 3,323,757 - MISSILE AUTOPILOT

[5] Page 65, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures

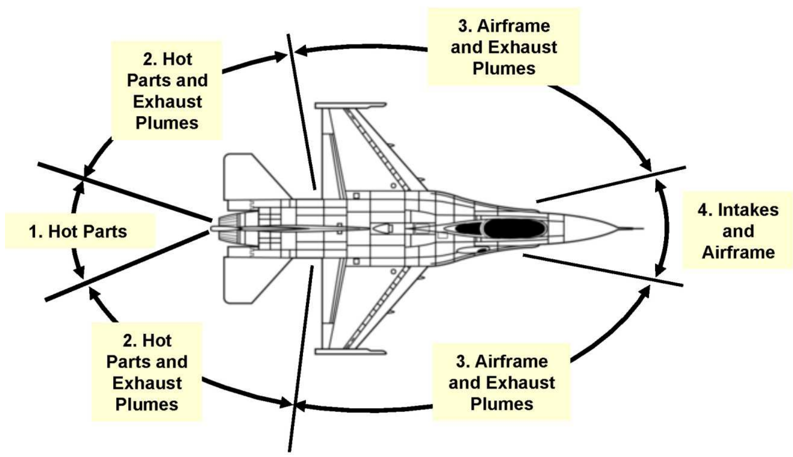
Target infrared signature, and sensor material sensitivity



Temperature ranges of a jet aircraft that can be targeted by heat-seeking missiles.[6]

Target Aspect angle

Target infrared signature depends on its aspect angle.

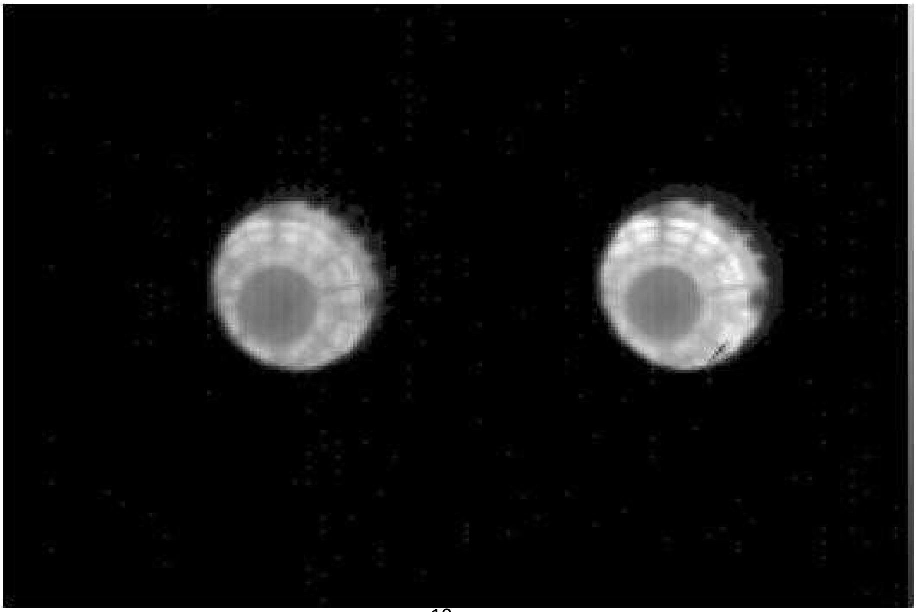


Engine hot parts are visible from tail aspect only. (region 1, and 2)
Engine exhaust plume is visible from almost all aspects. (region 1, 2, and 3)
In photo contrast, or UV region, the target is visible in all aspects. (all regions)[7]

[6] Page 65, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures
[7] Page 36, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures

Uncooled Lead Sulfide (PbS) photo resistor

Lead Sulfide was used in the first heat-seeking missiles, which homed on the hottest part of the aircraft, the internal engine parts. For effective tracking, it was necessary for the missiles to approach the aircraft from the rear to achieve a clear view of the tracking point. These early sensors had no cooling and as a result were restricted in sensitivity.[8]



Tailpipe of an F-14[10]

The compressor blades inside the engine are the hottest areas, and the external engine tailpipe parts are slightly cooler. Both are in the range of 1,000°K to 2,000°K, which means that their energy peaks in the 1 to 2.5µm wavelength range. [9]

First IR missiles used Lead Sulfide (PbS) detectors and Spin Scan optics. These were very short legged and strictly tail aspect only missiles, needed to look-at and track the target engine tail pipe.

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[8] Page 374, EW 104, EW Against a New Generation of Threats
[9] Page 372, EW 104, EW Against a New Generation of Threats
[10] Page 37, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures

Spin Scan tracker (AM logic)

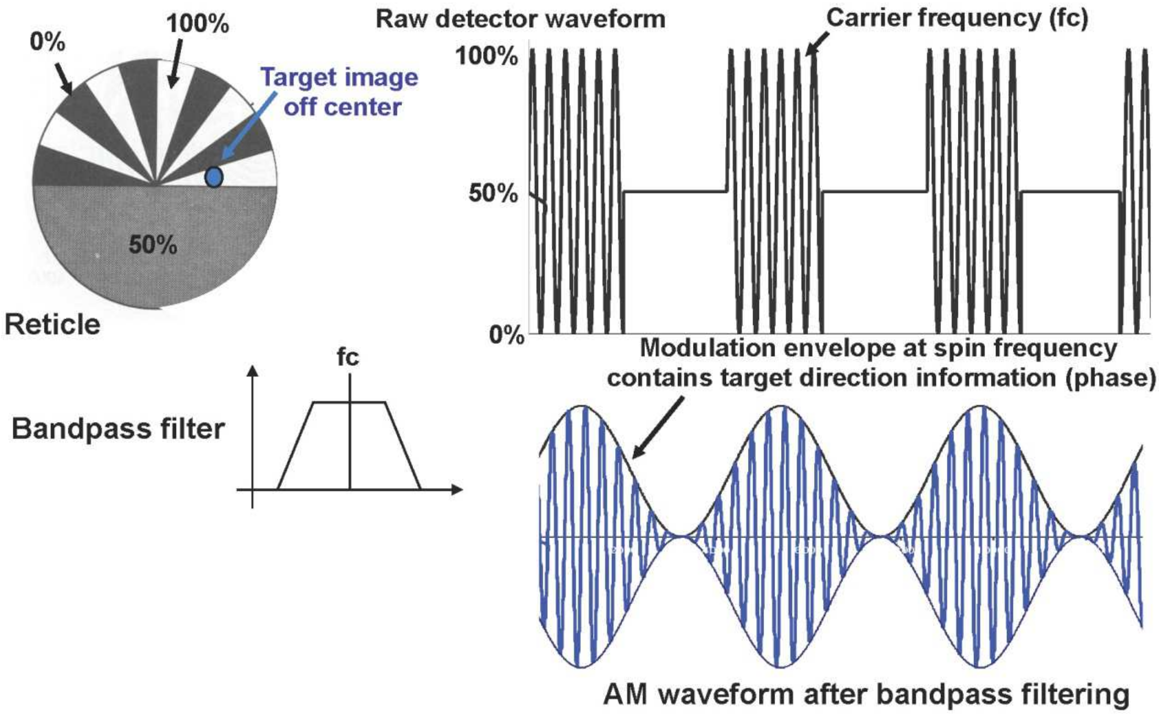
The optical and reticle design of most early missiles used what is called a spin-scan tracker. Spin scan has the following characteristics:

1. The tracker servo loop drives to null the signal to zero. Zero signal occurs when the target is on the optical axis and the target image is at the center of the reticle.

2. If the target is off-center, an error occurs. As a consequence, an AM carrier is generated in which the phase of the modulation envelope contains target direction information.

3. With spin scan, the missile is always looking at the target. Always looking at the target has enormous consequences for jammer countermeasures.[11]

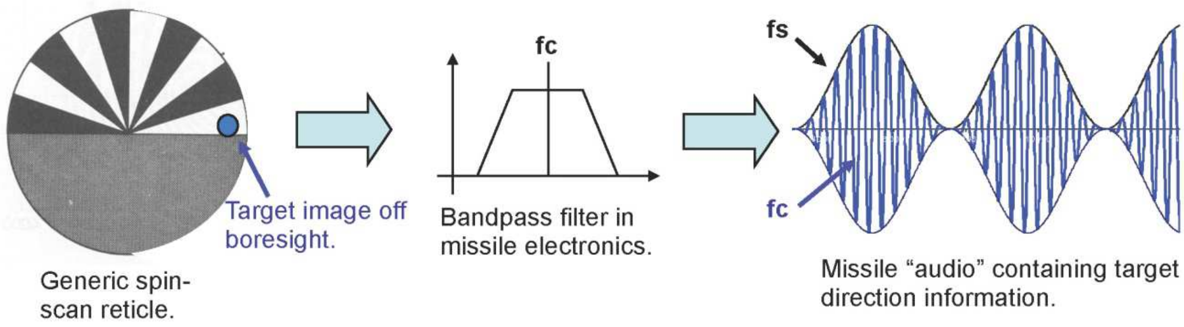
This reticle shown has five spokes in a half disk (or ten spoke cycles if the full disk is covered). If the disk is spun at 100 revolutions per second (6,000 rpm), the modulation frequency of a target signal would be 1,000 hertz.



The other half of a reticle is often given a transmission of 50% rather than made completely opaque to produce a more balanced modulation envelope. The result is an amplitude modulated (AM) carrier frequency, as illustrated. An electronic band-pass filter centered at this carrier frequency improves the signal-to-noise (S/N) ratio and helps reject lower frequency components from background sources.[12]

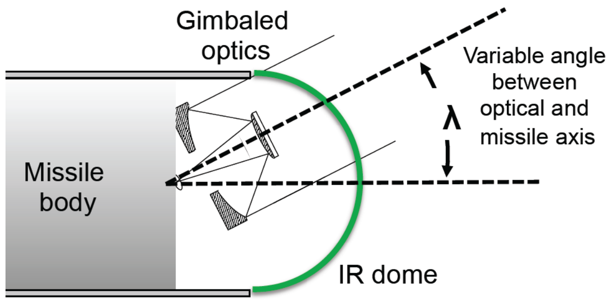
[11] Page 71, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures
[12] Page 70, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures

The result of this filtering is a smooth AM waveform (blue curve), in which target direction information is contained in the phase of the modulation envelope. This envelope is rectified and filtered to produce an error signal to control the gyro precession.

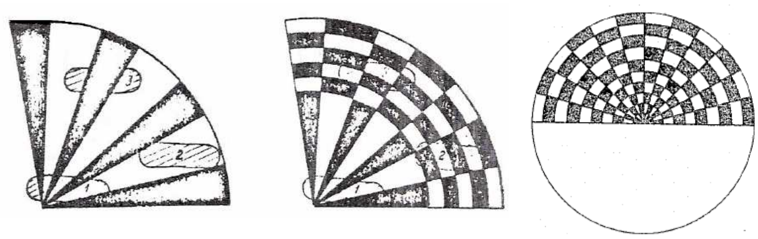


The signal generated by a target located off optical center.

The reticle modulates the target irradiance with two frequencies to create an AM signal. When the target image falls on the spokes of the reticle, a higher frequency carrier is impressed on the target. An electronic band-pass filter that is centered about the carrier frequency improves target S/N ratio and helps reject signals from extended background sources with image sizes that spill over multiple spokes of the reticle.
When the target image falls in the phasing sector of the reticle where there are no spokes, no modulation occurs, and the signal amplitude that is passed by the electronic filter drops to zero. The resulting waveform is an AM envelope at a spin frequency that is impressed on the carrier.



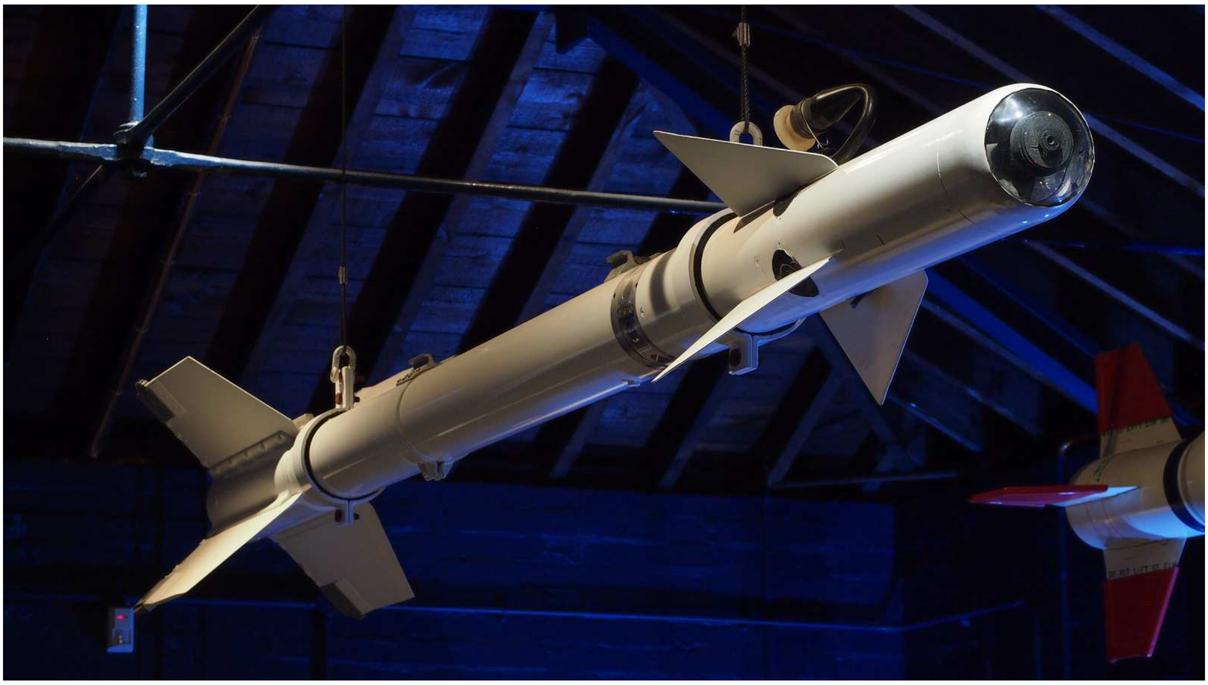
After the signal is rectified and filtered, the carrier is removed and the remaining signal is a sine wave at the spin frequency. The timing or phase of this signal with respect to a spin reference signal tells target direction. Target direction is always in relation to the inertial reference established by the gyro, not the missile body. The tracker servo causes the gyro to precess in a direction to null out the signal and put the target in the center.[13]



In real life, checkered reticle is used (rightmost one) instead of spokes, as it better filters large horizontal, reflected (1, 2, 3) natural infra-red sources (clouds, lakes, etc.).

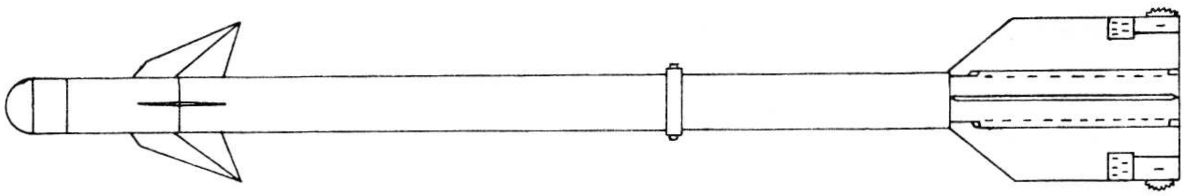
[13] Page 95, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures

AIM-9A/B Sidewinder



Development of Sidewinder began in 1950 at the NOTS (Naval Ordnance Test Station) - later renamed as NWC (Naval Weapons Center) - at China Lake. The idea was to create a very simple heat-seeking air-to-air missile by equipping a 12.7cm (5 in) rocket with a Lead Sulphide (PbS) photo cell in a hemispherical glass nose to detect IR radiation. Another simple, yet effective, idea was the use of "Rollerons" (slipstream-driven wheels at the fin trailing edges acting as stabilizing gyros) as roll-stabilizing devices. The first test missiles were fired in 1951, and on 11 September 1953, the first air-to-air hit on a drone was scored. In the same year, the prototype missile received the official designation XAAM-N-7 (AIM-9*). General Electric began low-rate production in 1955, and in May 1956, the AAM-N-7 (AIM-9A*) Sidewinder-I entered U.S. Navy service. Only 240 Sidewinder-I missiles were built, and full-rate production missiles (built by Ford Aerospace (Philco) and General Electric) were known as AAM-N-7 (AIM-9B*) Sidewinder-IA. [14]

**Post-1963, designation.*



More than 95,000 AIM-9B missiles were produced until 1962.

40,000 by Aeronutronic (Philco-Ford)
40,000 by General Electric
15,000 by the German firm Bodensee Geratechnik[15]

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[14] Raytheon (Philco/General Electric) AAM-N-7/GAR-8/AIM-9 Sidewinder
[15] Page 173, Sidewinder - Creative Missile Development at China Lake

The missile used a 2.5" glass dome nose window, transparent to infrared radiation, providing the gimballed seeker for a ±25° field of view (FOV). The mirror assembly provided a 4° instantaneous field of view (IFOV), projected on to a PbS (Lead Sulphide) uncooled detector. Because of the design of the optical system, the AIM-9B was strictly a tail aspect weapon, as it was blind to anything cooler than a tailpipe. The modest 8°/sec seeker tracking rate limited the weapon to non-maneuvering targets. [16]

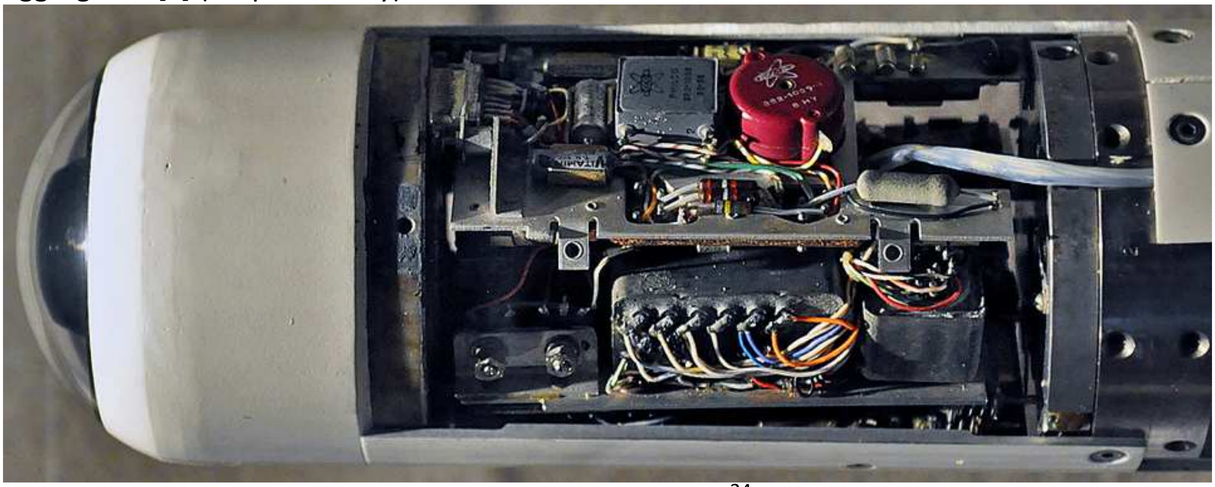
Seeker electronics were built from fourteen vacuum tubes, but only nine of these were used during flight. [17]

A hot gas generator provided actuator power for the nose canards, and was limited to 20sec burn duration before exhaustion. Unlike other missiles of the day, the Sidewinder did not employ active roll stabilization (via gyros and differential control input), instead employing rollerons, i.e. slipstream spun metal discs embedded in the trailing edge of the wingtips, which acted as four tiny gyros stabilizing the missile mechanically.[18]

Designed to intercept lumbering bombers, the AIM-9B was ill suited to knife-fights with MiG-17s at low level, as its launch load factor limit was only 2g, and the missile had a maximum overload capability of 12g.[19]

Mk17 rocket engine had 2.2sec burn time, delivering 17.5kN thrust[20], and accelerated the weapon 1.7 Mach above the launcher speed.[21] Maximum launch ranges are 1,8km at sea level, and 10,6km at 15km altitude.[22]

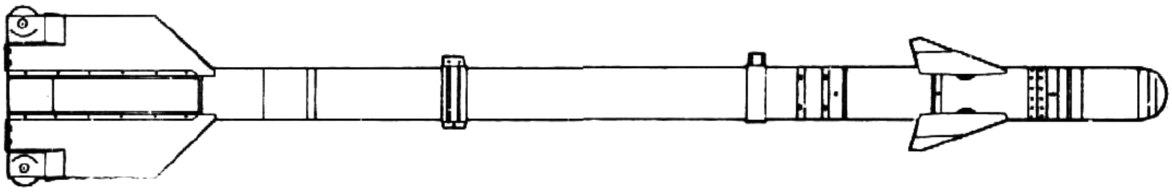
28 MiGs were killed for 175 launches between 1965 and 1968, by USAF F-4C/D aircraft, an aggregate P[k] (kill probability) of 16%.[23]



AIM-9B Seeker head[24]

[16] The Sidewinder Story, the Evolution of the AIM-9 Missile
[17] Page 174, Sidewinder - Creative Missile Development at China Lake
[18] The Sidewinder Story, the Evolution of the AIM-9 Missile
[19] Az AIM-9L Sidewinder légiharc-rakéta
[20] The Sidewinder Story, the Evolution of the AIM-9 Missile
[21] Az AIM-9L Sidewinder légiharc-rakéta
[22] Page 3, Standard Missile Characteristics AIM-9B Sidewinder-1A
[23] The Sidewinder Story, the Evolution of the AIM-9 Missile
[24] NAS China Lake Naval Armament and Technology Museum

R-3S (K-13A) Article 310A (AA-2A Atoll)



In early 1958 an example of the "Sidewinder" arrived in the USSR from China. This missile was launched by a Taiwanese pilot during a coastal incident, failed to explode and fell into a muddy rice paddy. Another "Sidewinder", in September 1958 hit the side of a Chinese MiG-17 and did not exploded, and was brought back safely to the airfield intact. [25]

The appropriateness of reproduction "Sidewinder" was questioned based on the low combat effectiveness of these missiles in the air battles over the Taiwan Strait. Deputy Chairman of the Council of Ministers DF Ustinov pointed out the lack of combat experience on the side of the Taiwanese pilots as a reason, rather than the characteristic of this new weapon. According to data at the disposal of the Soviet Air Force, there have been only 5 missile launches.[26]

In 28 November 1958, Vympel design bureau was instructed to copy the captured Sidewinder, and to suspend work on its own K-7 missile type. Disassembling the missile illustrated the achievement of the Americans, who created an outstanding design. Simple - light, compact, easy to operate, and structurally the missile consisted of only 20 moving parts. It was more difficult to reverse engineer the seeker, and the electronic boards having numerous elements which have been squeezed into the compartment of 45 cm in length, and were encapsulated with plastic to protect against overload.

Master carvers from Yakutia were brought in, to extract these tiny electronic pieces intact.

The final "product" R-3S (K-13A, Article 310A) retains the design and even the basic dimensions of the captured "Sidewinder", except increased weight of the warhead and motor.

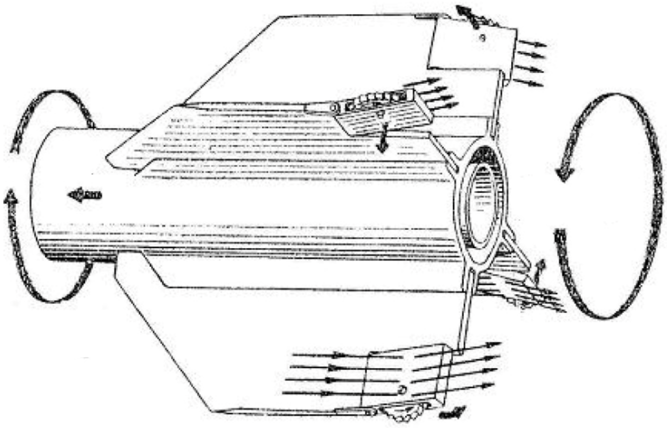
The seeker (TGSN 451K) located in the front of the rocket, under a semicircular fairing transparent to infrared radiation.

The middle part holds the control module with power supply, optical proximity and piezo-electric impact fuse, warhead weighing 11.3 kg and the solid fuel engine thrust of 25kN from a 20.5 kg of nitroglycerin-based fuel (NMF-2K). Engine operating time is 1.7~3.2 seconds (depending on altitude), range does not exceed 7.6 km.

After launch, the on-board energy source was enough for a flight of 21sec.

Minimum launch range without the risk of own aircraft flying into debris was 0.9km.
R-3S weighed only 75.3 kg, which easily allows aircraft reload even manually.[27]

[25] Page 8..9, Советские авиационные ракеты воздух-воздух
[26] Page 11, Авиация и Космонавтика No.2 2002
[27] Page 8..9, Советские авиационные ракеты воздух-воздух



The design of the R-3S reused the rollerons on the rear wings, which were intended to ensure flight stability. In flight these spin at 40-60 thousand rev/min and becomes a kind of gyroscope responsive to the angular roll rate and causing aileron deflection, countering bias. Simple and effective design, eliminating the need for dedicated roll control.

In February 1960, the K-13 was launched into serial production at several plants.[28]

In accordance with the Sino-Soviet agreement of 30 March 1961, the documentation of K-13 and samples of this missile were transferred to China. The missile was put into serial production under the designation PL-2, and later repeatedly modernized as a result of the work of Chinese designers.[29]

Hungary fielded over 4'800 pieces for its: MiG-21F13, MiG-21PF, MiG-21MF, MiG-21Bis, and MiG-23MF fighters.

[28] Page 9, Советские авиационные ракеты воздух-воздух
[29] Page 11, Авиация и Космонавтика No.2 2002

9K32 Strela-2 (SA-7 Grail)

Soviet Union received limited information that the United States in 1958 began the development of portable SAMs equipped with passive heat seeker. In the late fifties American TV showed a soldier shooting a missile at air targets from the launch tube on his shoulder. This testified the real possibility of creating a man portable anti-aircraft missile.

Work on the creation of portable anti-aircraft missile system "Strela-2" started in 25 August 1960. The lead development of the complex "Strela-2" (9K32), has been assigned to special design bureau SKB GKOT, the only one agreed to accept the task, right after its earlier 3M6 Shmel (AT-1 Snapper) MLCOS anti-tank missile was accepted into service.

The main difficulty in the development of seeker head was the creation of a gyro stabilization device with small weight and size. The solution was the elimination of the three axis gyroscope platform, and two channel controls used in larger sized rockets, and go to single channel control with a rotating missile (15/sec) and an associated a small gyroscope head. The created seeker had a mass of only 1.2 kg. Guidance method of proportional navigation not required large transverse accelerations.

Difficult was the task of creating the propulsion system. The solution was two stages. The launch stage fully burnt out in the tube and accelerated the missile to 30m/s. The second stage started by pyrotechnic delay, at safe distance of the soldier, accelerated and kept the speed of the missile at 430-450 m/s. Light missiles with blunt fairing rapidly decelerates after engine burnout, limiting maneuverability on the passive portion of its flight. To reduce aerodynamic drag the rocket has large elongation and small diameter, only 72mm. Traditional solid fuels had 10~15 times slower burning speed with a narrow combustion chamber. The required burning rate (40 mm/s) was achieved using a composite propellant and laying metal wires into the charge for fast fuel warm up accelerating their ignition.

The small warhead (1.17kg) could cause damage to the target only by direct hitting it.
If it missed the target it was ignited in self-destruct after 11~14s of flight.

The complex "Strela-2" has been successfully tested in January 1968 and was accepted for service.
In 2 September 1968 modernization of the complex "Strela-2" started, and during February 1970 the complex 9K32M "Strela-2M" was adopted.[30]

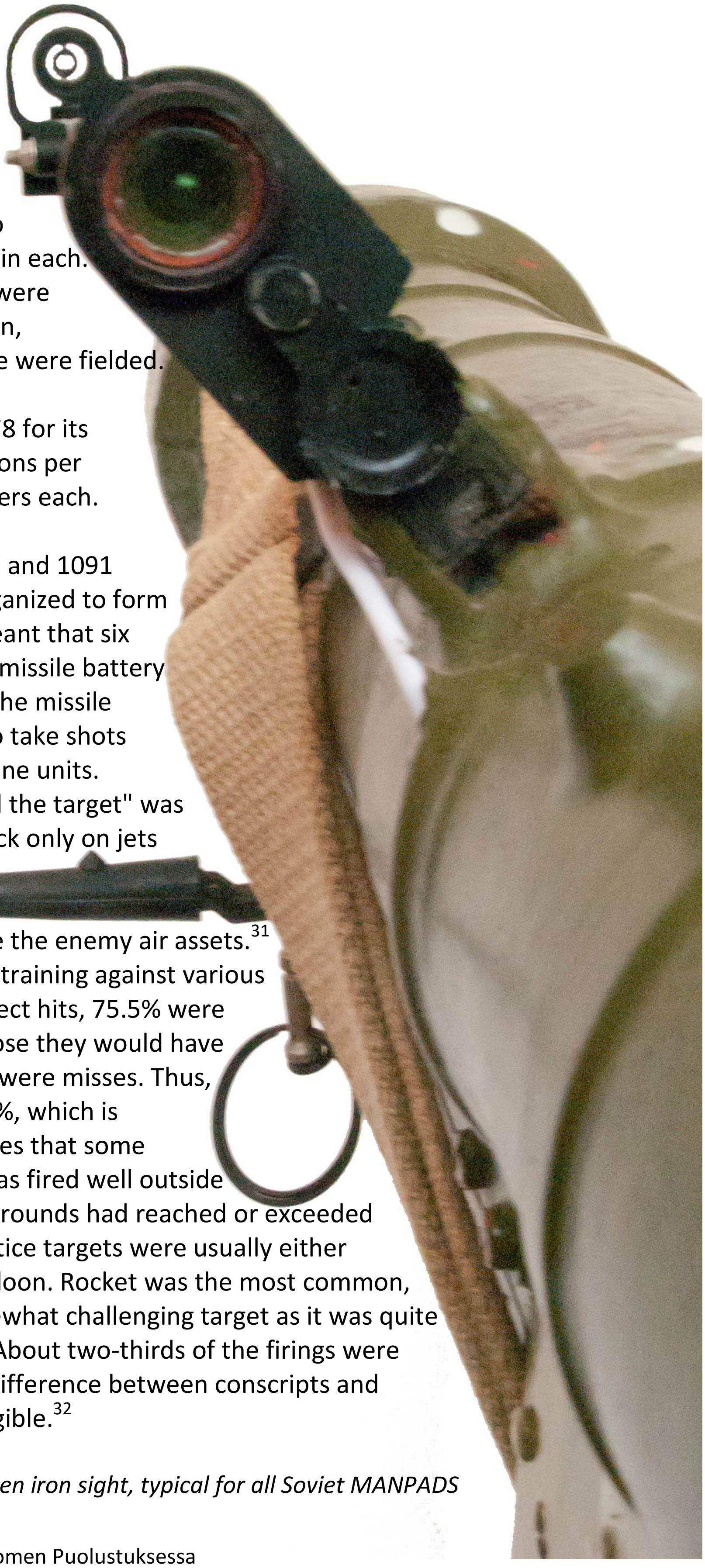
[30] Page 71..74, Техника и Вооружение No. 5-6 1999

East Germany fielded 1,896 launchers, together with 6,112 missiles from 1973.

Hungary fielded the 9K32M Strela-2M version from 1977 for the air defense of its first echelon mechanized regiments. Each of the 10 mechanized regiments had two firing platoons with 6 launcher in each. For each launcher, 12 missiles were allocated. Altogether 21 platoon, 128 launchers, and 1540 missile were fielded.

Czechoslovakia fielded it in 1978 for its mechanized regiments, 3 platoons per regiment, armed with 3 launchers each.

Finland acquired 122 launchers and 1091 missiles in 1978. They were organized to form six batteries which basically meant that six most important brigades got a missile battery each. Tactics were to position the missile teams well behind front line, to take shots against targets attacking frontline units. Strela's ability to really "defend the target" was of course limited as it would lock only on jets exhaust, thus their role was defined to attrite the enemy air assets.[31] 611 missiles were expended in training against various targets: of these, 10% were direct hits, 75.5% were "aircraft hits" (i.e. passed so close they would have likely hit a real aircraft), 14.5% were misses. Thus, the hit probability was over 85%, which is especially good when one figures that some misses were because missile was fired well outside launch envelope, or that many rounds had reached or exceeded their operational lifetime. Practice targets were usually either target rockets, or drone, or balloon. Rocket was the most common, it was uncomplicated but somewhat challenging target as it was quite fast and flight time was short. About two-thirds of the firings were made by conscripts; accuracy difference between conscripts and professional soldiers was negligible.[32]



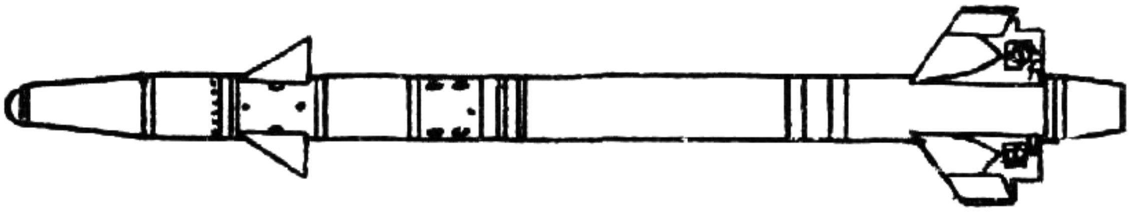
9K32M Strela-2M (SA-7b Grail) open iron sight, typical for all Soviet MANPADS

[31] Page 128, Ilmatorjuntaohjukset Suomen Puolustuksessa
[32] Page 134, Ilmatorjuntaohjukset Suomen Puolustuksessa

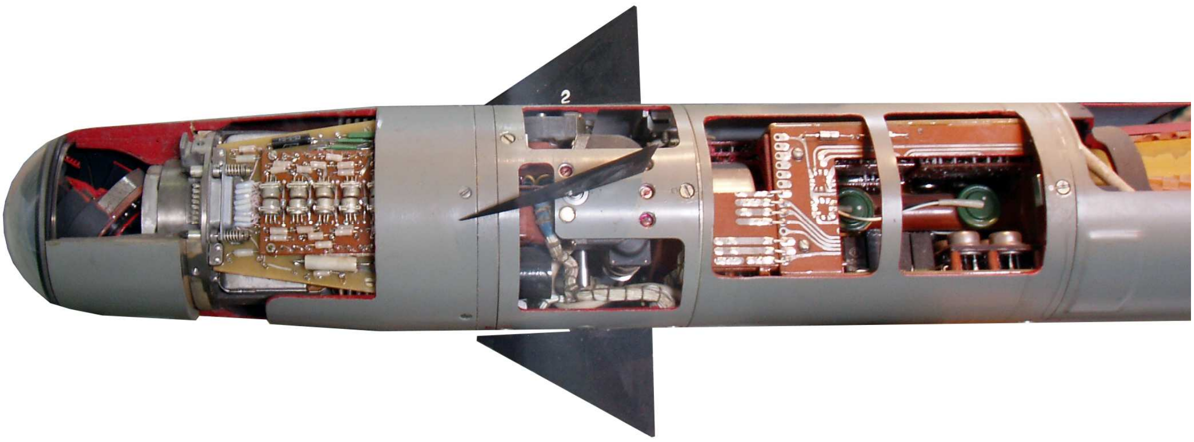
9K31 Strela-1 (SA-9 Gaskin)

The development of this complex began 25 August 1960 in accordance with the Decree of the USSR. Decree provided for the development of lightweight portable air defense missile system, consisting of two pieces weighing not more than 10-15 kilos each.
It was designed to destroy air targets that fly at a distance of up to 2000m.

Driven by the same Decree another portable anti-aircraft missile complex - 9K32 "Strela-2" - was being developed which had a greater degree of technical risk. After solving the fundamental issues associated with the development of Strela-2, the question arose about the future fate of the complex Strela-1, which had almost the same flight characteristics.
To save the "Strela-1", the design bureau appealed to the Government with a proposal to create a greater range (4200m), self-propelled missile system.

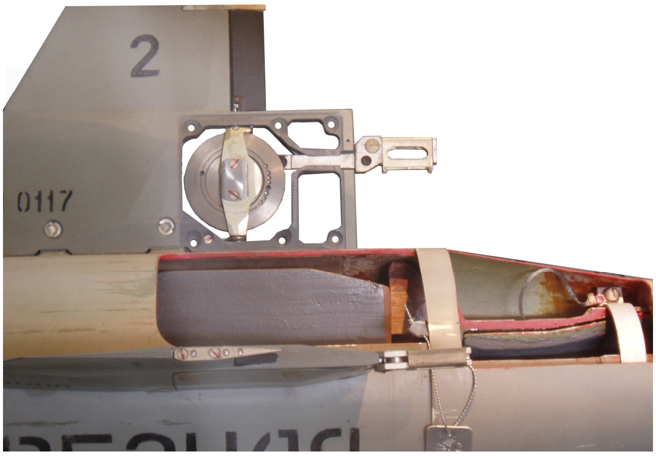


The proposal was accepted, and the all aspect capable SAM "Strela-1" was adopted at 25/04/1968.[33]



In the development of 9K31 Strela-1, unlike other missiles (such as the American "Redeye"), it was decided to use Photo Contrast detector at the visible part of the spectrum 0.4~0.65µm, not infrared. In those years, due to the low sensitivity of infrared detectors, locking on incoming targets were impossible, therefore shooting at the enemy aircraft could be only in pursuit, mainly after it performed its combat missions. In these tactical conditions there is a high probability of destruction of anti-aircraft missile systems before they can launch rockets. At the same time, the use of Photo Contrast detector provides the ability to destroy targets also on a collision course, but only against targets visible on a background of clear sky, away from the horizon.

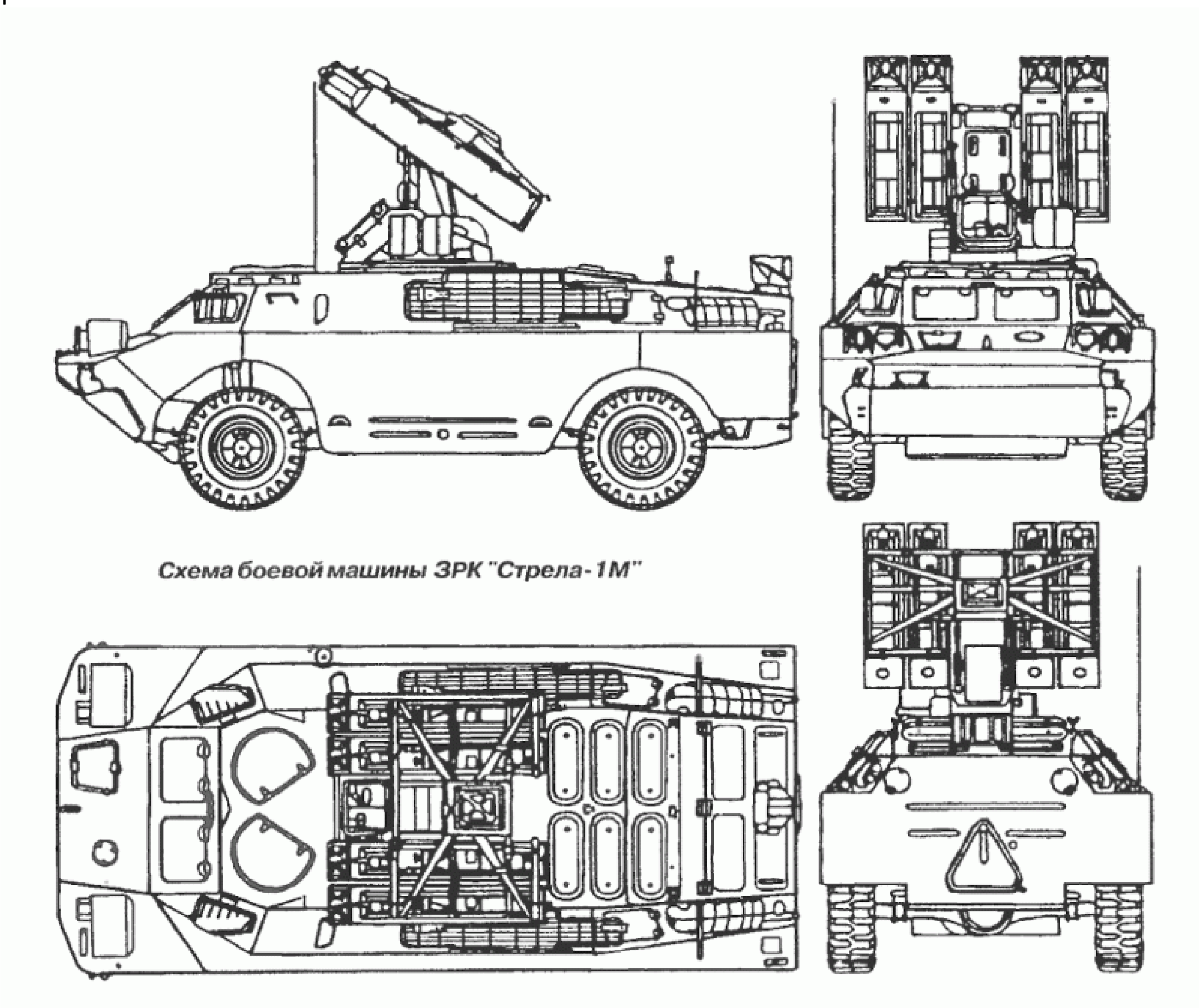
[33] Page 55..56, Техника и Вооружение No. 5-6 1999



Missile was roll stabilized by the rollerons. To spin those up during launch, an elegant method was used. On the rollerons, rope was spooled up, and was connected to the launch container. During launch, the rope was unrolled during missile acceleration and spun up the rollerons.

Missile had no inbuilt self-destruct system, it simply safetied the warhead after 13~16s of flight.

Strela-1M was fielded in December of 1970.
In comparison with the autonomous Strela-1, the Strela-1M platoon was designed to work together with a Shilka platoon, and directed by the PU-12M mobile air defense command post.[34]



Each vehicle has 4 ready to launch missiles on the turret, and 2 reloads at its side

[34] Page 55..58, Техника и Вооружение No. 5-6 1999

Hungary fielded the 9K31M Strela-1M version during 1976-77 for the air defense of all mechanized regiments of its 5th army (11th tank; 7th, 8th, and 9th mechanized division). Each of the 10 mechanized regiments received one firing battery with 4 vehicles in each. Altogether 10 batteries and 42 vehicles were fielded.

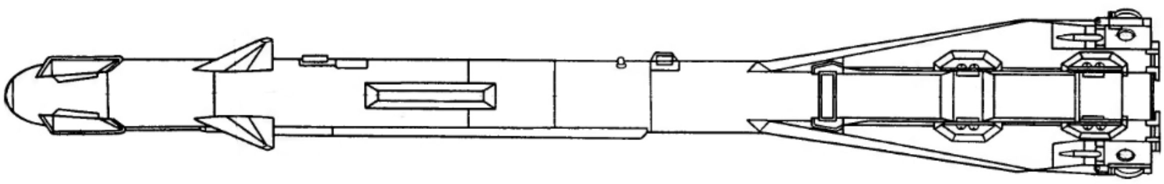
East Germany planned to arm 2 tank divisions (7th and 9th) and 3 mechanized divisions (1st, 4th, and 11th) between 1976 and 1980 with the Strela-1M. Until 1977, however, only 12 combat vehicles were received by the NVA. Thus only three tank regiments of the 7th tank division (14th, 15th, 16th tank regiment) fielded it. Further fielding NVA with this anti-aircraft missile system could not take place due to supply difficulties by the USSR.

Czechoslovakia fielded only 4 vehicles in 1978 at just one mechanized regiment (3.msp) of the 1st tank division. Further fittings could not take place due to supply difficulties by the USSR.

Poland fielded just 16 vehicles altogether. 2 tank regiments (25th and 18th) and at 2 mechanized regiments (9th and 12th) received 4-4 vehicle each.

R-60 (K-60) Article 62 (AA-8A Aphid)

During an extensive air battle, the identification of the nationality of a target using only the aircraft's radio IFF system is almost impossible. To avoid shooting friendly planes, usually visual identification is also required, but it could be performed at best, only at few kilometers. As a result, by the end of the sixties in the United States, Soviet Union and France, almost at the same time formed an idea of the need to develop small missiles specifically designed for use in close combat maneuvering.[35]



Development started in 1967, at the Molniya design bureau and the smallest, lightest (43.5kg), and most maneuverable (of its time) Soviet missile was fielded in 18th December 1973.

R-60 seeker head[36]

The uncooled rear aspect only OGS-60TI seeker has an exceptional target tracking rate of 35°/s, and could be aimed ±12° off the plane boresight by the fighter radar or infra-red search and track sensor.

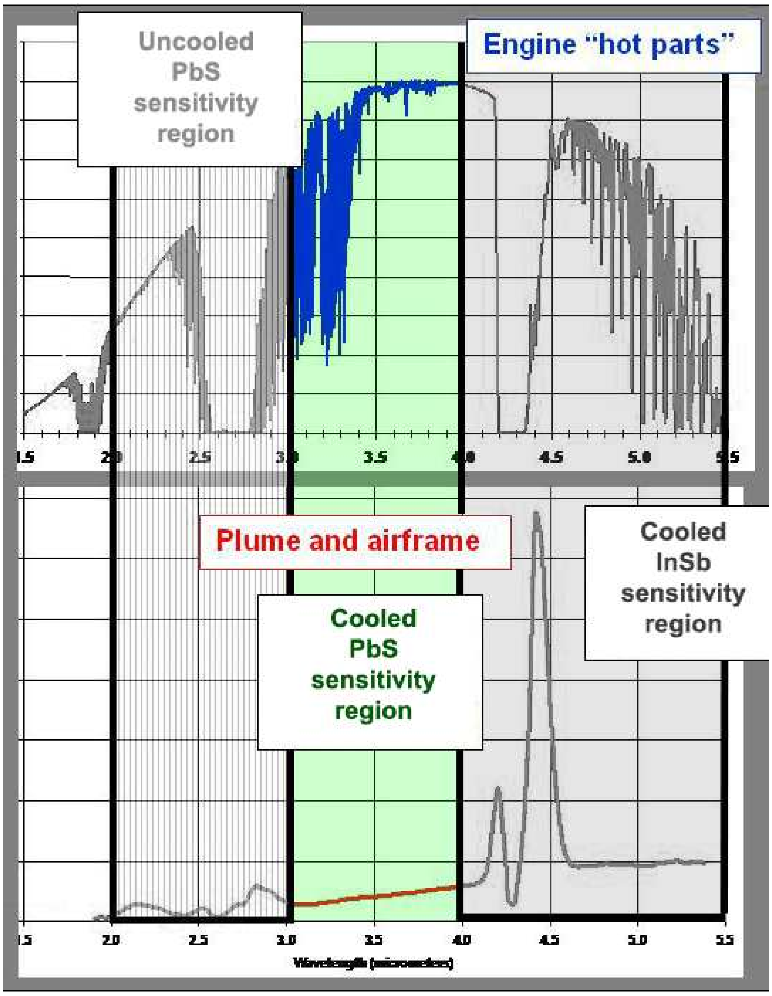
The PRD-259 dual-thrust engine burn time is 3~5s, providing the missile of 7,2km range at 12km altitude, and less than third of this at low alttude.

The radio proximity fuse is triggered 2.5m from the target, the tungsten rod warhead of 3kg.[37]

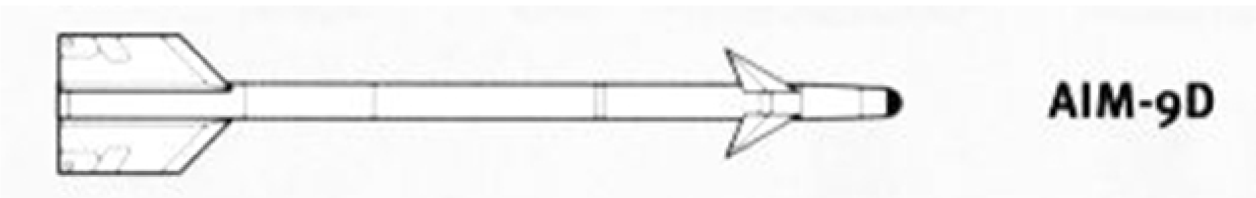
[35] Page 12, Авиация и Космонавтика No.3 2002
[36] Музей войск ПВО, Подмосков
[37] Page 13, Авиация и Космонавтика No.3 2002

Cooled Lead Sulfide (PbS) detector

Cooling Lead Sulfide to -196°C (77°K which is the boiling point of nitrogen at the atmosphere) is considerably increase its sensitivity (1,5-2x target lock on range) and signal-to-noise ratio.

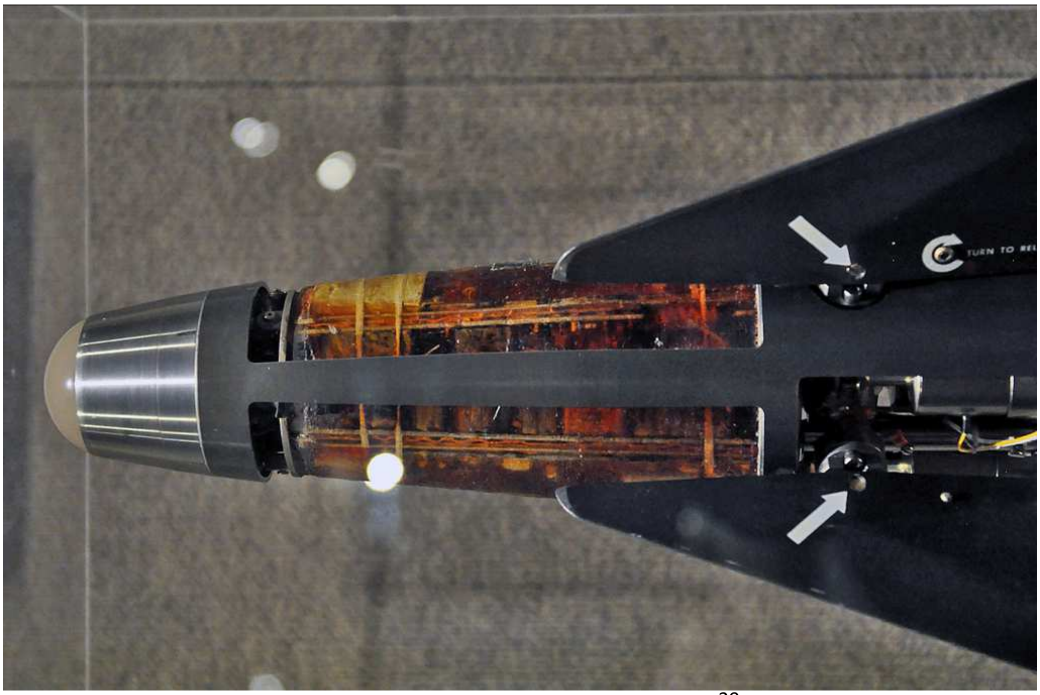


AIM-9D Sidewinder (NAVY)



The most important change in the AIM-9D was the use of a Nitrogen cooling system for the PbS detector element, coupled to a redesigned optical system. The new optical system retained the tilted Cassegrain of the earlier subtype, but was more compact, fitting into an ogival nose section, and spun at a higher frequency of 125 Hz, rather than the 70 Hz of the B-model. The glass nose dome was replaced by a much smaller Magnesium Fluoride dome, which provides better transparency to longer wavelength (cooler) infrared emissions.[38]

[38] The Sidewinder Story, the Evolution of the AIM-9 Missile



AIM-9D Sidewinder seeker head[39]

The Nitrogen coolant was contained in a 6 liter bottle in the Navy LAU-7 launcher, and provided for 2.5 hrs. of seeker cool down.

The seeker changes provided a higher target tracking rate of 12deg/sec, assisted by an improved actuator system, which delivered up to 100 lb.ft of torque. Both of these measures improved missile maneuverability, while a longer gas generator burn provided for a 60 second usable flight time. The rocket motor was changed to a Hercules Mk.36, with more impulse and longer burn.

Changes were also introduced to the fusing, with the option of an infrared fuse or a radio-frequency proximity fuse, which fired a new continuous rod warhead. Continuous rod warheads have a casing of lengthwise rods welded together at alternate ends, on detonation the rods expand into a circle about the missile before breakup, upon which a torus of fragments is produced about the axis of the weapon. These rods are like knives which chop into the skin and structure of the target.[40]

1,850 AIM-9D missiles were built by Raytheon between 1965 and 69, as they underbid the AIM-9B producer Philco-Ford offer.

Philco-Ford offered $8,000 per copy, while Raytheon's bid was $3,500. China Lake (designer of the Sidewinder missile) estimated that $6,000 per copy was the reasonable price, figured that Raytheon producer of the AIM-7 Sparrow-III was buying in to the business.[41]

[39] NAS China Lake Naval Armament and Technology Museum
[40] The Sidewinder Story, the Evolution of the AIM-9 Missile
[41] Page 181, Sidewinder - Creative Missile Development at China Lake

MIM-72A/B Chaparral

Starting in 1959 the U.S. Army MICOM (Missile Command) began development of an ambitious anti-aircraft missile system under their "Forward Area Air Defense" (FAAD) program, known as the MIM-46 Mauler. In testing the Mauler proved to have numerous problems in 1963. MICOM was directed to study whether or not the Navy's AIM-9D Sidewinder missile could be adapted for the ground-to-air role. Since it was guided by an infrared seeker, it would not be confused by ground clutter like the radar-guided Mauler.

The new concept, the "Interim Forward Area Air Defense" (IFAAD) evolved.

The Chaparral was to be a quick fix, interim weapon system which would remain in the field some 2 to 4 years until the MAULER became available. Specifically, the system would be an unsophisticated assemblage of slightly modified, off-the-shelf hardware consisting of the M113 armored personnel carrier with structural modifications to support the M45 mount; Navy LAU-7A launch rails; and AIM-9D Sidewinder missiles modified to accommodate firing at zero initial velocity.[42]

The main concern was that at shorter distances the missile would not have time to lock onto the target before it flew out of range, so to serve this need a second vehicle based around the M61 Vulcan cannon was specified. Both would be aimed manually, eliminating the delay needed for a fire control system to develop a "solution". Neither vehicle concept had room for a search radar, so a separate radar system using datalink was developed for this role.

The studies were completed in 1965 and the Chaparral program was begun.
The first Chaparral battalion was deployed in May 1969.

The MIM-72A missile was based on the AIM-9D Sidewinder. The main difference is that to reduce drag only two of the fins on the MIM-72A have rollerons, the other two having been replaced by fixed thin fins. B model for training was identical to the A model with the exception of a different warhead fuse.

Between 1966 and 1971, 5236 MIM-72A missiles and 436 fire units were fielded by the US Army, 12 were sold to Israel, along with 216 missiles.

1969
School Support, Fort Bliss
8th Inf. Div., Germany

1970
3d Inf. Div., Germany
32d AADCOM, Germany*
3d Armored Div., Germany
1st Armored Div., Germany
1st Inf. Div., Germany

[42] Page 34, History of the CHAPARRAL Air Defense System

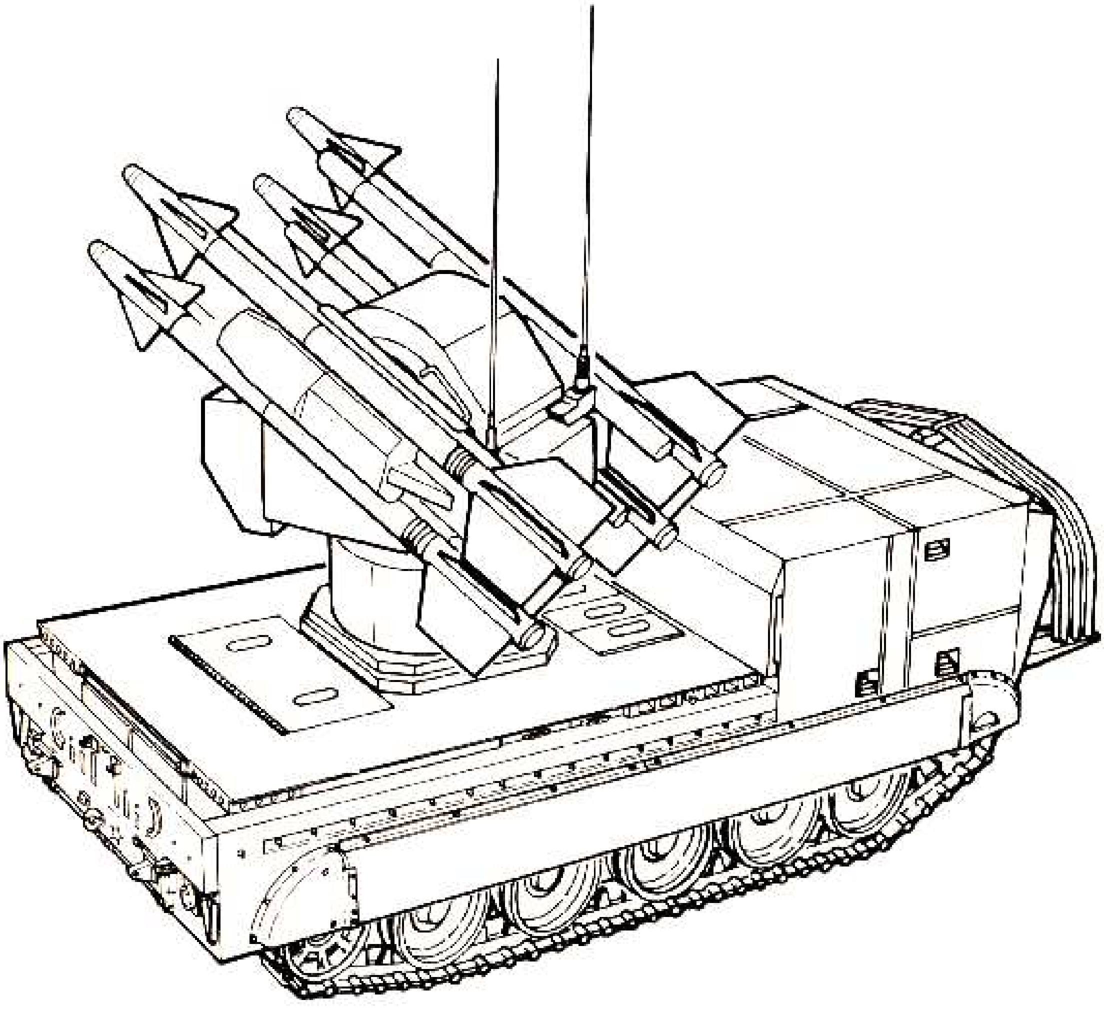
1971
2d Inf. Div., Korea
2d Armored Div., Ft Hood
STRICOM, Ft Bliss
25th Inf. Div., Hawaii

1972
4th Inf. Div., Ft Carson

1973
9th Inf. Div., Ft Lewis

1974
1st Calvary Div., Ft Hood

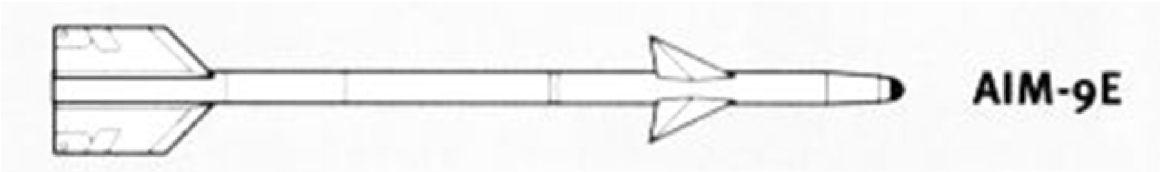
*32d AADCOM fielded six composite batteries of eight Chaparral and eight Vulcans each. All other units had two composite batteries of 12 Chaparrals and 12 Vulcans in each.[43]



The M48 fire unit has 4 ready to launch missiles on the turret, and 8 disassembled reloads stored inside of the vehicle.

[43] Page 110, History of the CHAPARRAL Air Defense System

AIM-9E Sidewinder (USAF)



Unlike the USN which was focused on the tactical air battle, the USAF had diluted its resources into several AAM programs and thus lagged in the development of their own Sidewinder subtypes. Vietnam saw the AIM-9B perform questionably, and the USAF sought improvements to the design to enhance performance against fighter type targets. The result was the AIM-9E.

A Magnesium Fluoride dome was adopted, a more compact optical assembly was used, with a faster 100 Hz reticle rate, and a 16.5°/sec tracking rate.
The AIM-9E saw the adoption of a similar low drag nose to the Navy subtypes, but using a conical rather than ogival profile, a distinguishing feature of this family to this very day.

The most significant design change was the adoption of a cooling for the PbS detector element, the USAF opting for Peltier thermoelectric cooling. This arrangement has the advantage of unlimited cooling time on the launch rail, subject only to the availability of electrical power. The seeker improvements expanded the weapon's acquisition envelope and increased its P[k], although not dramatically.
Over 5,000 rounds were rebuilt by Philco-Ford from AIM-9Bs.[44]

AIM-9F Sidewinder (NATO)

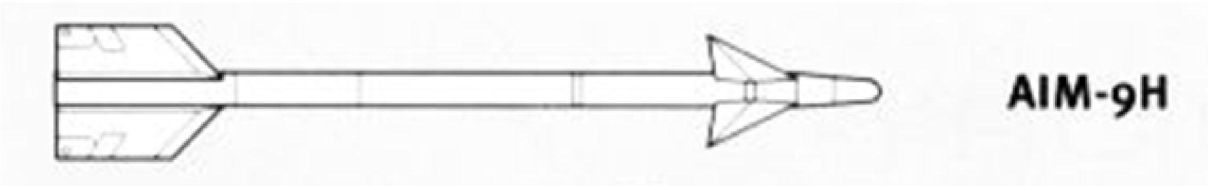
The AIM-9F (also known as AIM-9B FGW.2) was a European development of the AIM-9B, of which 15,000 were built by Bodensee Gerätetechnik (BGT) in Germany. It featured a CO2-cooled seeker, some solid-state electronics, and a new nose dome. This version entered service in 1969, and most European AIM-9Bs were converted to AIM-9F standard.[45]

[44] The Sidewinder Story, the Evolution of the AIM-9 Missile
[45] Raytheon (Philco/General Electric) AAM-N-7/GAR-8/AIM-9 Sidewinder

AIM-9G Sidewinder (NAVY)

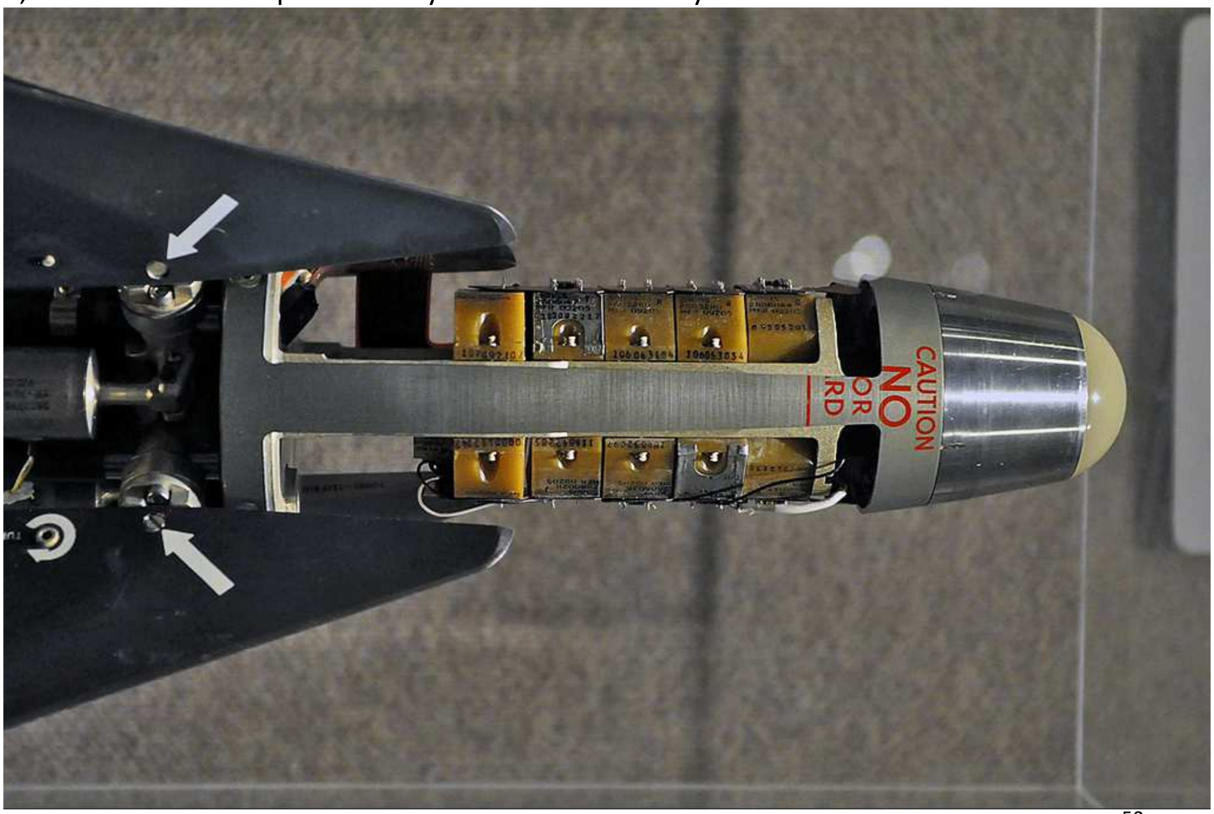
AIM-9G, employed SEAM (Sidewinder Extended Acquisition Mode), a facility which slews the optics through a search pattern to acquire the target allows slaving of the optics to radar or a helmet sight.[46] The very heavy 70s helmet mounted sight was despised by fleet pilots and little used. 2,600 AIM-9G were built by Raytheon from 1970 to 1972.[47]

AIM-9H Sidewinder (NAVY)



The Hotel saw some radical changes resulting from experience with the D/G, which suffered reliability problems due the intolerance of vacuum tubes to repeated recoveries on aircraft carrier decks. The AIM-9H was the first solid state Sidewinder, with the complete guidance package built with semiconductors. In redesigning the electronics, the optical system was essentially retained.

While few of the AIM-9H were fired in combat due shortages of supply, they are reported to have scored a much higher kill rate per launch than any other Sidewinder in the campaign.[48] 7,700 AIM-9Hs were produced by Philco-Ford and Raytheon between 1972 and 1974.[49]



AIM-9H Sidewinder all-transistor seeker head using cordwood module packaging[50]

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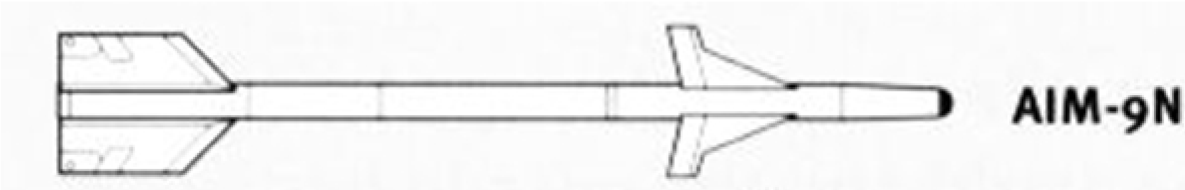
[46] Raytheon (Philco/General Electric) AAM-N-7/GAR-8/AIM-9 Sidewinder
[47] Page 187, Sidewinder - Creative Missile Development at China Lake
[48] The Sidewinder Story, the Evolution of the AIM-9 Missile
[49] Raytheon (Philco/General Electric) AAM-N-7/GAR-8/AIM-9 Sidewinder
[50] NAS China Lake Naval Armament and Technology Museum

AIM-9J/N/P Sidewinder (USAF)



The follow-on version to the AIM-9E was the AIM-9J, which was rushed into the SEA theatre in July, 1972. The Juliet model saw incremental improvements to the AIM-9E design, with hybrid electronics using a mix of solid state and tube technology, and an improved control system using a longer burning gas generator for a 40 sec flight time. 6,700 of this subtype were eventually built or rebuilt from AIM-9Bs.

In 1973, Ford began production of an enhanced AIM-9J-1, later redesignated the AIM-9N. The November model employed a similar configuration to the Juliet, but the three main printed circuit boards were substantially redesigned.
Close to 7,000 of this version were built, mainly for export.

While the AIM-9L fulfilled the role of the frontline all aspect dogfight missile, a need still existed for a second tier weapon for use in less demanding situations, and also suitable for export to less than absolutely trusted allies. This requirement was fulfilled by the AIM-9P family, derivatives of the AIM-9J/N.

The AIM-9P-2 and P-3 were introduced in the mid-seventies and use improved guidance electronics, a new rocket motor and an active optical fuse.

The AIM-9P-4 is an incremental development of the AIM-9P-3, with an all aspect seeker using some of the technology developed for the AIM-9L. In comparison with its cousin, it is less agile but still a very effective missile.

The AIM-9P-5 is further improved by the addition of a counter-countermeasures capability.

21,000 of various AIM-9P subtypes have been built and are in use with the USAF and many export customers.[51]

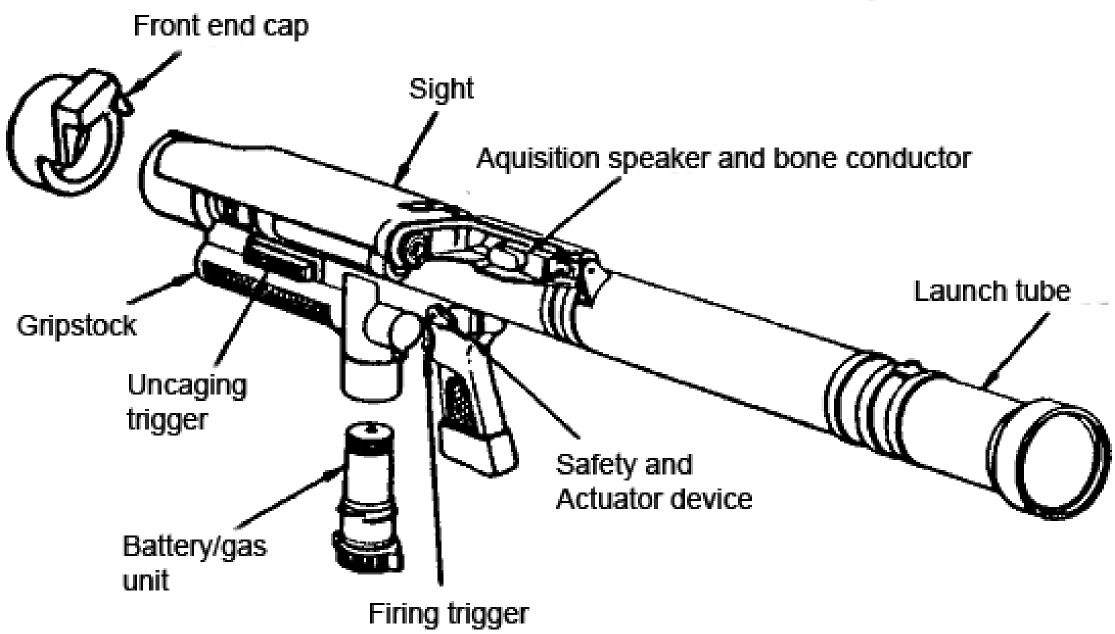
[51] The Sidewinder Story, the Evolution of the AIM-9 Missile

FIM-43C Redeye

In 1948 the United States Army began seeking new infantry air-defense weapons, as machine guns were ineffective against new fast jets. In 1957 official requirements were formulated, and in 1958 development started.
Production of the systems began in May 1967.

Redeye missile flight sequence:
As the missile leaves the tube around 25 m/s, spring-loaded fins pop out, four stabilizing tail fins at the back of the missile, and two control surfaces at the front of the missile. Once the missile has travelled 6m, the sustainer motor ignites, and takes the missile to its peak velocity of Mach1.7 in 5.8 seconds. Its inability to turn at a rate greater than 6G means that it can be outmaneuvered if detected.[52]

Between 1967 and 1973, more than 26'000 pieces were fielded by the US, 1'093 Sweden, 1'018 West Germany, 540 Denmark, and 216 Australia.[53]

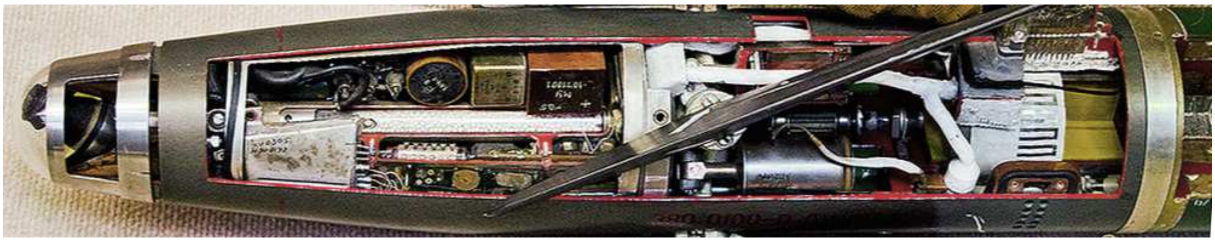


[52] Page 146..148, History of the REDEYE Weapon System
[53] Page 155, History of the REDEYE Weapon System

R-13M (K-13M) Article 380 (AA-2C Atoll)

The development begun in 1969 and already fielded in January 1974.

The modernized R-13M (K-13M, article 380), differs from its predecessor by the increased area of the tail and rudder, with the slanted rolleron better dampening the roll rate, and the use of solid state elements.



Nitrogen cooling of the seeker (TGSN IN-70) has increased its sensitivity, while the tracking rate is doubled compared with the R-3S and reached 12°/s.

The motor has increased impulse of 2800 kgf, controlled flight time of 54s up to a maximum of 15km launch range.

The fuse is replaced by a more reliable one with 5m radius of sensitivity. Reducing the distance compared to the R-3S dictated more accurate hits and a new type of warhead. The warhead has a grid of 200-mm rods, along the body and the ends welded together in a checkerboard pattern. When detonating, the unfolding grid of 744 rods formed a large expanding ring. The radius of effective destruction was 7.5m.[54]

Launching R-13M was possible maneuvering overload up to 3.7g[55]

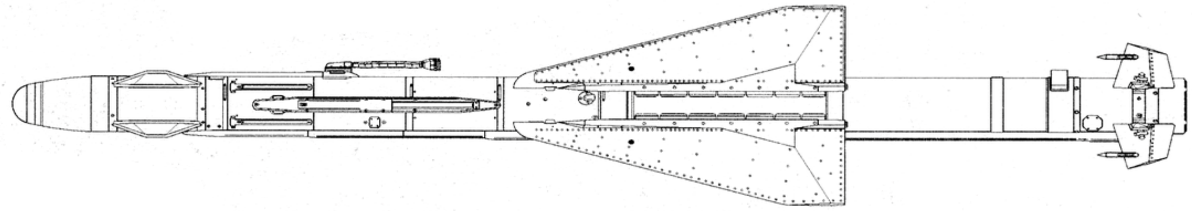
Hungary fielded over 2'500 pieces for its: MiG-21Bis, MiG-23MF, and Su-22M3 planes.

[54] Page 24, Советские авиационные ракеты воздух-воздух

[55] Page 47, Советские авиационные ракеты воздух-воздух

R-23T (K-23) Article 360 (AA-7B Apex)

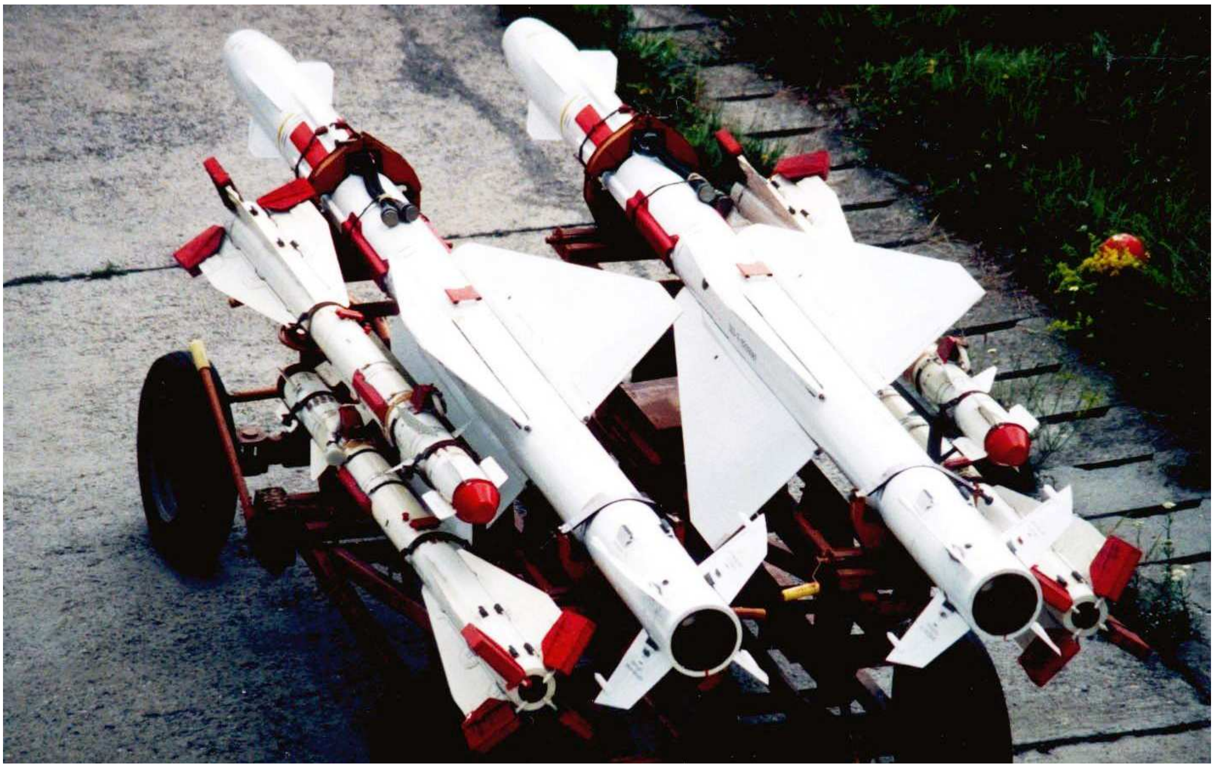
In response to the US F-4 Phantom, on 3 December 1963 Resolution № 1199-445 "On creation of tactical fighter-interceptor MiG-23 and its main weapon, the K-23 missile" initiated the development by the Vympel design bureau. For the first time in Soviet history, the missile was designed with solid state elements. MiG-23M (Flogger-B) with the radar RP-23, and K-23 missiles (R-23R and R-23T) was adopted on 9 January 1974.[56]



Compared to the primary weapon of the MiG-23M, the all aspect, semi active radar guided; 27km ranged R-23R Article 340 (AA-7A Apex), the R-23T Article 360 (AA-7B Apex) liquid nitrogen-cooled (TGS-23) seeker had FOV ±60°, and was limited to rear aspect attacks only with 16km lock-on range.

The two rows of rods in the 26kg warhead are aligned to form a 8m grid, by the detonation of 6kg explosives.[57]

The 217kg missile has 35s flight time. Overload during launch can be 5g.[58]

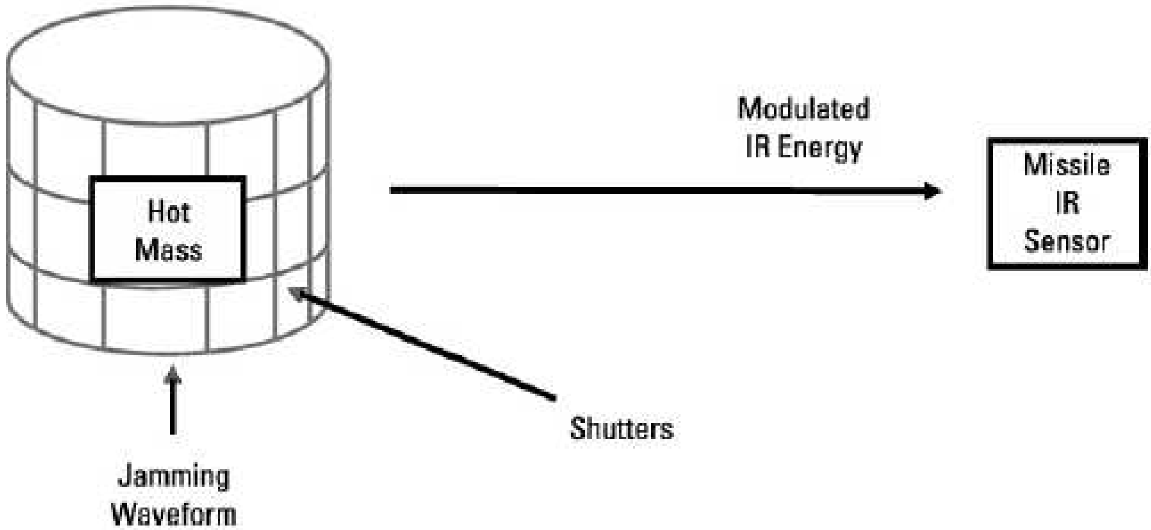


Hungary fielded 107 pieces for its: MiG-23MF fighters.

[56] Page 21..23, Авиация и Космонавтика No.9 2002
[57] Page 31..32, Советские авиационные ракеты воздух-воздух
[58] Page 47, Советские авиационные ракеты воздух-воздух

Onboard thermal jammer

Development of jammers began in late 1960s as IR threats started to proliferate. The hope for jammers was that they would solve the problem inherent with decoys: the need for a reliable missile warning, and the limited quantity available in aircraft dispensers. A jammer could be turned on all the time.



The first challenge was a search for high-intensity modulated sources in IR with (ideally) long life and high reliability.

Two different types of thermal sources evolved and eventually made their way into operational systems:[59]

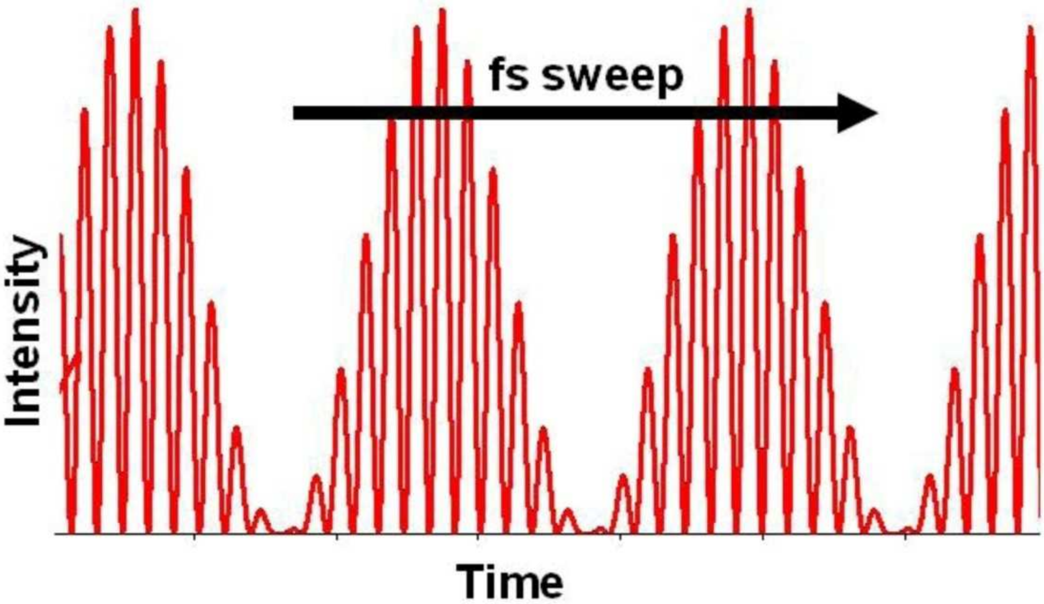
Mechanically modulated element heated to incandescence - ALQ-144

[59] Page 94, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures

Pulsed cesium vapor arc lamp - L-166V-11E

The thermal jammers are highly effective against Spin Scan (AM logic) missiles and still have utility today because of the wide proliferation of these older missile types.

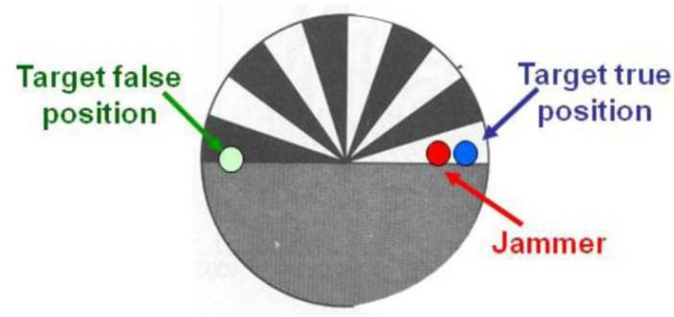
Basic jammer strategy is to inject a signal into the target tracker that resembles that of a valid target aircraft. The waveform created by the jammer must pass through the missile's electronic filtering, just as a target signal does. Jammers may have different waveform shapes, depending upon the method used to create the IR source, but the most efficient waveform in terms of jamming influence for the amount of irradiance received is one that resembles the waveform created by the reticle modulation of a real target.

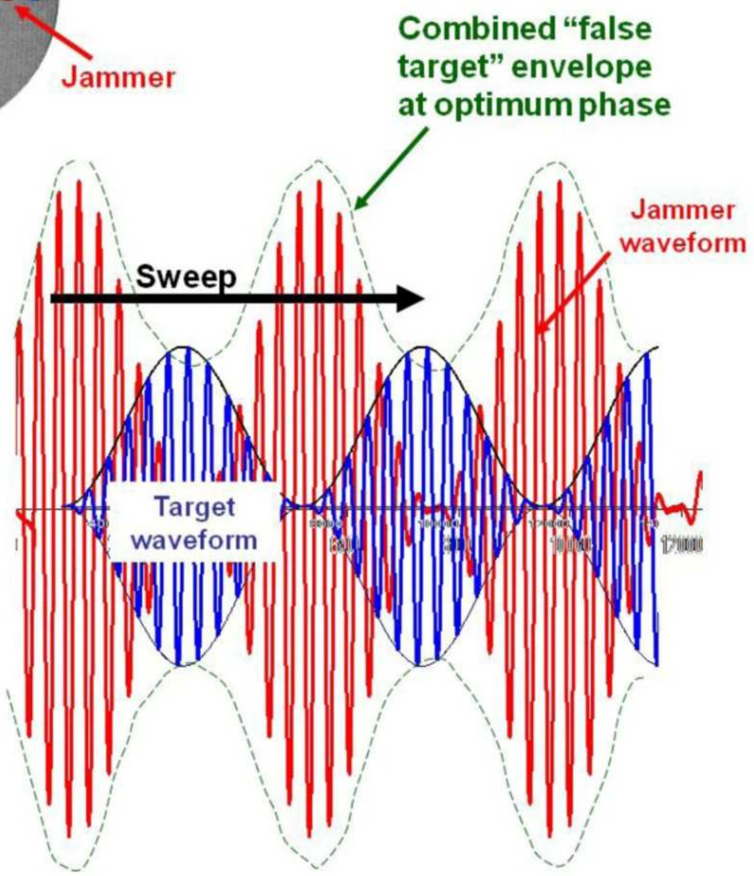


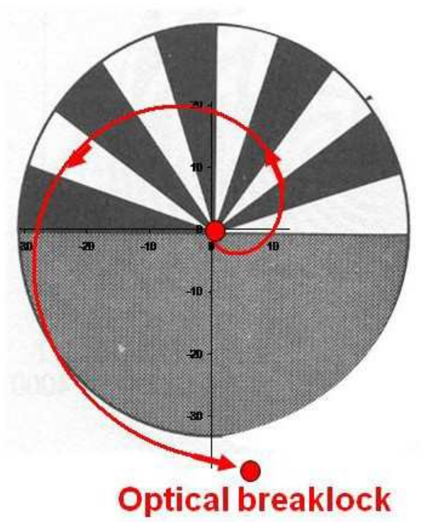
Because IR missiles are passive, and there is no present operational method of getting feedback from the missile, jamming must be done "open loop." The jammer modulation envelope must be swept through the known frequency range of the missile. During part of the cycle, when the jammer signal is in phase with that of the target, the jammer will add to the target's irradiance. As a result, a jammer will usually expand the range at which a target can locked onto.[60]

[60] Page 96, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures

The jammer is located onboard the target aircraft; but, when the phase of the jammer modulation is opposite that of the target, the net envelope of the combined jammer and target waveform makes the target appear as if it were in the opposite direction from the boresight. The result is to push the tracker toward the false target and away from the real target.







The apparent target position is the vector sum of the target and jammer signals. As a jammer is swept in frequency and consequent phase, the apparent direction to the target rotates, thus causing the missile track point to nutate, or wobble, about the true target position.

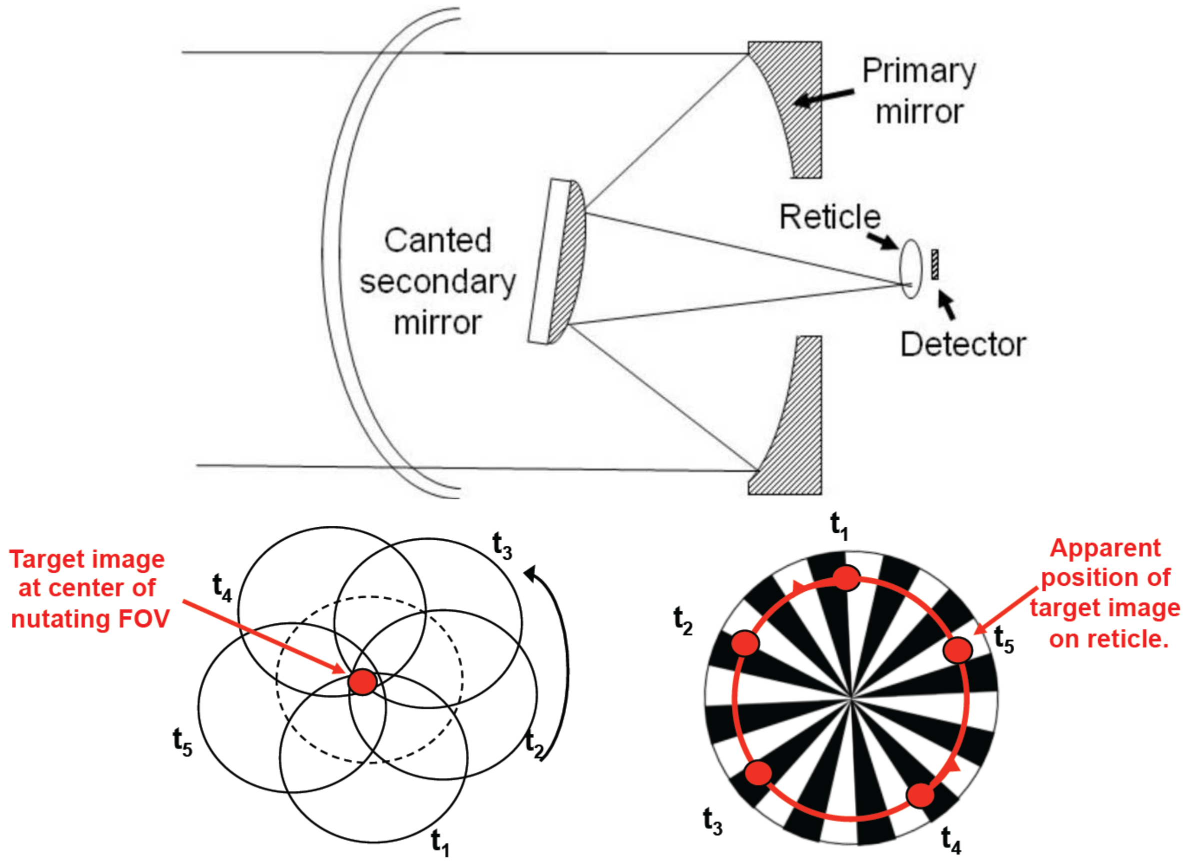
The nutation will cause an outward spiral that can "walk" the track point and missile FOV off the target and achieve what is known as an optical break lock. If an OBL can be achieved, the jammer has won the engagement because most IR missiles do not have the ability to search and reacquire a target once the missile is in flight.[61]

[61] Page 97..98, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures

Conical Scan tracker (FM logic)

Target trackers with a single IR detector require mechanical scanning of the target scene. The tracker that has been described earlier is what is known as a spin-scan design. A spin scan is highly vulnerable to jammers because the tracker optics is always looking at the target; and, consequently, false position information can be injected at any time during the scan rotation. The next step in tracker evolution was the conical-scan design.

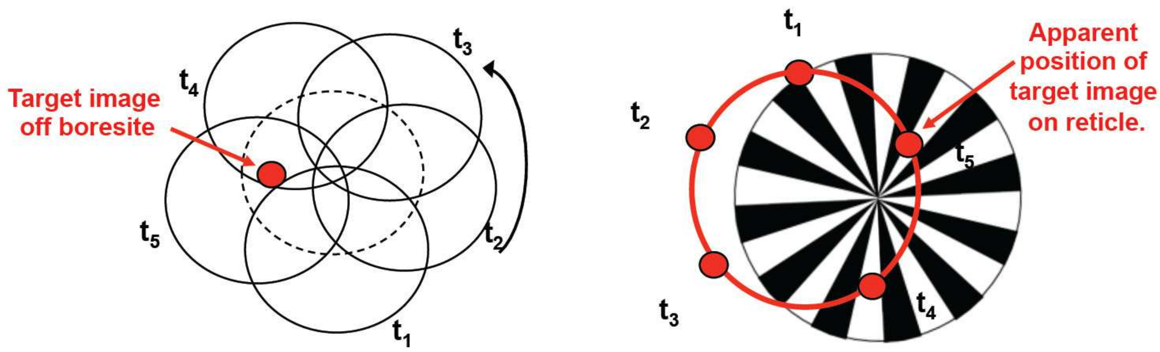
Conical-scan trackers borrowed a concept that fire control radars had used for decades. Instead of staring straight ahead, the IFOV of a conical scan is offset; and, as it scans, the IFOV sweeps out a circular pattern. A conical scan can be implemented by simply offsetting the secondary mirror in a Cassegrain telescope, as shown.



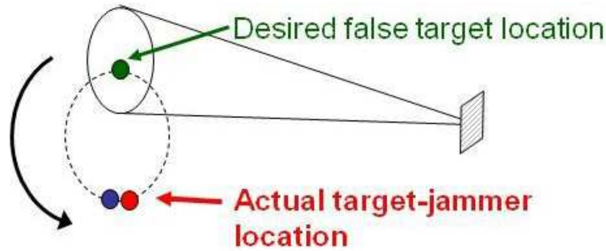
For a target centered on the optical axis, the IFOV sweeps out an overlapping circle.

The target image falls on the edge of the reticle rather than in the center. Conical-scan trackers use a different reticle design with spokes all the way around rather than in only one-half of the disk. This configuration produces a detector waveform with constant amplitude. For tracking near the optical axis, the target image is slightly offset, thus resulting in a frequency change as the image crosses spokes at different distances from the center. For this case, the electronics use frequency modulation (FM) rather than amplitude modulation (AM), a factor that results in a tighter tracking loop.[62]

[62] Page 73, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures



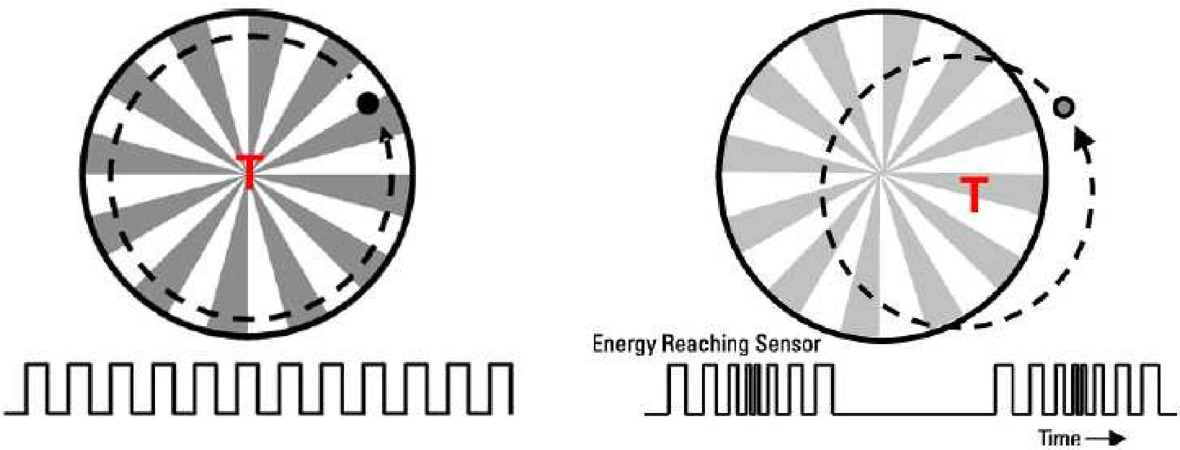
If the target is farther off center, the image falls off the reticle during part of the scan, shown at times t_2 and t_3. During this time, the target is outside the IFOV and no radiation is received from the target. The implication for countermeasures is that no information can be injected into the tracker when it is not viewing the target.[63]



In theory, conical scan is impossible to be defeated with an onboard thermal jammer, because the missile does not look at the target during the time the jammer needs to be injecting a signal to push the track away.

In practice, it might be possible for a strong jammer to defeat conical scan because of:

1. Optical scattering and reflections are always present in real life optics that are never perfect, and a strong jammer signal from outside of the IFOV can still get through.
2. Perturbations that are induced in missile flight. Even if there is no OBL, the jammer modulation disturbs missile flight, thus scattering the hit pattern at the target and resulting in a miss by some percentage of shots. [64]



When the target (**T**) is centered in the tracker (i.e., at the optical axis), the reticle produces a constant frequency square wave of energy into the sensing cell, if it's off axis, the signal is frequency modulated (FM logic).[65]

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[63] Page 74, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures

[64] Page 100, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures

[65] Page 366..367, EW 104, EW Against a New Generation of Threats

9K34 Strela-3 (SA-14 Gremlin)

Development of portable SAM "Strela-3" (9K34) with 9M36 missiles has been set to the same Decree, under which work on SAM "Strela-2M" were deployed in 1968.

Among the new technical solutions and high combat and operational characteristics of the complex were:

- new deep-cooled homing head, providing a sensitivity two orders of magnitude higher than the sensitivity of the seeker of complex "Strela-2M", which significantly expanded the lock-on range.

- automatic launch mode, allows the system to automatically launch the missile, when the target is in the engagement zone.

The rocket engine, launcher, and other components are the same as in Strela-2M.

In 18 January 1974 the complex was adopted. [66]

Mainly 3rd world countries fielded it beside the Soviet Union.

Hungary, Poland, Czechoslovakia, and East Germany decided to skip it, in favor of the all aspect 9K310 Igla-1 (SA-16).

[66] Page 74..75, Техника и Вооружение No. 5-6 1999

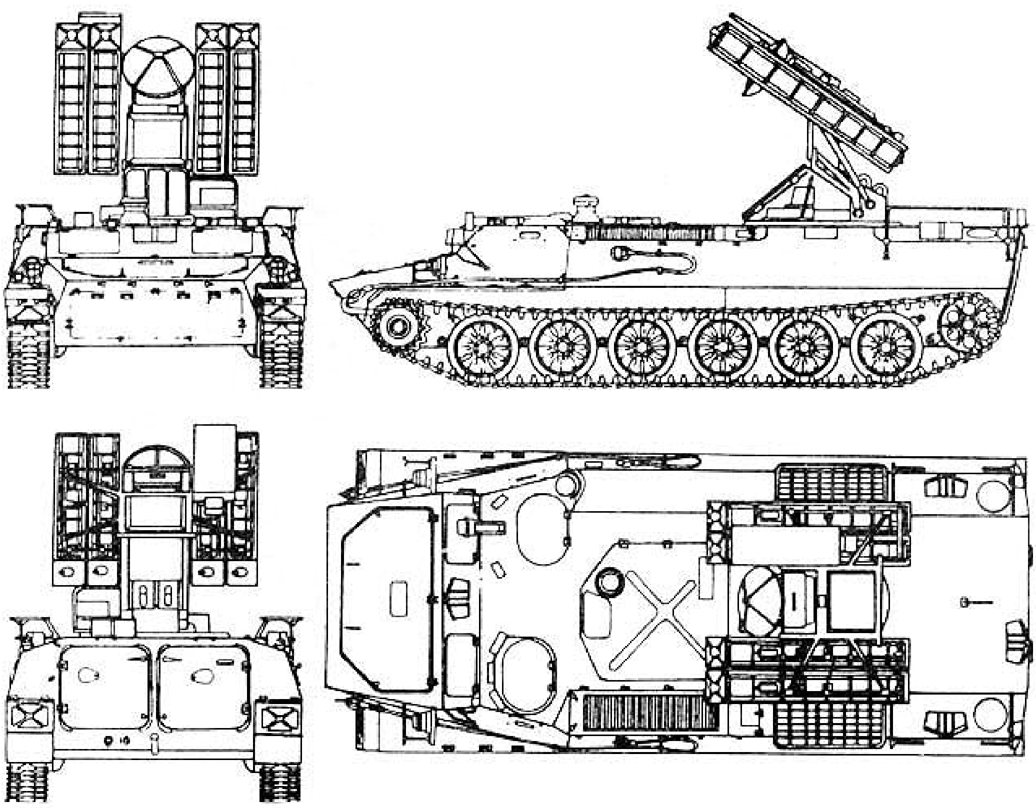
9K35 Strela-10SV (SA-13A Gopher)

Work on the creation of self-propelled air defense system "Strela-10" began under the Decision of the Central Committee of the CPSU and the USSR Council of 24/07/1969. Despite the fact that at the same time development of anti-aircraft gun-missile system "Tunguska" was ongoing, the creation of a simple cheap SAM, based on the further development of the complex type "Strela-1", was considered appropriate from an economic point of view. During 1974, the system was presented for state trials but failed and only accepted into service in 16 March 1976. [67]

During flight, the 9M37 missile of the Strela-10SV used one of the two (before launch) selectable channels:

- The photo contrast channel (also used by the Strela-1M) did not require cooling, and could be used against incoming targets (besides receding), but was not protected against natural optical interference. (heavy clouds with strong contrast, horizon line)
- The infra channel required prior cooling, could be used against receding targets, and was effective against natural optical interference.[68]

To limit missile rotation during flight, rollerons were used, but instead of spinning them with the airflow, they were spinned by the engine combustion. Rod warhead was introduced with a weight of 3kg. The 10.3km ranged millimeter wave rangefinder radar provided firing zone and lead angle calculation.



Vehicle has 4 ready-to-launch missiles on the turret, and another 4 missiles stored inside

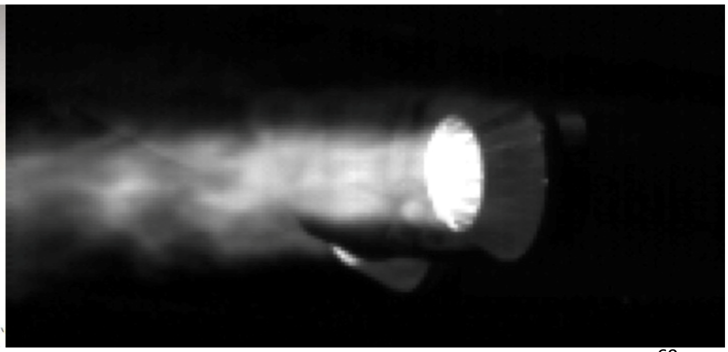
[67] Page 59, Техника и Вооружение No. 5-6 1999

[68] Page 60..61, Техника и Вооружение No. 5-6 1999

Cooled Indium Antimonide (InSb) detector

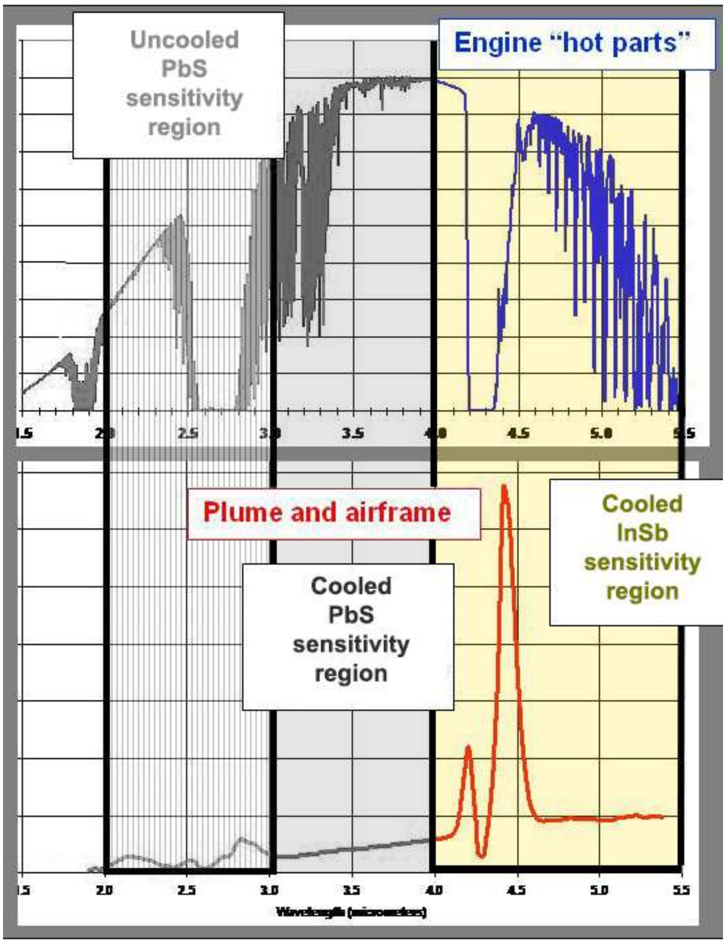
With cooled Indium Antimonide sensor, it was possible to track the aircraft's plume. Because the plume can be seen from most of the front or the side of the aircraft, the missiles could track from almost any angle, making these all-aspect missiles.

Indium Antimonide (InSb)



Engine Plume and hot parts of an F-14[69]

Plume size varies greatly depending upon mass flow. Plume radiance is greatest at the exit nozzle and diminishes with distance as the exhaust gases are cooled by mixing with the air.
Plume of a jet aircraft engine may be 15m or more in length.
Plume of a helicopter or turboprop engine may be only 1.5m in length.[70]



Missiles using this sensor material need to adjust their aim at the final stage of the missile's flight by introducing bias to the signal sent from the seeker to the guidance system, causing it to steer the missile towards the airframe of the aircraft ahead of the exhaust plume.

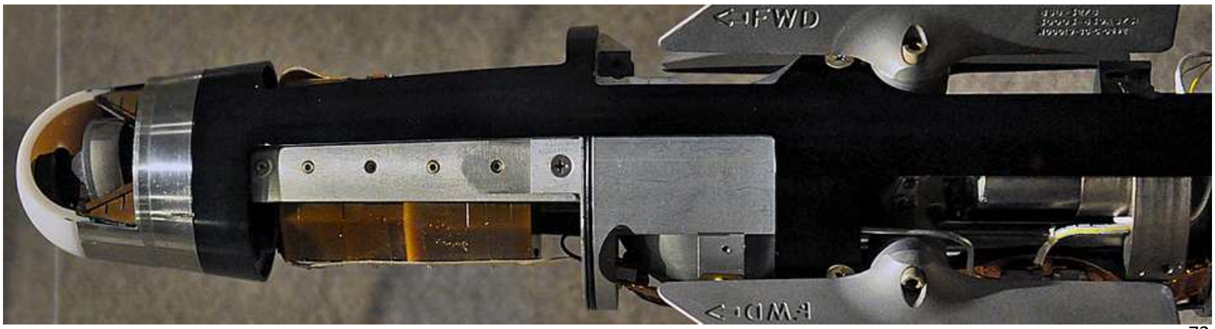
[69] Page 35, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures
[70] Page 39, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures

AIM-9L Sidewinder

The AIM-9L is essentially an AIM-9H with a new optical system, new fuse and new cooling system.

The Cassegrain system of the H was retained, but a new FM reticle was adopted, necessitating some fundamental changes to the guidance electronics.

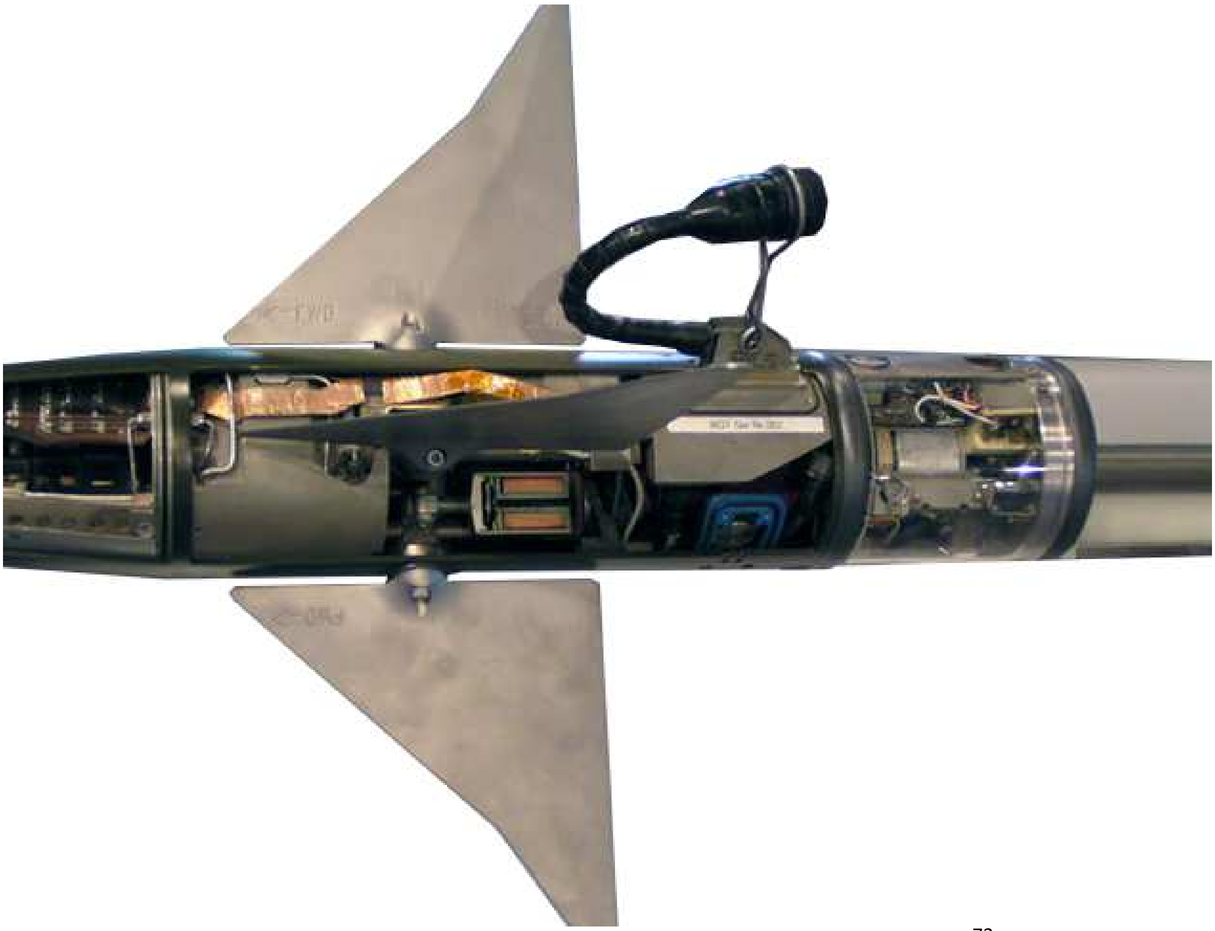
A new Indium Antimonide (InSb) detector was used, enclosed with an optical filter in an Argon cooled container. This optical system allows acquisition and tracking of targets from all aspects, due the longer wavelength sensitivity of the InSb, with the filter employed to reject shorter wavelengths. [71]



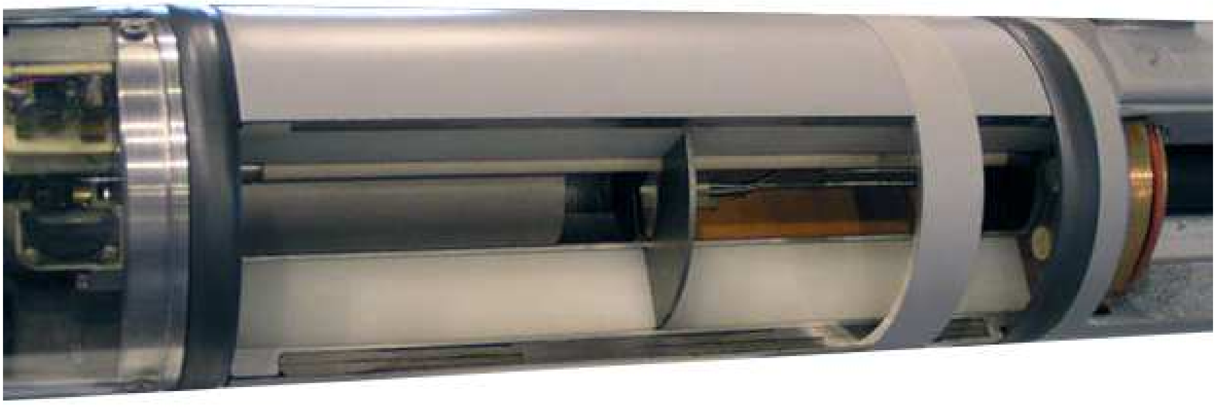
The seeker has a ±40° field of view, with ±27.5° off the plane boresight targeting capability [72]

The control actuators of the AIM-9H were retained

[71] The Sidewinder Story, the Evolution of the AIM-9 Missile
[72] Az AIM-9L Sidewinder légiharc-rakéta



The double delta canards gave much better maneuver performance of 35g[73]; launch load limit is 7g.
Above the gas generator (providing 1 minute of energy during flight) is the electric connector to the aircraft.
Behind it, is the DSU-15B AOTD (Active Optical Target Detector) active laser proximity fuse using solid state Gallium Arsenide laser paired to a Silicon photodiode, with 10m of detection range.[74]



The 9.4kg WDU-17B warhead has a double row of 194pcs titanium rods, and PBXN-3 type explosive.[75]

[73] Page 195, Sidewinder - Creative Missile Development at China Lake
[74] Az AIM-9L Sidewinder légiharc-rakéta
[75] Az AIM-9L Sidewinder légiharc-rakéta

Last two thirds of the missile has the Hercules-Bermite Mk-36 solid fuel engine.
The 27kg Flexadyne charge has 6s of burn period, accelerating the weapon 2.5 Mach above the launcher speed. At high altitude, the maximum kinematic range is 17km.
Practical range is 10km for incoming, and less than half for receding targets.[76]
Production started in 1978, and more than 16'000 AIM-9Ls have been built by Philco-Ford, Raytheon, BGT (Germany), and Mitsubishi (Japan).[77]
During the 1982 Falklands war, it scored 17 kills by 21 hits from 26 launches, achieving 80% hit rate. Four missiles were fired out of range; one was fired in error during a bombing run.[78]

Hungary fielded the AIM–9L/I–1 Sidewinder in 2006 for its JAS-39EBS HU Gripen fighters.
These are older AIM–9L missiles refurbished with AIM-9M components, from the German Diehl Bodenseewerk Gerätetechnik (BGT) Defense and is considered an operational equivalent to the initially "US only" AIM-9M.

[76] Az AIM-9L Sidewinder légiharc-rakéta
[77] Raytheon (Philco/General Electric) AAM-N-7/GAR-8/AIM-9 Sidewinder
[78] Page 163, Falklands Air War

MIM-72C Chaparral

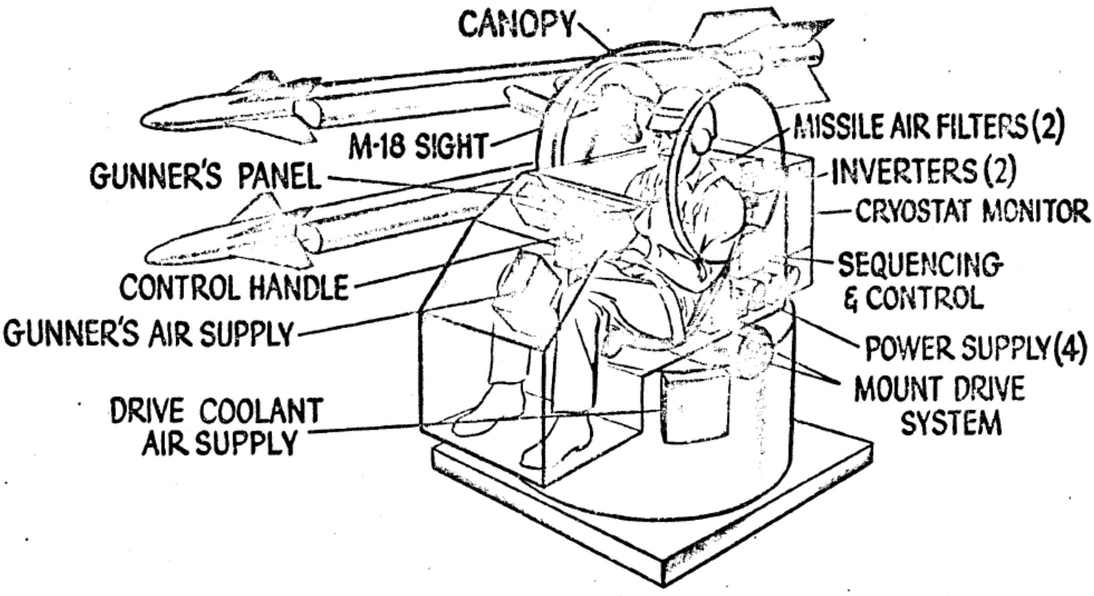
The guidance section phase of the product improvement program was directed toward the development of an improved seeker to provide the Chaparral a full head-on detection capability, to reduce the dead zone of the system, and to reduce susceptibility to modulated infrared countermeasures. The initial program proposal, submitted in 1970, called for a solid state (tubeless) guidance package to improve productability, reliability, and maintainability.

Two proposals were evaluated, one of these was the AN/DAW-1 guidance section designed by the Aeronutronic Division of Philco-Ford, and other was the Chaparral version of the Navy's AIM-9L missile. Philco-Ford's AN/DAW-1 proposal was determined to be a more cost effective and timely improvement for Army requirements. During tracking tests, the AN/DAW-1 seeker successfully demonstrated target acquisition capability in the forward hemisphere at a range of 4 to 6 kilometers.[79]

C models were deployed between 1976 and 1981, reaching operational status in 1978.

MIM-72E/F Chaparral

The basic Chaparral weapon was conceived in 1965 as a stop-gap system that could be fielded in a relatively short time to help fill the void in forward area air defense caused by the delay of the Mauler program. However, flight test results disclosed a number of limitations requiring design improvements.



Of prime concern was a smoke problem with the rocket motor; i.e., the smoke signature obscured gunner visibility, lengthened the time between firing the first round and engaging a second target, and betrayed the fire unit to artillery counteraction.
The test firings in 1978 used a new smokeless motor, which greatly improved visibility after firing and made it much easier to fire follow-up rounds. [80]
Existing missiles were upgraded with the new motor to become the MIM-72E, while new-build versions (otherwise identical) were known as the MIM-72F.

[79] Page 117, History of the CHAPARRAL Air Defense System
[80] Page 111, History of the CHAPARRAL Air Defense System

FIM-92A Stinger Basic

The most significant problem with Redeye was that it was effective only in specific engagement circumstances: the soldiers on the ground had to fire the missile directly at the exhaust of the target aircraft in order to allow the weapon's infrared (IR) seeker to establish a lock. This meant that the missile could only be fired at the target after it had passed over and, presumably, had already delivered its munitions in the area.

Redeye was referred to as a "revenge" weapon for this reason.

The Army began advanced development on a replacement for Redeye, dubbed Redeye-II and later renamed the Stinger, in 1967. The contract to develop Stinger (officially designated FIM–92) was awarded to General Dynamics in 1972.

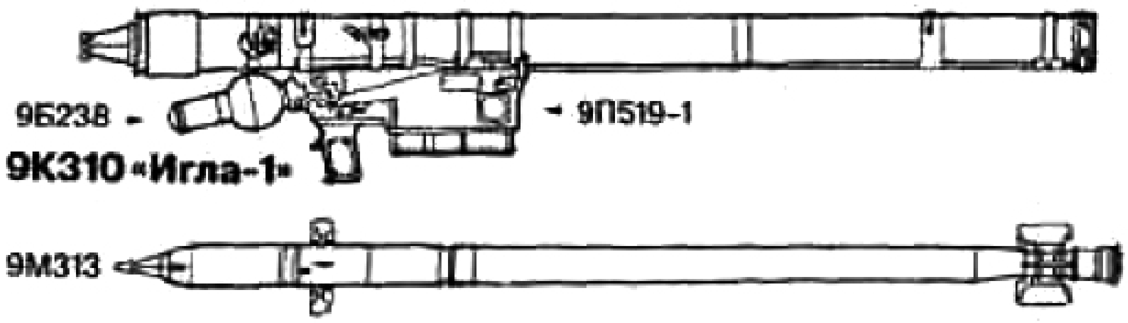
Stinger Basic, used an improved reticle design, called conical scanning developed by General Dynamics. In this type of seeker, the reticle was fixed in place and the spot image was scanned in a circle by spinning mirrors, and picked up by the argon cooled Indium Antimonide (InSb) detector. If the target was on the optical axis the circle would be centered on the reticle; if it was off-axis, the circle would be off the reticle center. The on-center pattern produced a symmetrical square wave signal because the amount of time spent on the reticle's transparent vanes was the same as that on the opaque vanes. If the circle was off-center there was varying time spent on the two types of vanes, producing a modulation of the frequency of the signal. Unlike the sort of spinning reticle used by Redeye, errors do not increase as the deviation from true alignment decreases.

The Stinger achieved initial operating capability in 1981.[81]
A total of 15,669 FIM-92A (Basic Stinger) missiles were produced between 1978 and 1987.

[81] Page 8..10, Critical Technology Events in the Development of the Stinger and Javelin Missile Systems

9K310 Igla-1 (SA-16 Gimlet)

The development of the Igla short-range man-portable air defense system began 12 February, 1971.



The main goals were to create a missile with better resistance to countermeasures and wider engagement envelope than the earlier Strela-2/3 series. Technical difficulties in the development quickly made it obvious that the development would take far longer than anticipated, and in 1978 the program split in two: while the development of the full-capability Igla would continue, a simplified version (Igla-1) with a single band Nitrogen cooled Indium Antimonide (InSb) seeker would be developed to enter service earlier than the full-capability version could be finished. [82]

The 9K310 Igla-1 system were accepted into service in the Soviet army on 11 March 1981.

Igla-1 is much superior to Strela-2M in essentially all respects.
Seeker head proved many times more sensitive than old Strela seeker, now frontal aspect attacks against jets were possible. Seeker also had ability to filter out jammers.
Guidance had an interesting feature - unlike Strela, it did not guide directly to the hottest part of the target (i.e. jet exhaust), but slightly ahead of it, thus hitting more vulnerable parts of the aircraft instead of exhaust pipe. [83]

The missile features an aerospike mounted on a tripod, which reduces the shock wave, thus providing less dome heating and greater range. The name Igla is derived from this device.

[82] Page 76, Техника и Вооружение No. 5-6 1999
[83] Page 226..227, Ilmatorjuntaohjukset Suomen Puolustuksessa

Finland fielded it in 1986, around 160 launchers (9'650 Ruble per launcher - 9'315 Euro*) and over 1500 missiles. (38'000 Ruble per missile - 36'840 Euro*) 302 missiles were expended in training, producing only 40 misses. Hit rate was thus around 87%. [84]
in 2009
East Germany started Strela-2M swapping in 1988. 270 launchers were fielded with 550 missiles.
Czechoslovakia and Poland did not field the Igla-1.

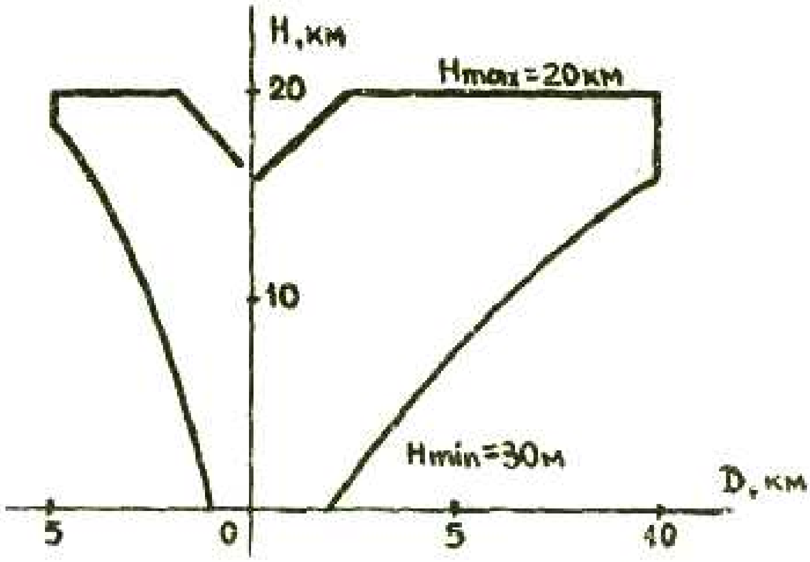
Hungary fielded it from 1986, exchanging one-to-one the Strela-2M at 3 of its first echelon (14th, 15th, 33rd) mechanized regiments.

[84] Page 227..228, 237, Ilmatorjuntaohjukset Suomen Puolustuksessa

R-60M (K-60M) Article 62M (AA-8B Aphid)

Almost simultaneously with the adoption of R-60, work began the modernization.
The new cooled, all aspect OGS-75 seeker off boresight targeting capability was increased to ±17°.

The new more lethal, depleted uranium rod warhead had an increased weight of 3.5kg, increasing the missile total weight to 44kg.[85]



R-60M missile range/height envelope[86]

Hungary fielded 285 pieces R-60 and R-60M for its: MiG-21Bis, MiG-23MF, Su-22M3, and MiG-29 planes.

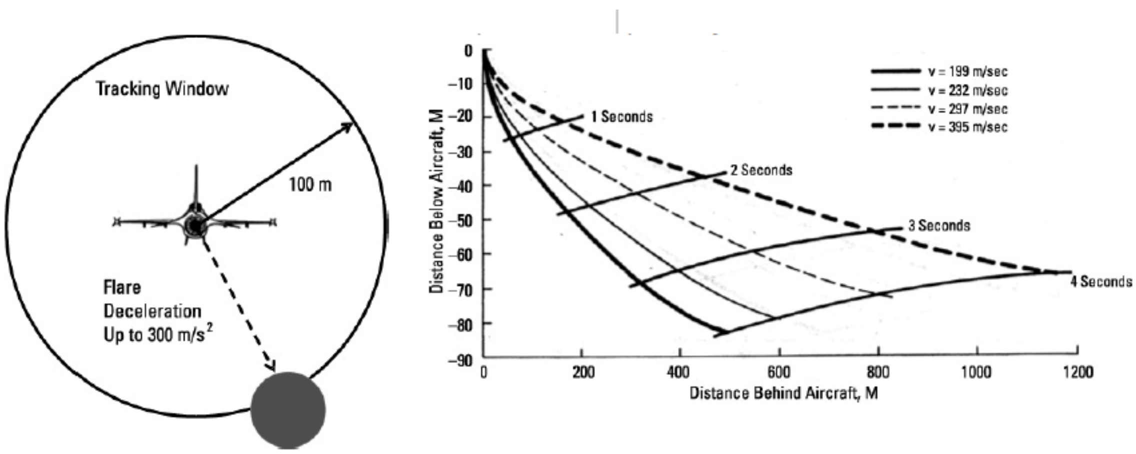
[85] Page 13..14, Авиация и Космонавтика No.3 2002
[86] Page 142, Российское ракетное оружие 1943-1993 г.г.

Pyrotechnic Flare

In the United States, a number of agencies and laboratories were involved in flare development in the early 1950s. The major research and testing were initially done at what was then the NOTS (now NAWCWD), China Lake, California, and, from the late 1960s, were carried on by what was then the Naval Ammunition Depot (now the Naval Surface Warfare Center [NSWC]), Crane, Indiana.

A pyrotechnic does not depend upon external oxygen for reaction; and, consequently, the reaction temperature is not greatly affected by altitude or airspeed. The most energetic composition in terms of IR emissions per mass was found to be a composition of magnesium, Teflon, and Vitron. The product of a magnesium–Teflon reaction is a stream of particles of amorphous carbon that are heated to incandescence by the chemical reaction. Carbon gives the pyrotechnic flare its characteristic spectral shape, very closely approximating that of Planck's curve. In the airstream, a burning magnesium–Teflon flare has a comet-like appearance as the hot carbon particles produce a trail behind the flare. Because the reaction temperature is very stable with altitude and airspeed, the intensity is proportional to the number and rate of the carbon particles produced.[87]

Flares must come up to an effective energy level while they are within the tracking area of the attacking missile. Depending on the design of the flare and the speed of the target aircraft, the aerodynamic deceleration of the flare may be as much as $300m/s^2$. Because the diameter of threat field of view is typically less than 200m at the time the flare is deployed. This calculates to a little over a half-second for the flare energy to exceed the target energy by enough to assure that the missile transfers its tracking from the target to the flare. Note that this energy level must be achieved in this time period at all of the wavelengths at which the threat missile may be tracking.



Separation of a typical flare, from the aircraft dispensing it, from an altitude of 3km. (left) Vertical and horizontal flare separation, as a function of the airspeed of the aircraft. (right)[88]

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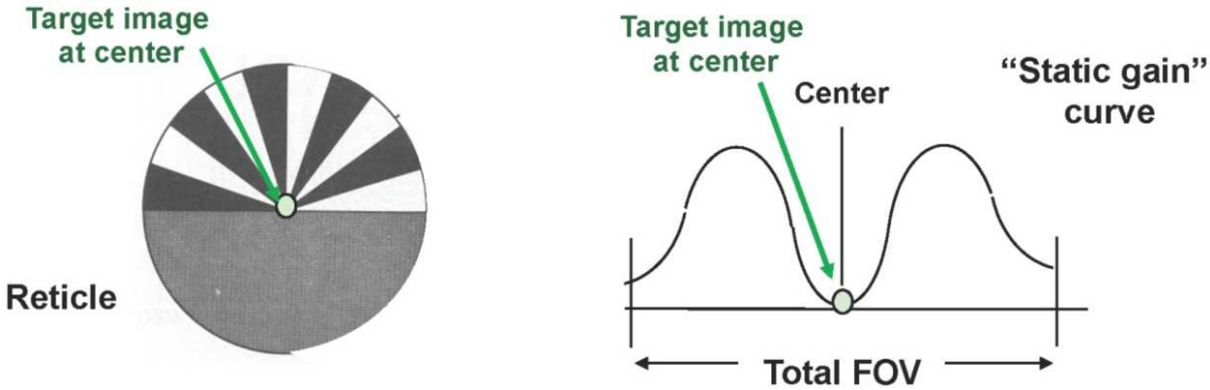
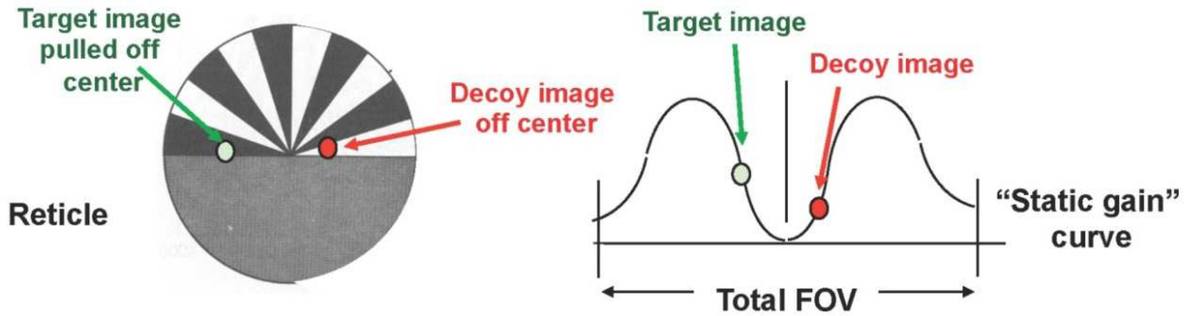
[87] Page 84, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures
[88] Page 378..379, EW 104, EW Against a New Generation of Threats

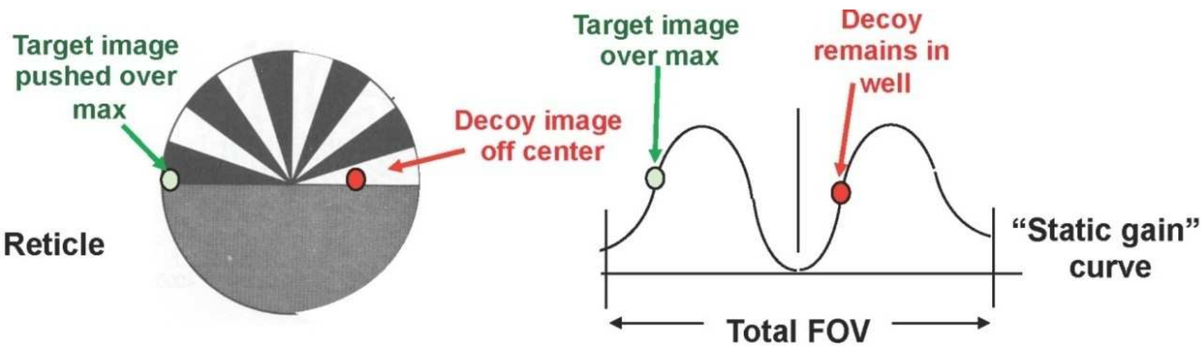
If the flare irradiance is greater than that of aircraft target, the track point will bias toward the flare. As the flare separates from the aircraft, the target will be pushed over the maximum point of the static gain curve. The flare will remain within the well. At that point, the flare has won.



Before flare is dispensed—tracker servo holds target at center of FOV.



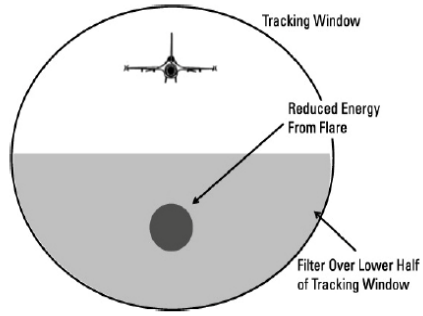
After flare is dispensed—servo tracks centroid of weight images as decoy separates.



Point at which flare wins— flare separated from aircraft until target image moved over maximum point of static gain curve; flare remains in well.[89]

[89] Page 81..82, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures

Flare filtering by position



Because a launched flare will fall below the launching aircraft, the tracker could place a filter over the lower part of the tracking window or in the lower rear quadrant if tracking from abeam. This will reduce energy received from the flare and thus allow the tracker to see the intended target as the more attractive target.[90]

9K35M Strela-10M (SA-13B Gopher)

Decision of Ministry of Defense in 1977 started the complex "Strela-10SV" modernization.

The GSN of the 9M37M missile could differentiate the target from the flare based on their different trajectory. All other characteristics remained the same as the Strela-10SV.
During 1978, the state trials were completed, and in 1979, the Strela-10M was accepted into service.[91]

[90] Page 383..384, EW 104, EW Against a New Generation of Threats
[91] Page 61, Техника и Вооружение No. 5-6 1999

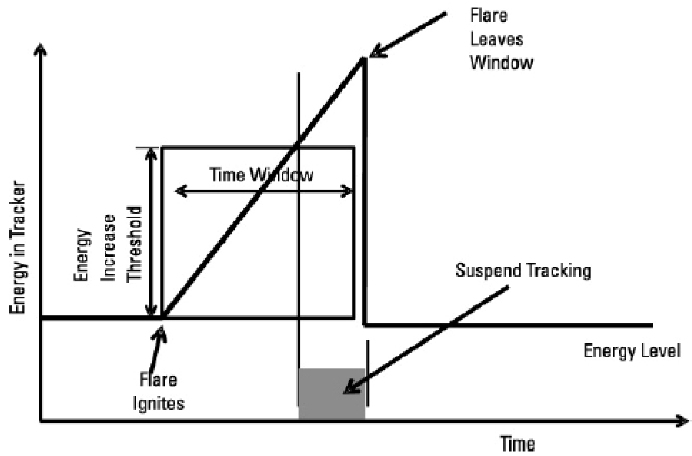
East Germany was the first Warsaw Pact ally to field it in 1983 at one of its 8th tank regiment of its 8th mechanized division. It was a so-called advance delivery, as the originally ordered 9K31M Strela-1M (SA-9 Gaskin) were not available in quantity from the Soviet Union. From 1986, normal deliveries are continued, and altogether 36 vehicles and 680 missiles armed 2 tank divisions (7.th and 9.th) four vehicles per each of the four regiments per division.

Czechoslovakia also received advance delivery (for the same reason as East Germany) in 1983-84, to complete arming its 1st tank division (interrupted by Strela-1M shortages). From 1987, normal deliveries are continued, and altogether 44 vehicles armed 2 tank divisions (1st and 9th), and one mechanized division (15th), four vehicles per each of the four regiments of the divisions. (One regiment of the 1st tank division still used the Strela-1M)

Hungary fielded just 4 vehicles in 1986, for its first echelon 15th mechanized regiment, part of its sole 11th tank division.

Poland fielded also just 4 vehicles, at the 24th tank regiment.

Flare filtering by energy rise time

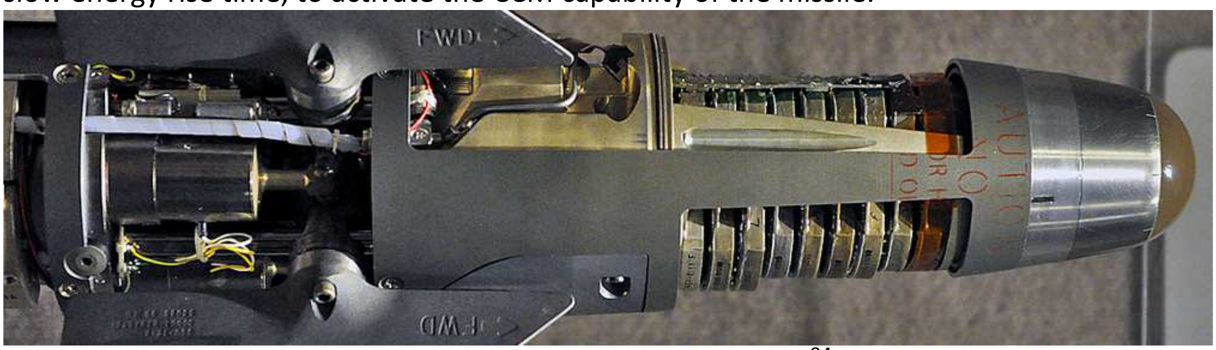


A flare can decelerate at 300 m/s² and the tracking window is only about 200m wide at acquisition. The flare must thus reach its maximum energy in about half a second. This requires that the chemicals chosen for flare construction must build up their energy extremely quickly. This creates a much higher rate of energy rise, compared to a jet engine capable of.

Thus, if the energy increase rate from an object in the tracking window over a preset time interval is above a certain threshold, the tracker stops tracking.
Then, when the energy in the tracker field of view drops to its previous level (as the flare leaves the tracking window), the tracker can start tracking again.[92]

AIM-9M Sidewinder

AIM-9M is essentially an improved AIM-9L. It has improved background rejection, counter-countermeasures capability (CCM) and a low smoke motor to reduce the visual signature of the inbound weapon.[93]
Flare rejection circuits were upgraded following the 1991 Gulf war, as Soviet flares had too slow energy rise time, to activate the CCM capability of the missile.



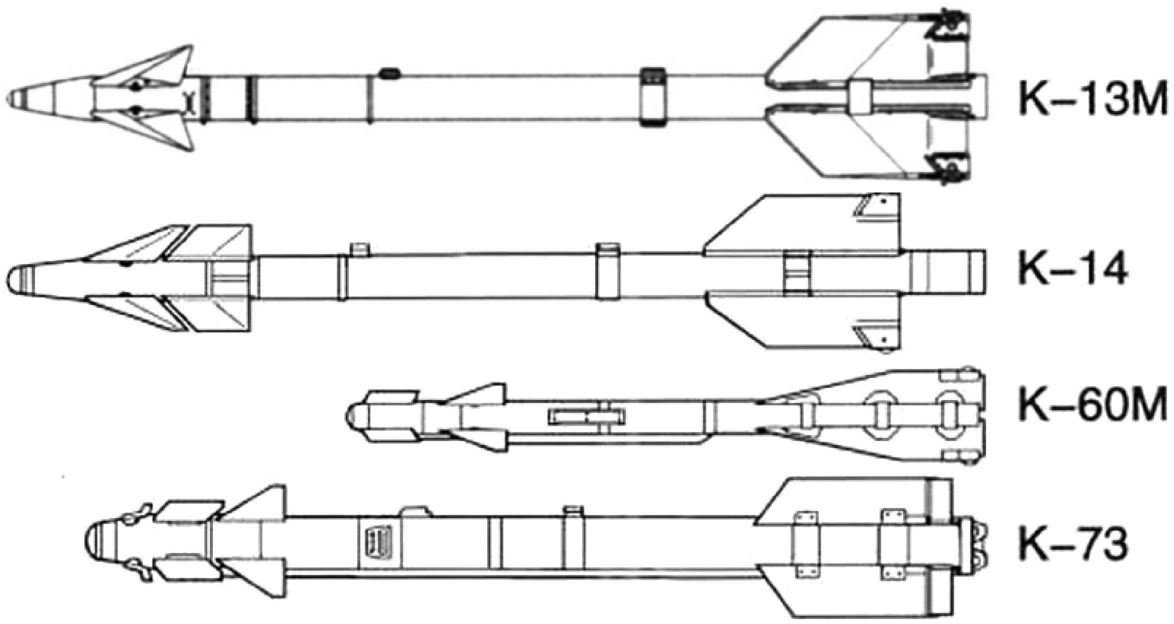
AIM-9M Sidewinder seeker head[94]

AIM-9M version entered production in the US in 1982, and more than 7'000 missiles have been built by Raytheon.[95]

[92] Page 381..382, EW 104, EW Against a New Generation of Threats
[93] The Sidewinder Story, the Evolution of the AIM-9 Missile
[94] NAS China Lake Naval Armament and Technology Museum
[95] Raytheon (Philco/General Electric) AAM-N-7/GAR-8/AIM-9 Sidewinder

R-73 (K-73) Article 72, RMD-1 (AA-11 Archer)

The USSR Council of Ministers adopted a decision on 26 July 1974 two new fighters (MiG-29 and Su-27) will be developed, along with their new air-to-air weapons.

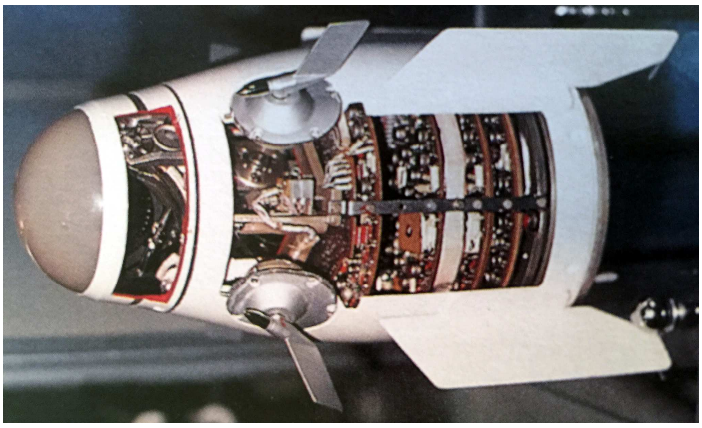


Vympel design bureau proposed the enhanced version of its K-13M, but the new K-14 design had inferior performance compared to the Molniya design bureau K-73 (based on the K-60M), so the latter was adapted.

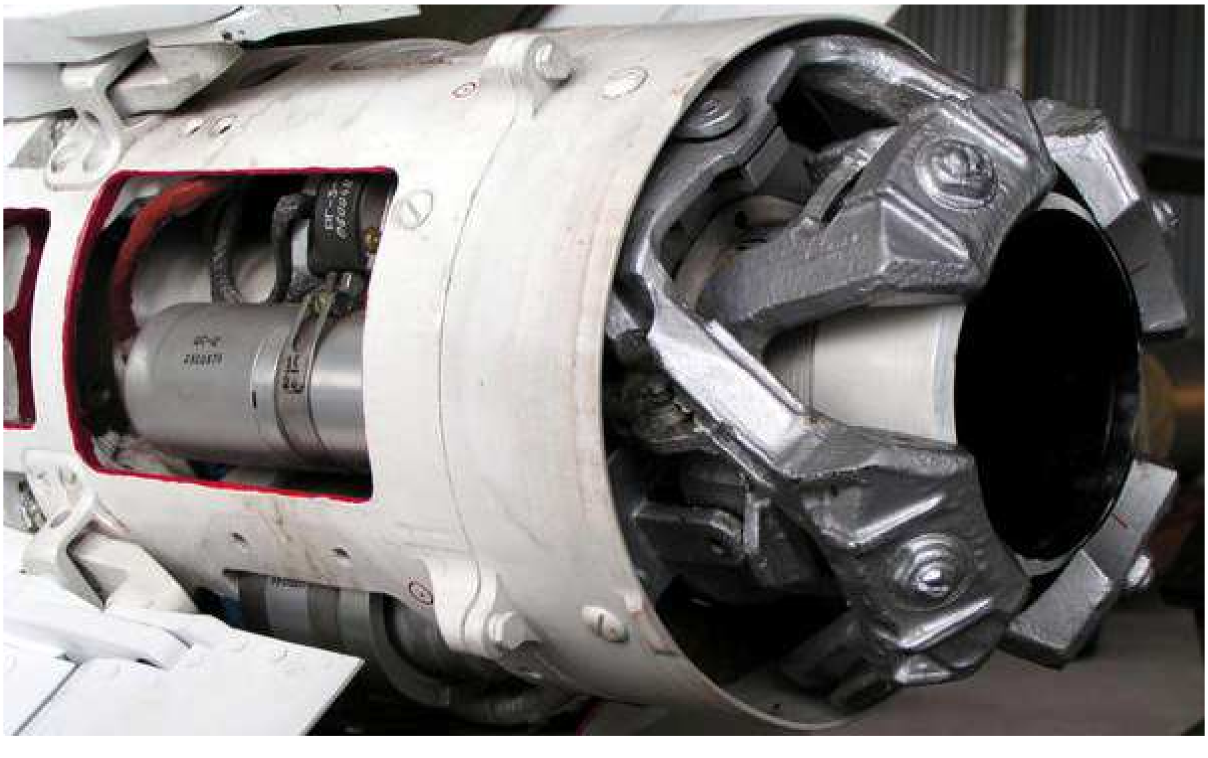
The missile has a similar aerodynamic design as of the R-60. To ensure exceptional maneuverability, a thrust vectoring steering system was used first time in the world.

The development was delayed when the Molniya design bureau was appointed for the Buran space shuttle design, and all plans and test results had to be transferred over to Vympel to complete development in June 22, 1984.[96]

[96] Az R-73 légiharc rakéta

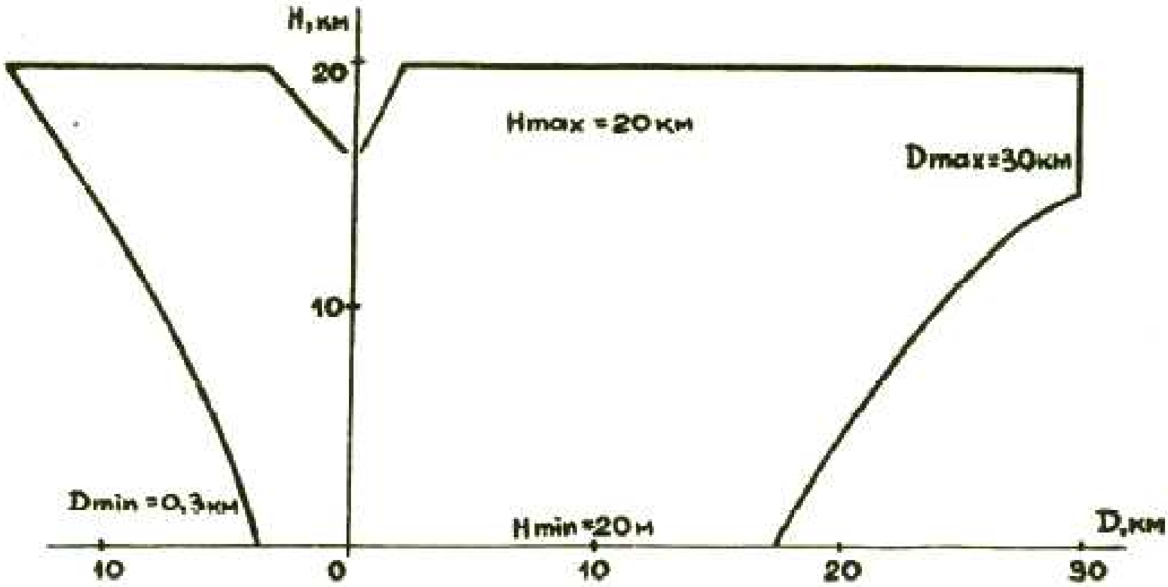
 

The rocket's nose has four angle of attack sensor used by the autopilot, to limit the intensity of the maneuvering. The MK-80 "Mayak" Nitrogen cooled Indium Antimonide (InSb) seeker has ±75° FOV, target tracking rate of 60°/s, and could be launched ±45° off the fighter boresight, slaved to the Shchel-3UM head mounted sight having target acquisition capability ±60° off the fighter boresight, limited only by the two sensors located under the HUD had to see all three infra lamps mounted on the pilots helmet. The radio proximity fuse has 3.5m of effective range, where it detonates the 7.4kg rod warhead.

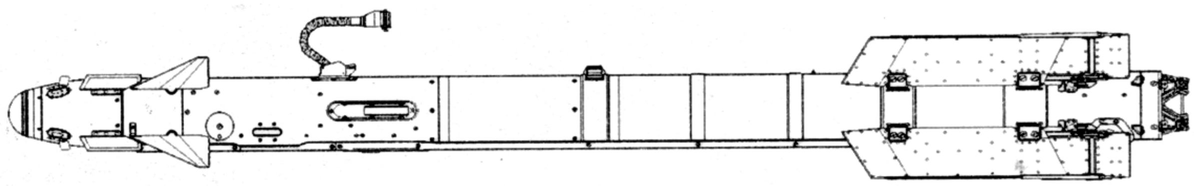


The 55kg engine burns for 4.7~6s providing 12~16kN thrust, trailing dense white smoke, and accelerating the missile to Mach 2.5.
During engine operation, the thrust vectoring steering system allows the missile to pull 40~60g. (all three depends on launch altitude)[97]

[97] Az R-73 légiharc rakéta



R-73 missile range/height envelope [98]

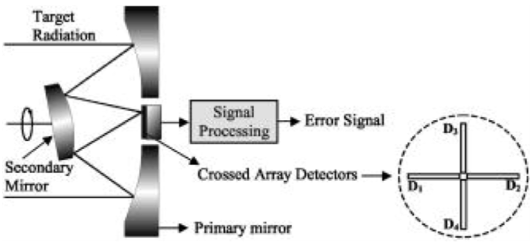


Export started in 1988, first deliveries of the R-73E was received by East Germany.

Hungary fielded the R-73E missile with its MiG-29 fighters in 1993.

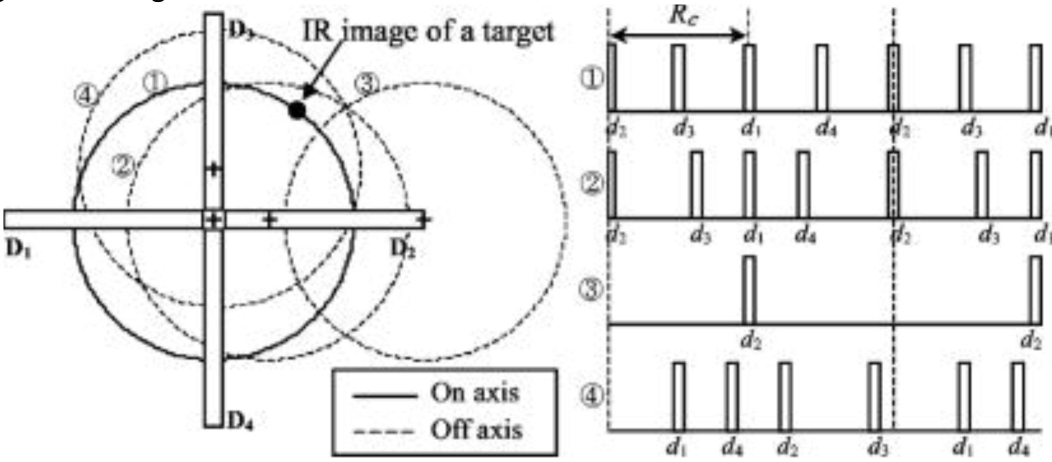
[98] Page 146, Российское ракетное оружие 1943-1993 г.г.

Crossed Linear Array Tracker



The crossed linear array has four narrow linear sensors. The secondary mirror is nutated to move the IFOV in a conical scan. As the target passes through each of the four sensors, an energy pulse is generated. The location of the target relative to the optical axis of the tracker is determined from the timing of the energy pulse in each sensor.[99]

The crossed array seeker simulates the action of a reticle in a con-scan system through the physical layout of the detectors themselves. Classical photocells are normally round, but improvements in construction techniques and especially solid-state fabrication allows them to be built in any shape. Scanning is carried out identically to the con-scan, which causes the image of the target to scan across each of the detectors in turn.



[100]

For a target centered in the FOV, the image circles around the detectors and crosses them at the same relative point ①. This causes the signal from each one to be identical pulses at a certain point in time. However, if the target is not centered ②③④, the image's path will be offset, as before. In this case the distance between the separated detectors causes the delay between the signal's reappearance to vary, longer for images further from the centerline, and shorter when closer. Circuits connected to the mirrors produce this estimated signal as a control, as in the case of the con-scan. Comparing the detector signal to the control signal produces the required corrections.

The advantage of this design is that it allows for greatly improved flare rejection. Because the detectors are thin from side to side, they effectively have an extremely narrow field of view, independent of the telescope mirror arrangement. At launch, the location of the target is encoded into the seeker's memory, and the seeker determines when it expects to see that signal crossing the detectors. From then on any signals arriving outside the brief periods determined by the control signal can be rejected. Since flares tend to stop in the air almost immediately after release, they quickly disappear from the scanner's gates. The only way to spoof such a system is to continually release flares so some are always close to the aircraft.

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[99] Page 370, EW 104, EW Against a New Generation of Threats
[100] Two-color infrared C-CM based on the signal ratio between two detection bands for a crossed-array tracker

Mistral

In 1977, a technology group formed by the French Joint Chiefs of Staff and the Délégation Générale pour l'Armement (DGA, French Weapons Procurement Authority) began a study of different short-range gun and missile point defense surface-to-air systems to meet a tri-service requirement for a Very Low-Level Air Defense (VLLAD) system.

By 1979 the choices had been narrowed to buying a new third-generation missile system to be known as the Sol-Air-Très Courte Portée (SATCP, surface-to-air very short range).

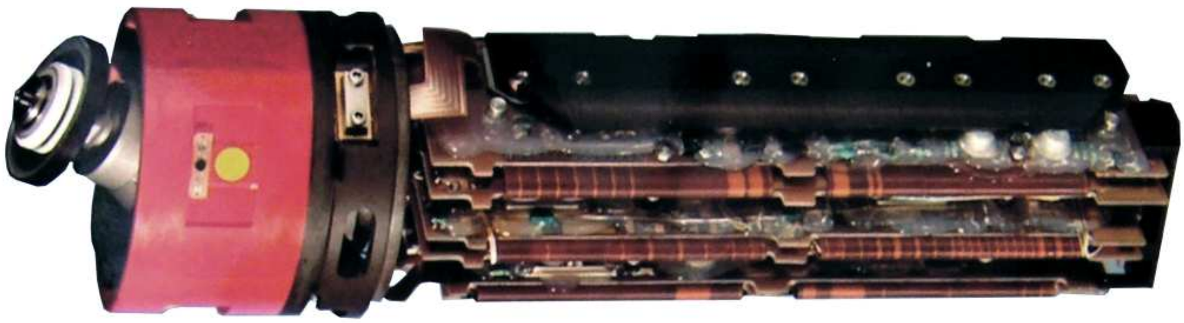
Subsequently, the SATCP has become known as the Mistral, an acronym of transportable light anti-aircraft missile in French. (Missile Transportable Antiaérien Léger)

In September 1980, following further technical and feasibility studies, Matra was named as the company responsible for developing and producing the Mistral.

Mistral achieved initial operational capability with the three French services in January 1990.[101]

An IR transparent magnesium fluoride pyramidal-shaped seeker cover was used to reduce the drag factor.

Mistral is larger than shoulder-launched missiles. Missile is faster, had large warhead (1kg explosive and 1'500 tungsten balls) and laser proximity fuse with 3m of sensitivity. Missile seeker contained four separate detection elements and was more sensitive than in smaller missiles. Approaching jet aircraft without afterburner could be tracked at distances of 4-5km and light helicopter at 3-4km, this was beyond even the new Igla's performance. Seeker was programmed to reject flares based on their angular movement; however it was not as insensitive to flares as Igla. Finland fielded it in 1991.[102]



MISTRAL Seeker[103]

[101] Page 10, Jane's Land-Based Air Defence 2000-2001
[102] Page 254..256, Ilmatorjuntaohjukset Suomen Puolustuksessa
[103] Association pour le souvenir de la SAT - Autodirecteur MISTRAL

In April 1997, $100 million contract was signed between the Hungarian MoD and the then Matra BAE Dynamics (now MBDA) for Mistral missiles, 45 ATLAS two round firing posts mounted on German Mercedes-Benz Unimog (4×4) light trucks (each vehicle has 2 ready to launch missile on the ATLAS firing post, and 6 reload missiles inside), and 9 MCP (Mistral Co-ordination Post) also on Unimog, having a 28km ranged pulse Doppler X-band radar.[104]

ATLAS two round firing post

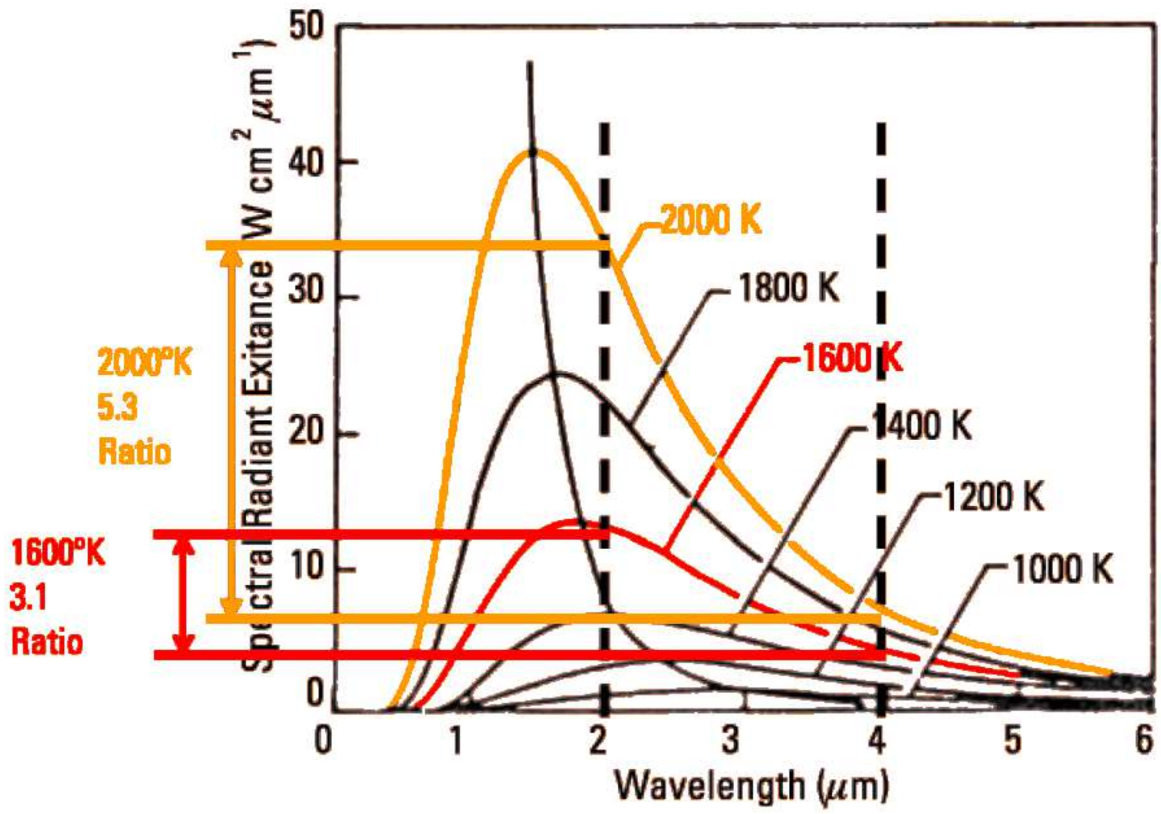
Hungarian ATLAS on Unimog, ATLAS dismounted, and MCP (Mistral Co-ordination Post)

[104] Page 10..12, Jane's Land-Based Air Defence 2000-2001

Dual Band Seeker

One of the issues faced by heat-seeking missiles is to discriminate against flares and other high-temperature distractions from the target. Conventional distractors are much hotter than the targeted parts of the target aircraft. Magnesium flares are 2,200°K to 2,400°K. This causes the distractor to emit much higher energy than the target. Therefore, a very hot magnesium flare will capture a missile's tracker and lead it away from the target.

However, if the missile detects its target at two wavelengths, it can, in effect, calculate the temperature of the targeted object. This allows the missile to track a target at a chosen temperature, or at least to discriminate against false targets that are much hotter than the real target.



Two hot objects, a **flare at 2,000°K** and a **target at 1,600°K**, measured at two separate wavelengths (2 µm and 4 µm).

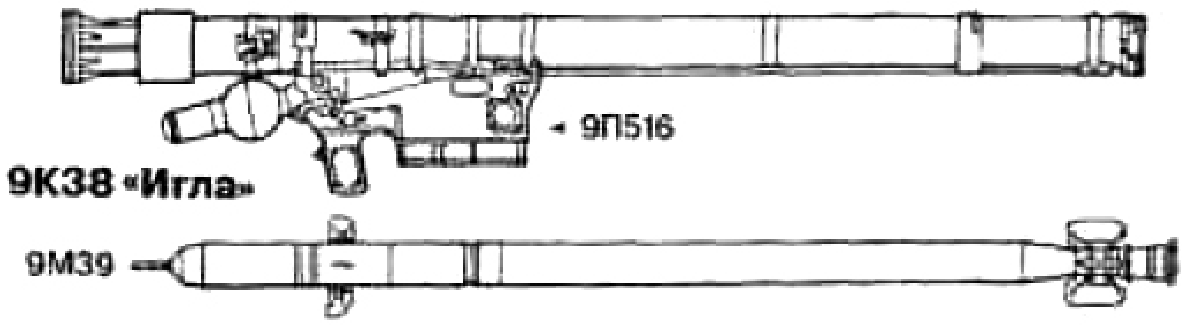
The **2,000°K flare** emits **5.3 times** the energy at 2 µm that it does at 4 µm.
The **1,600°K target** emits only **3.1 times**, as much energy at 2 µm as it does at 4 µm.

If only the tracking waveform for objects with the proper energy ratio range are input to the missile's processor, the missile will ignore the flare at the wrong temperature and track the target at the right temperature.[105]

[105] Page 375, EW 104, EW Against a New Generation of Threats

9K38 Igla (SA-18 Grouse)

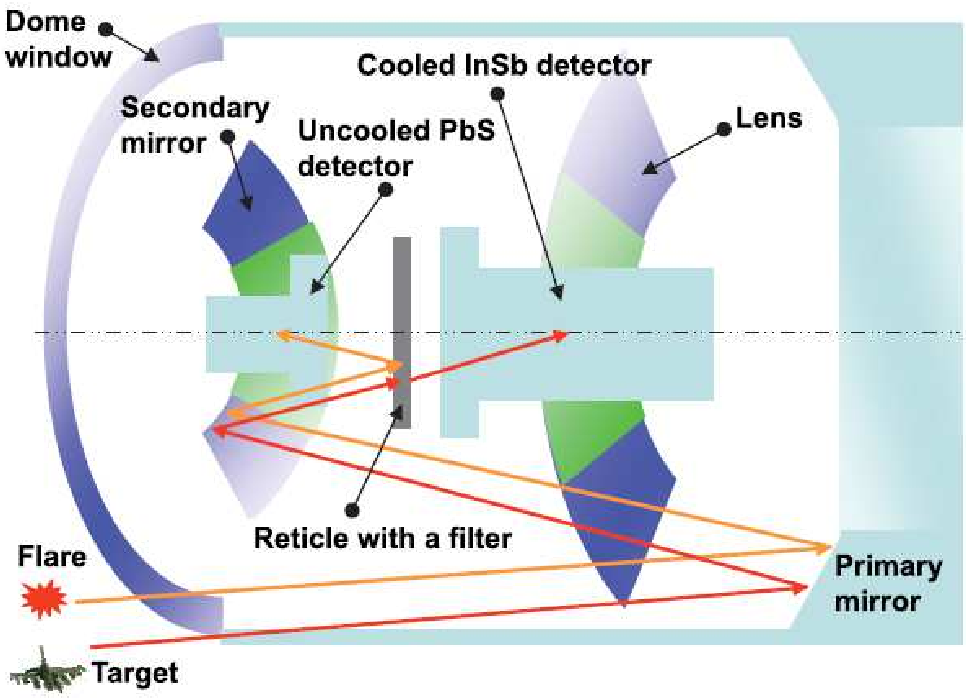
The development of the Igla short-range man-portable air defense system began 12 February, 1971. The main goals were to create a missile with better resistance to countermeasures and wider engagement envelope than the earlier Strela-2/3 series.



Technical difficulties in the development quickly made it obvious that the development would take far longer than anticipated, and in 1978 the program split in two: while a simplified version (Igla-1) with a single band IR seeker entered service earlier, the development of the full-capability Igla continued.[106]

The 9K38 Igla system were accepted into service in the Soviet army on 23 September 1983.

Most important feature was the new Nitrogen cooled dual band seeker, which was about twice as sensitive as Igla-1's. Its ability to avoid countermeasures was superior to other similar missiles. Seeker completely ignored all IR flares. The countermeasure avoidance was also effective against IR jammers.[107]



The spinning reticle is located between the two detectors. On its window, there is an IR filter, which is transparent for the **engine plume** while reflecting signals of the **flares**.

[106] Page 76, Техника и Вооружение No. 5-6 1999
[107] Page 244..245, Ilmatorjuntaohjukset Suomen Puolustuksessa

The missile features an aerospike attached directly to the seeker dome, which reduces the shock wave, thus providing less dome heating and greater range. The name Igla (Russian for Needle) is derived from this device.

Igla was not fielded by Warsaw Pact nations other than the USSR, as it cleared for export just after the Cold War ended.

Finland fielded 912 missiles in 1994. Cost of a launcher was $13,580, and missile costed $66,680. Compared to older types, relatively few Iglas were expended in training. 67 missiles were fired, and only seven missed (10%). Hit rate was thus around 90%.[108]

9K338 Igla-S (SA-24 Grinch)

Laser proximity fuse were added, to increase hit probability, and maximum effective range.

State tests were completed in December 2001 and the system entered service in 2002. Series produced by the Degtryaev plant since December 1, 2004

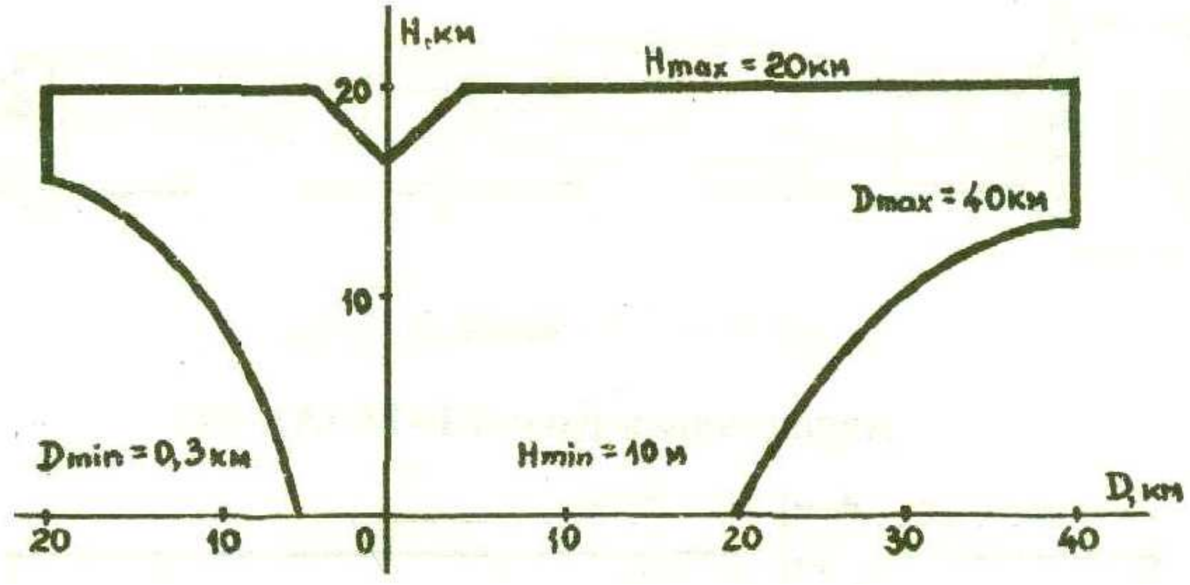
[108] Page 246..247, Ilmatorjuntaohjukset Suomen Puolustuksessa

R-73M RMD-2 (AA-11 Archer)

Development of the extended range K-73 was started by the Resolution of the USSR Council of Ministers on December 28, 1984. It was first displayed in 1997, at the MAKS air show.

The dual band seeker off boresight launch capability was increased to ±60°, so it could fully utilize the Shchel-3UM head mounted sight target acquisition capability.

Engine solid fuel weight was increased with an additional 5kg, extending maximum launch range to 40km at high altitude.



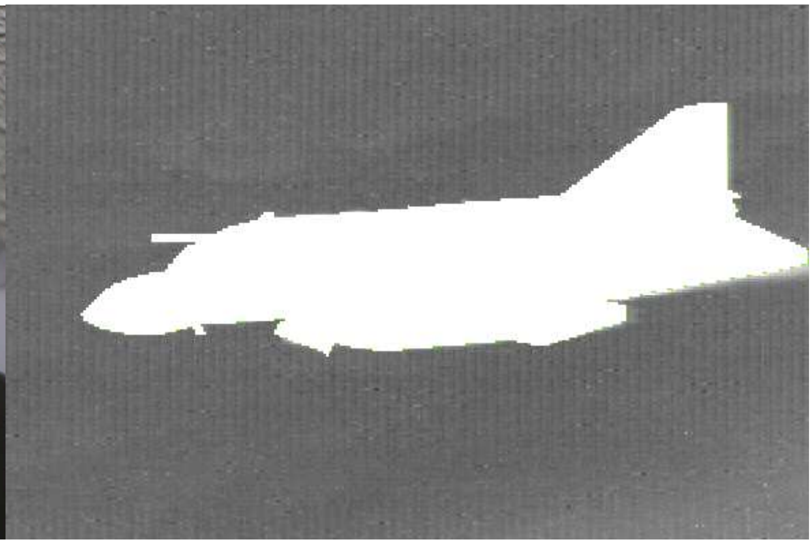
R-73M missile range/height envelope [109]

[109] Page 147, Российское ракетное оружие 1943-1993 г.г.

Cadmium Sulfide (CdS) detector

Cadmium Sulfide is a near ultraviolet (UV) detector (0.3~0.4 µm) material for sensing radiation blanked by the aircraft skin from the generic UV background.
Its conductivity increases when irradiated with UV light (leading to uses as a photo resistor).
It is also a core component of photovoltaic (solar) cells one of the first cells from 1954.

CdS

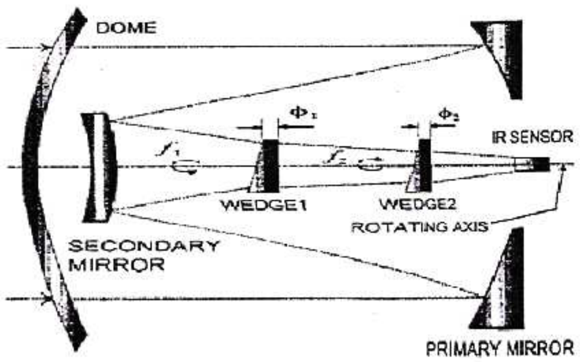


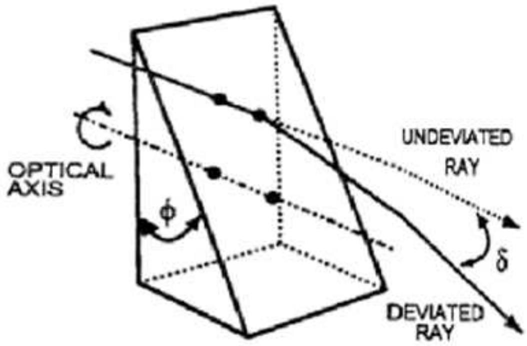
F-4 target in negative UV

FIM-92B Stinger POST seeker

Rosette scan tracker (pseudo imaging seeker)

Rosette scan has very narrow instantaneous field of view (IFOV) compared to spinning reticles. This provides much more accurate target discrimination.[110]

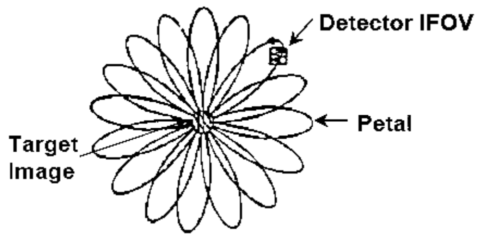




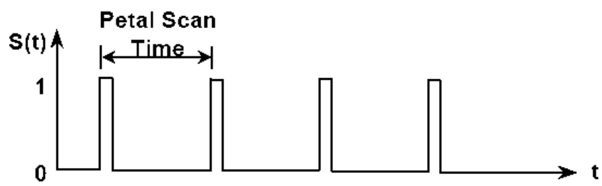
111

The rosette seeker uses much of the mechanical layout of the conical scan system, but instead of a reticle, it uses prisms to create a more complex pattern drawing out a rosette. A major advantage is that the rosette seeker scans out a wider portion of the sky, making it much more difficult for the target to move out of the field of view.

- Pseudo Imaging
- Small Field-of-View Detector Scanning a Rosette Pattern Using Two-Counter-Rotating Optical Elements
- Small IFOV
  - **Provides Greater Sensitivity**
  - **Resistant to Jammers**
  - **Resistant to False Targets**



A Rosette Scanning Pattern



Normalized Signal Pulse Sequence for On-Axis Image 112

Rosette scan produces a very complex output. Objects within the seeker's IFOV produce completely separate signals as it scans around the sky; the system might see the target, flares, the sun and the ground at different times. In order to process this information and extract the target, the individual signals are sent into a computer memory.

Over the period of the complete scan this produces a 2D image, which gives it the name pseudo imager. Although this makes the system more complex, the resulting image offers much more information. Flares can be recognized and rejected by their small size, clouds for their larger size, etc.

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[110] Page 10, Critical Technology Events in the Development of the Stinger and Javelin Missile Systems
[111] Page 3, Recognition of the Real Target in the Rosette Pattern
[112] Slide 49, ATI Professional Development Short Course Sampler, DIRCM Principles

FIM-92B Stinger POST (Passive Optical Seeker Technique)

In mid-1977, after a four-year advanced development program and just before the basic Stinger was released for production, General Dynamics was awarded a full-scale engineering development contract for the next generation of Stinger. This involved the fitting of a microprocessor-controlled Passive Optical Seeker Technique (POST) homing head which uses a dual Infra-Red (IR) and Ultra-Violet (UV) rosette-pattern image scanning guidance technique to enhance the missile's target detection capabilities.[113]

The seeker exploits the low UV reflectance of aircraft compared to the Sun lit sky background, and guides the missile on to the UV 'hole' in the sky represented by the target. The concurrent use of UV and IR allows unambiguous rejection of flares. [114]

Another major improvement in Stinger–POST was the incorporation of integrated digital circuits (two microprocessors) to perform the seeker signal processing functions, electronic packaging and performance improvement over the analog circuitry found in Basic Stinger.[115]

600 FIM-92B (Stinger-POST) missiles were produced between 1983 and 1987.

FIM-92C Stinger RMP (Reprogrammable Microprocessor)

This design (as the name Reprogrammable Microprocessor indicates) enabled the onboard microprocessor to be updated with new software as new information on threats and countermeasures became available. Properly programmed, the processor can recognize countermeasures (like flares) and filter them out from the information it sends to the guidance system.[116]

Stinger RMP entered production in 1987.
The US Army requirement was for 29,108 FIM-92C Stinger-RMP rounds with last funding for procurement being provided in FY92.[117]

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[113] Page 35, Jane's Land-Based Air Defence 2000-2001
[114] MAN PORTABLE SURFACE-AIR MISSILES
[115] Page 10..11, Critical Technology Events in the Development of the Stinger and Javelin Missile Systems
[116] Page 11, Critical Technology Events in the Development of the Stinger and Javelin Missile Systems
[117] Page 36, Jane's Land-Based Air Defence 2000-2001

FIM-92D/E Stinger Block-I

In FY92, an upgrade contract was placed to improve the FIM-92A/B/C performance against the latest countermeasures. Known as the FIM-92E Block 1 rounds, modifications were made to the RMP software to track low-signature targets such as UAVs, cruise missiles and light helicopters, in even more cluttered countermeasures environments. A ring-laser gyro roll sensor and a lithium battery were also fitted.[118]

The roll frequency sensor uses laser ring gyros to measure the roll rate. The missile's orientation to true vertical is set before firing and is then used to compute the relative position of the missile during flight. This information is used to synchronize control instructions from the guidance unit, allows the missile to compensate for missile tip off and potential gunner error with super-elevation and lead.[119]

FIM-92E Stinger Block I entered production in 1995 and is also still being manufactured. The program included upgrading all the remaining FIM-92A and FIM-92B missiles in the inventory as FIM-92D, involving up to 8,500 rounds plus.[120]

Stinger Block-II

This variant was a planned development based on the FIM-92E Stinger Block I version. The improvement included an imaging infrared seeker head from the AIM-9X. With this modification, the detection distance and the resistance to jamming was to be greatly increased. Changes to the airframe would furthermore enable a significant increase in range. Although the missile reached the testing phase, the program was dropped in 2002 for budgetary reasons.

[118] Page 36, Jane's Land-Based Air Defence 2000-2001
[119] Page 13, Critical Technology Events in the Development of the Stinger and Javelin Missile Systems
[120] Page 39, Jane's Land-Based Air Defence 2000-2001

MIM-72G Chaparral

To cope with the threat through the mid 1980's, the proposed improvement program of 1974 included a new guidance section using the rosette scan seeker developed by General Dynamics for the Stinger missile.

This new guidance section would provide an all-aspect engagement capability with infrared counter-countermeasure to defeat the postulated threat.[121]

In 1977 Ford and Texas Instruments started a project to give the Chaparral a limited all-weather capability through the addition of a FLIR camera. The FLIR device enables the gunner to acquire, track, and engage targets during clear weather, at night, and during some adverse weather. The FLIR receiver images the thermal emission (radiation) from the target. This energy is converted to a video signal, and subsequently displayed on the video display control panel. FLIR upgrades were carried out in 1984.

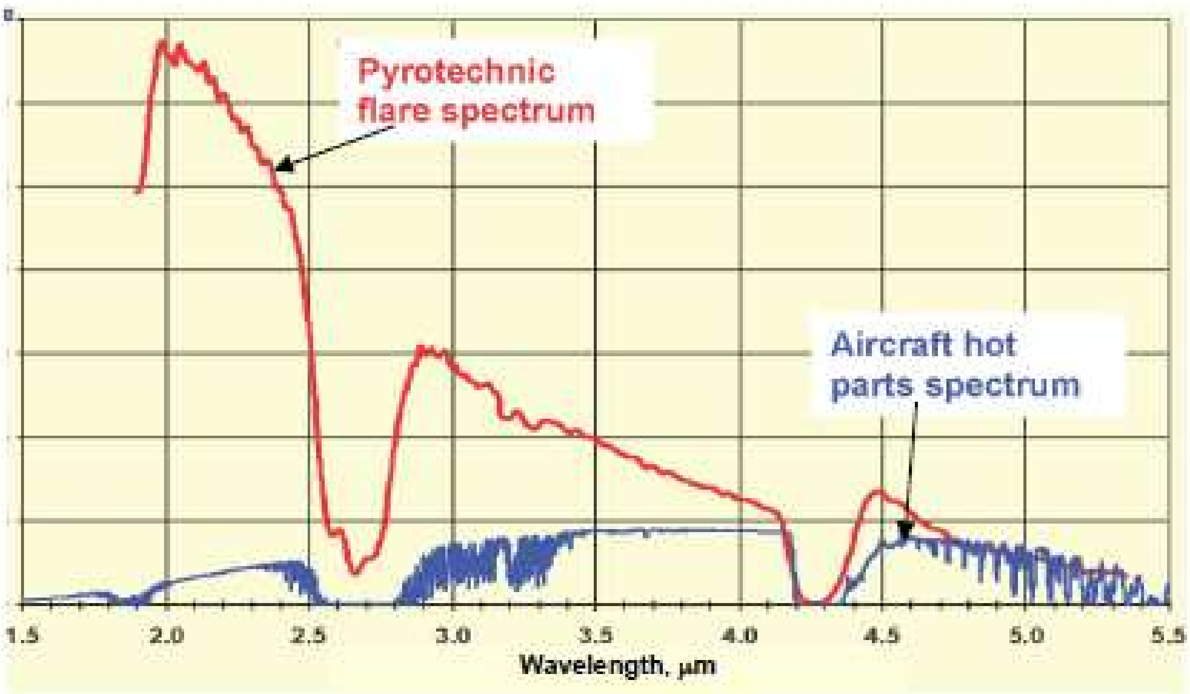
Ford was contracted to deliver MIM-72G starting in 1982, and all existing missiles had been updated by the late 1980s. New-build G models followed between 1990 and 1991.

By this point in time the system was already being removed from regular Army service, and being handed over to the National Guard.

[121] Page 120, History of the CHAPARRAL Air Defense System

Pyrophoric decoy

The counter to a spectral discriminant counter-countermeasure (CCM); is a thermal decoy that is a better spectral match to the aircraft. A better spectral match can be achieved with pyrophoric rather than pyrotechnic materials. A pyrophoric material reacts with oxygen in the air, and consequently, the intensity is affected by altitude and airspeed. [122]



Modern missiles employ counter-counter measures (CCM). Their more refined seeker heads use two or more spectral bands in an attempt to distinguish between the flare and the aircraft. Both IR and ultraviolet (UV) band may be used.
Trajectory or energy level rise discrimination may also be used by some seeker heads.

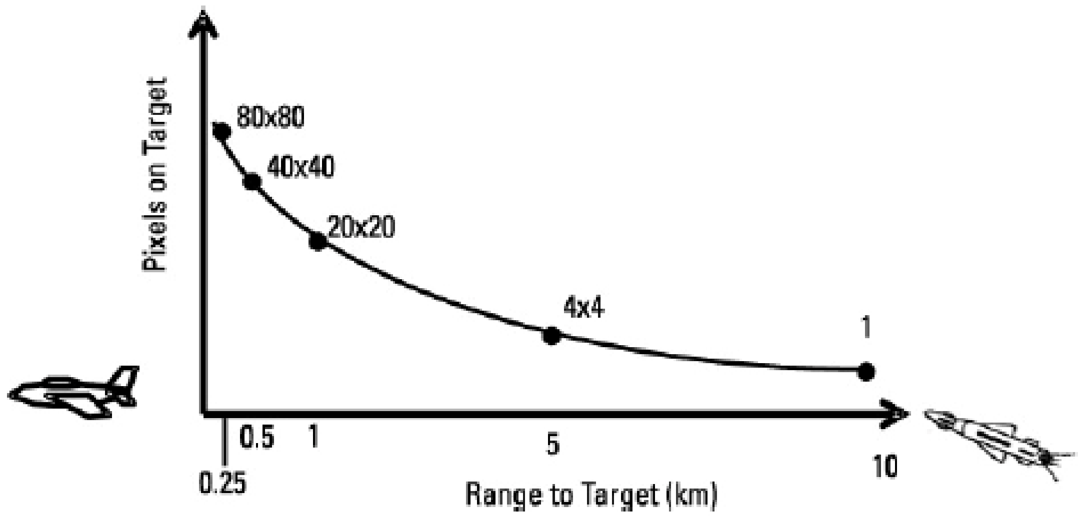
Pyrophoric decoy devices are sometimes called cool flares, but are not properly called flares because they do not burn. They actually oxidize very rapidly to create IR radiation not visible to the naked eye, to look like a target to a missile seeker.

Earlier, some pyrophoric decoy devices used liquids, but these were found to be dangerous and difficult to use, so the pyrophoric foil payloads are typically used now.
The basic approach is to manufacture a thin metal foil with highly porous surface that can then oxidize very rapidly when exposed to air. These devices do not burn; they smolder, producing a dull red glow. Thus, they are not visible by day or night at operational ranges, except for the flash caused by the charge which ejects the payload. Small pieces of 1-2 µm thick treated foil cut to fit the round or square decoy body are ejected and bloom to make a large cross section that provides an attractive target for the missile seeker. If a decoy is at the correct temperature, its energy versus wavelength profile will match the radiation characteristic of the target. [123]

[122] Page 89, Aircraft Infrared Principles, Signatures, Threats, and Countermeasures
[123] Page 385, EW 104, EW Against a New Generation of Threats

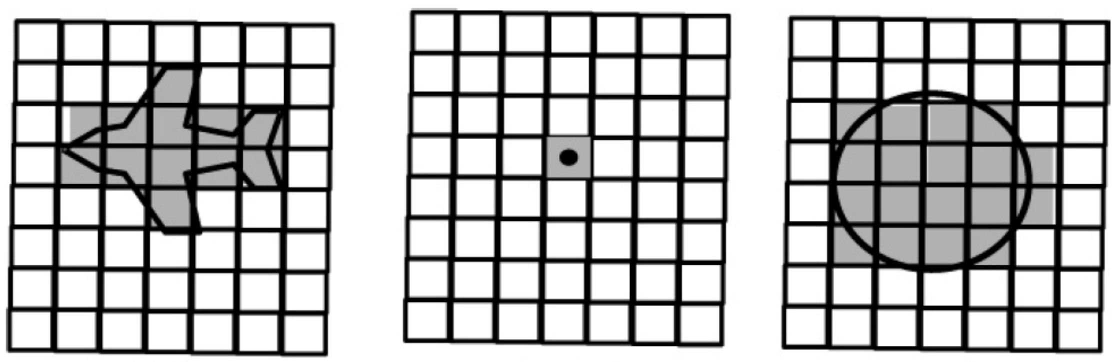
Imaging seeker

Imaging trackers operate in the atmospheric window at about 4 microns, which is where the jet plume signature peaks. Focal Plane Arrays (FPA) use Indium Antimonide (InSb) sensors cooled to 77°K.



Number of pixels covering the target aircraft, as function of the missile distance.

At an acquisition range of 10km, the target is in 1 or 2 pixels. At 5km the target covers 4 × 4 pixels, at 1km it covers 20 × 20 pixels, at 500m it covers 40 × 40 pixels, and at 250m it covers 80 × 80 pixels.



Target Pyrotechnic flare Pyrophoric decoy

During mid-course, the tracking FPA will typically have 7 × 7 or 9 × 9 pixels on the target aircraft. Note that the target presents a complex pattern of pixels receiving energy. The hot flare is physically small and therefore puts (lots of) energy into a single pixel. The gray-body decoy puts the amount of energy equivalent to a valid target into multiple pixels, as this type of decoys uses rapidly oxidizing foil pieces that bloom to fill a large volume. However, the shape of the energy pattern is changed from the spatial energy distribution of the target.

The key is that the shape does not have to look like an a priori stored image of what an aircraft should be. Rather, the tracker can reject the decoy because it does not correlate with the energy distribution seen a short time before.[124]

[124] Page 388..391, EW 104, EW Against a New Generation of Threats

AIM-132 ASRAAM

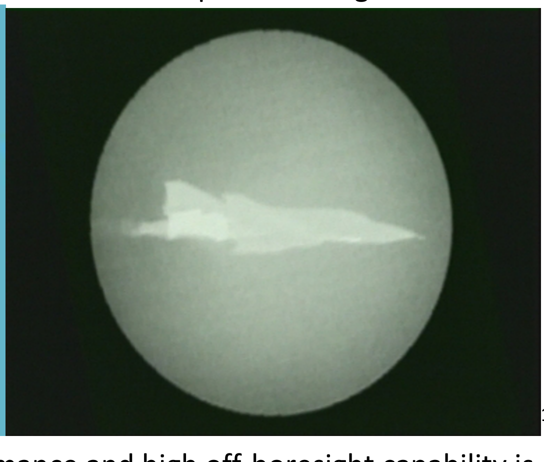
The Advanced Short-Range Air-to-Air Missile programme started in 1982, as part of a Memorandum of Understanding for a family of air-to-air missiles signed by France, Germany, UK and the USA. This MoU provided for AMRAAM to be developed by the USA and co-produced in Europe, while ASRAAM was to be developed by Europe and co-produced in the USA. ASRAAM was given the provisional US missile designator AIM-132.[125]

The Germans exited the ASRAAM program, deciding that much greater maneuverability was required to compete with the R-73.

US decided that they too desired better turning performance, while the strengthening Euro made the ASRAAM less financially attractive, so the US Air Force began its own program the AIM-9X. The French also decided to develop MICA instead.

This left British Aerospace (now Matra BAe Dynamics, part of EADS) in sole control of the program.

ASRAAM is heavily optimised for the best possible pre-dogfight performance, as in theory; whoever gets the first shot off is likely to win. Therefore the missile is built from the outset to acquire an opponent and successfully engage it at maximum possible range.



[126]

The key to the missile's acquisition range performance and high off-boresight capability is the Nitrogen cooled 128 x 128 element Hughes Focal Plane Array (FPA) seeker manufactured as a single Indium Antimonide die. The FPA is immune to flares as well as infrared jammers. The only robust countermeasure is a laser with sufficient power to blind it or burn it out.

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[125] Jane's Air-Launched Weapons 2002

[126] Matra-BAe AIM-132 ASRAAM

The missile can be fired in Lock-On-After-Launch (LOAL) mode. The electronics section contains an inertial package, which is 3-axis solid state accelerometer/fibre optical gyro package with sufficient navigational accuracy to fly the missile blind into the acquisition basket, where the seeker acquires the target.

This is conceptually the same model as is used by radar guided missiles such as the AMRAAM.

The ASRAAM Daimler-Benz Aerospace (now LFK part of EADS) warhead is a compact blast fragmentation design, fired by a Thorn-EMI laser proximity fuse.

The missile's REMUS powerplant manufactured by Royal Ordnance Summerfield, with a 6.5" external diameter, contains roughly 70% more propellant in comparison with the 5" Mk.36 Sidewinder motor. Using a low smoke, low flame propellant, the motor is designed with a boost only burn profile, providing a range in exess of 25km, and speed over Mach 3.5.

The first UK ASRAAM was delivered to the RAF in late 1998. It equips the RAF’s Tornado GR4 and Typhoon. It was also used by the RAF's Harrier GR7 force until its retirement.

In February 1998 ASRAAM was selected by the Royal Australian Air Force for use on their F/A-18 Hornets following competitive evaluation of the ASRAAM, the Rafael Python 4 and the AIM-9X.

8 July 2014 India & UK signed a deal to procure 384 ASRAAM from MBDA to replace the ageing Matra Magic R550, to be integrated onto the SEPECAT Jaguar strike aircraft.

AIM-9X Sidewinder

During the 1980s the United States had left short-range missile developments to its NATO partners, and focused on the medium range AIM-120 AMRAAM. By about 1990s it become obvious the Europeans were far from fielding their promised ASRAAM. After testing East German R-73 (AA-11 Archer) missiles, the US decided to develop another Sidewinder. Hughes Aircraft beat Raytheon for the $169 million development contract, shortly after that, Raytheon bought Hughes.[127]

The AIM-9X retains the Hercules-Bermite MK 36 motor and the WDU-17/B warhead of the AIM-9M. The rest of the airframe is new, however, and has much smaller fins and fixed canards for lower drag and higher flight performance. The guidance section is completely new, and features an IIR (Imaging Infrared) seeker (the same type used by the ASRAAM).

The new WPU-17/B propulsion section has a thrust vector steering system for significantly enhanced agility. The missile is compact enough to fit into the internal weapons bays of stealthy fighters like the F/A-22 Raptor and the F-35 Joint Strike Fighter, but can also be used on existing AIM-9 launchers. The AIM-9X can be cued ±80° off the fighter boresight with the JHMCS (Joint Helmet-Mounted Cueing System).[128]

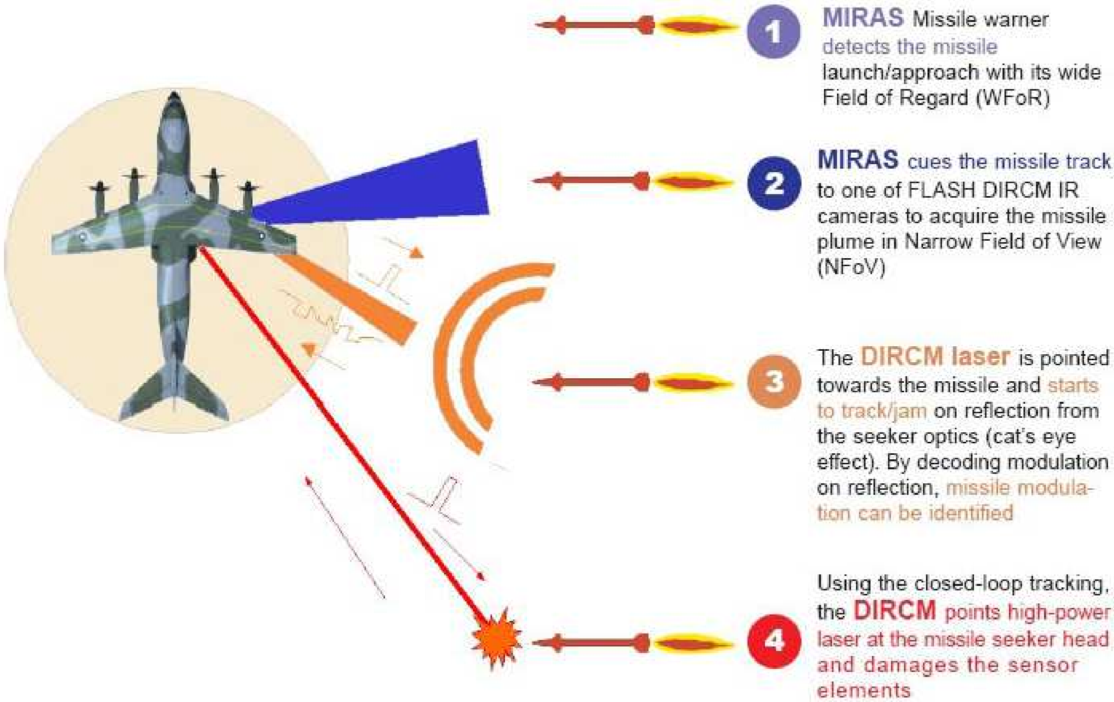
Fielded in 2003, as of June 2013, Raytheon has delivered over 5,000 AIM-9X missiles.

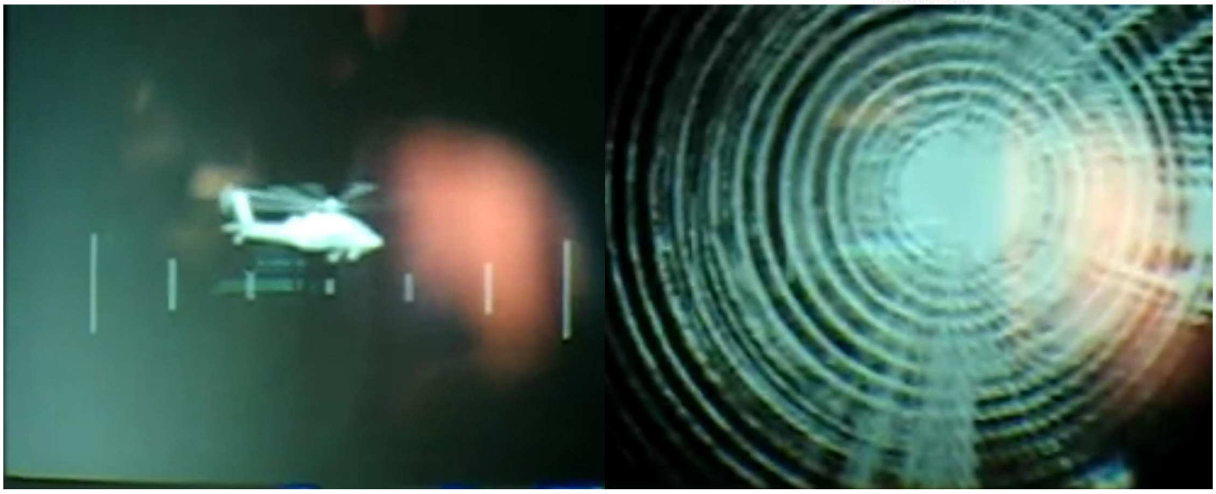
Testing work on the AIM-9X Block II version began in September 2008.
Block II adds Lock-on-After-Launch capability with a datalink, so the missile can be launched first and then directed to its target afterwards.

[127] Page 204..205, Sidewinder - Creative Missile Development at China Lake
[128] Raytheon (Philco/General Electric) AAM-N-7/GAR-8/AIM-9 Sidewinder

DIRCM

Directed Infrared Countermeasure can blind or burn out the missile seeker sensor.

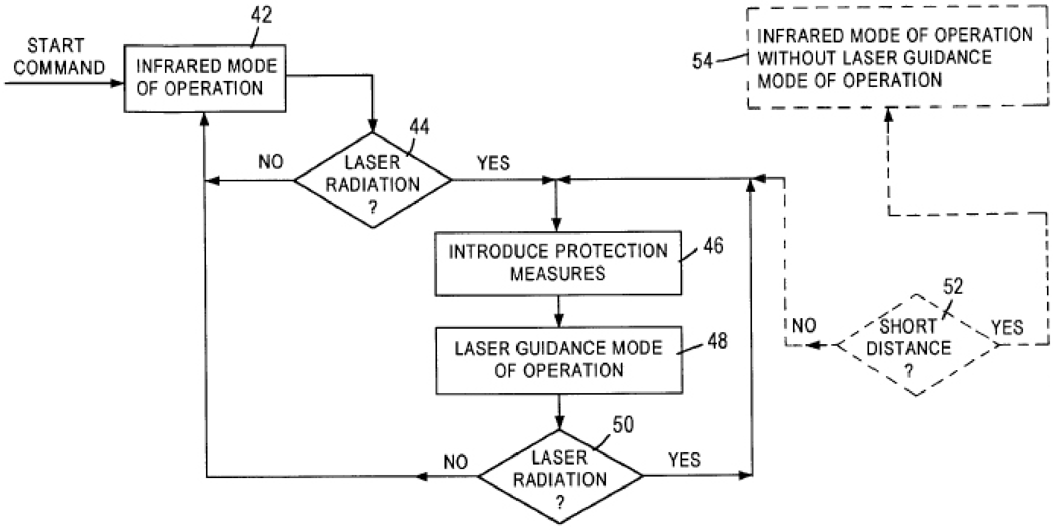




DIRCM before, and after activation

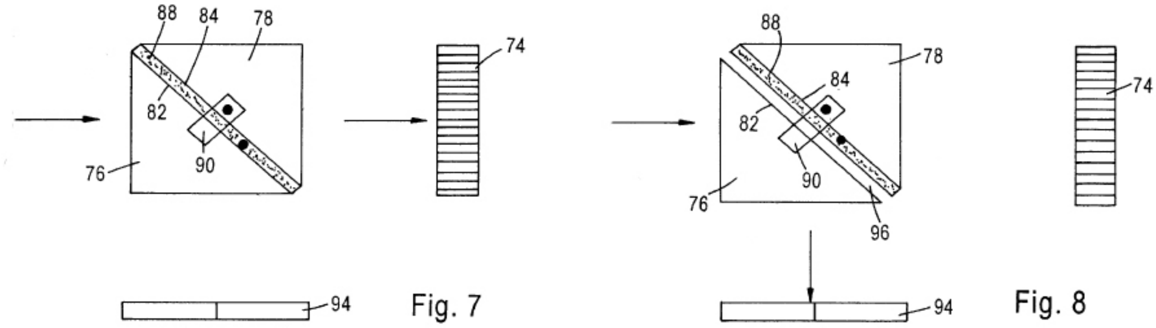
AN/AAQ-24(V) Missile Approach Warning - Missile seeker Laser blinding components

Imaging seeker with DIRCCM



US Patent 6,196,497 submitted by Bodenseewerk Geratetechnik GmbH, in 1998

Missile equipped with Directed Infrared Counter-Countermeasure (DIRCCM) can divert the DIRCM laser beam away from its sensitive IR imaging sensor, towards a laser detector with reduced sensitivity, and use it to continue tracking the target.



US Patent 6,196,497 submitted by Bodenseewerk Geratetechnik GmbH, in 1998

During **infrared mode of operation (Fig.7)** the IR light from the target goes through a **pair of prisms (76, 78)**, and the target image is generated on the **IR imaging sensor array (74)**.

An **IR transparent semiconductor layer (88)** is coated on the **second prism (78) inclined surface (84)**, having non-linear absorption behaviour with a high transmission to the low intensities of the infrared radiation, but heavy absorption of IR laser with high intensities.

When a **high intensity laser is detected (Fig.8)**, **piezo-actuators (90)** forms a narrow (in the order of the wavelength of IR light) **air gap (96)** between the two **prisms (76, 78)**.

This **air gap (96)** leads to a total light reflection occurring on the **inclined surface (82)** of the **first prism (76)**, and the somewhat defocused laser beam is directed towards a reduced sensitivity **four-quadrant laser detector (94)**. [129]

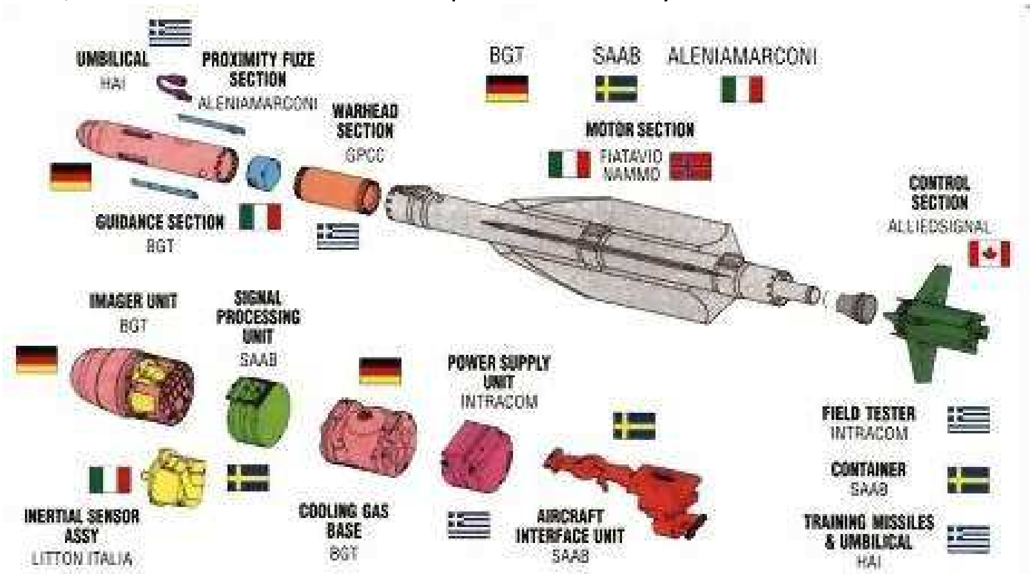
[129] US Patent 6,196,497 - Infrared seeker head for target seeking missile

IRIS-T

Infra-Red Imaging System – Tail/Thrust Vector Controlled

After German reunification in 1990, the German Air Force found itself with a large stockpile of Vympel R-73 missiles, and had the opportunity to fly the MiG-29 with its helmet-mounted sight, and properly evaluate it. It proved to be far more dangerous than had been assumed previously. It was clearly able to outperform all NATO IR tracking missiles, particularly in the ability to guide in high off-axis attacks, but also in terms of field of view, acquisition range, maneuverability, ease of target designation, and target lock-on. The Germans exited the ASRAAM program, deciding that much greater maneuverability was required to compete with the R-73.[130]

In July 1996, the 300 million Euros development started by an international consotium.



Germany (46%)

- Diehl BGT Defence GmbH & Co. KG (previously Bodenseewerk Gerätetechnik GmbH, BGT); the main contractor, guidance section integrator, imager and cooling unit

Italy (19%)

- MBDA-IT (former Alenia-Marconi); active radar fuze
- Fiat-Avio; rocket engine
- Litton Italia; inertial sensor

Sweden (18%)

- Saab Bofors Dynamics; image processor unit, aircraft interface unit and shipping container

Greece (9%)

- Intracom; power supply unit, field test equipment
- Pyrkal / Powder and Cartridge Company; warhead and safety equipment
- HAI - Hellenic Aerospace Industries; umbilicals, and training missiles

Canada (4%)

- Honeywell Aerospace (formerly Allied Signal Canada); flight control section

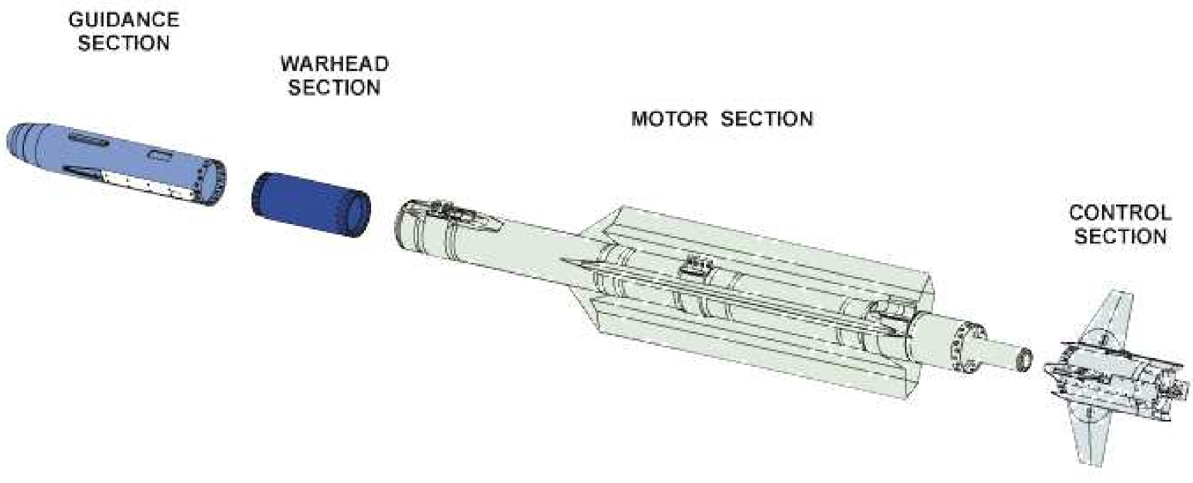
Norway (4%)

- Raufoss / NAMMO; rocket motor development

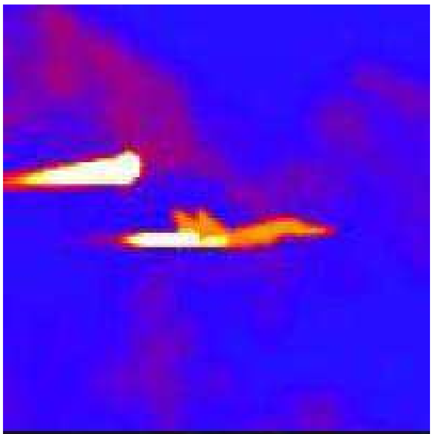
[130] Jane's Air-Launched Weapons 2002

The IRIS-T's design concept is to replace the Sidewinder canards with fixed vortex generators for high-angle of attack agility.

Fixed high-lift wings were added to the middle of the airframe, and the Sidewinder's large tail fins were replaced with small control fins that are mechanically coupled to jet vanes for Thrust Vectoring Control (TVC). The motor has low thrust initially so that the missile is able to make sharp turns at low speed for off-boresight launch, than accelerate for the final phase of attack. In its initial configuration the missile's rear section was significantly wider than the main body section, but the design was changed in 1996 and the rear section diameter is now the same as the main body, with extensions to position the TVC vanes in the motor efflux.[131]



[131] Jane's Air-Launched Weapons 2002



The BGT TELL seeker has been test flown against the MiG-29 `Fulcrum', Su-22 `Fitter', and the F-16 Fighting Falcon during captive flight trials.

Guidance is by an advanced mechanical scanning imaging IR seeker with a ±90° FOV. It uses a cooled scanned linear Indium Antimonide array with 4 × 128 detectors. A mirror scans the image onto the detector.[132]

The high dynamic range seeker acquisition range is matched with the missile kinematic range. It can be cued by radar, helmet mounted display, infrared search and track sensor, missile approach warner or data link.

It has unmatched resistance against IRCM and DIRCM.

Destruction of targets (including incoming A/A and S/A missiles) in the rear hemisphere can be achieved with lock-on after launch capability.[133]

German Air Force took first delivery of the missile on 5 December 2005.

IRIS-T is employed in fighter aircraft of the following countries;
- Eurofighter (Germany, Italy, Spain, Austria, and Saudi-Arabia)
- JAS-39 Gripen (Sweden, South Africa, and Thailand)
- F-16 (Greece, Norway)
- EF-18 (Spain)
- Tornado (Germany)

In all, approx. 4,000 missiles were ordered.

IRIS-T can successfully engage flying targets at a distance of up to 25 kilometers, reaches a speed of more than 3 Mach, weighs nearly 90 kg at a length of 2.94 meters and a body diameter of 12.7 centimeters.

The missile is fully compatible with existing Sidewinder interfaces and warrants a high rejection rate against infrared and laser countermeasures.[134]

[132] Jane's Air-Launched Weapons 2002
[133] IRIS-T, European Short Range Air-to-Air Missile
[134] Subjects in the Focus IRIS-T

Technical Summary

Air to Air Missiles

Type	Missile				Engine		Seeker	
	Weight	Flight time	Launch limit	Overload	Thrust	Burn time	FOV	Track Rate
AIM-9A/B Sidewinder[135]	71kg	21s	2g	12g	17,3kN	2,2s	±25°	8°/s
R-3S (K-13) Article 310[136] (AA-2A Atoll)	75kg	21s		12g	15,5kN	2,4s	±28°	6°/s
AIM-9D/G/H Sidewinder[137]	89kg	60s		18g	13kN	5s		12°/s
R-60 (K-60) Article 62[138] (AA-8 Aphid)	44kg	23s	7g	30g	5,7kN	4s		35°/s
R-13M (K-13M) Article 380[139] (AA-2C Atoll)	88kg	54s	3,7g		13kN	4,5s	±40°	12°/s
R-23T (K-23) Article 360[140] (AA-7B Apex)	218kg	35s	5g	20g			±60°	12°/s
R-73 (K-73) Article 72[141] (AA-11 Archer)	105kg	26s	8g	40~60g	14kN	6s	±75°	60°/s
AIM-9L/M Sidewinder[142]	86kg	60s	7g	35g		6s	±40°	

[135] The Sidewinder Story, the Evolution of the AIM-9 Missile
[136] Советские авиационные ракеты воздух-воздух
[137] The Sidewinder Story, the Evolution of the AIM-9 Missile
[138] Советские авиационные ракеты воздух-воздух
[139] Советские авиационные ракеты воздух-воздух
[140] Советские авиационные ракеты воздух-воздух
[141] Az R-73 légiharc rakéta
[142] Az AIM-9L Sidewinder légiharc-rakéta

Man Portable Air Defense Missiles

Type	System	Missile	Warhead	Missile		
	Weight			Self Destruct	Range	Speed
FIM-43C Redeye[143]	13.3kg	8.3kg	1kg		4500m	580m/s
9K32M Strela-2M[144] (SA-7B Grail)	15kg	9.15kg	1.17kg	11~14s	4200m	430m/s
9K34 Strela-3[145] (SA-14 Gremlin)	16kg	10.3kg	1.17kg		4100m	400m/s
FIM-92A Stinger (Basic)	15.7kg	10.1kg	1kg	17s	>4000m	
9K310 Igla-1[146] (SA-16 Gimlet)	17.9kg	10.8kg	1.27kg		5200m	600m/s
9K38 Igla[147] (SA-18 Grouse)	18,8kg	10.6kg	1.27kg		5200m	600m/s
FIM-92B Stinger (POST/RMP/Block-I)	15.7kg	10.1kg	1kg	17s	4800m	
Mistral[148]	24kg	17kg	3kg	14s	6000m	800m/s

Short Range Air Defense Missiles

Type	Container	Missile	Warhead	Missile	
	Weight			Range	Speed
9K31 Strela-1[149] (SA-9 Gaskin)	55kg	30.5kg	3kg	4200m	420m/s
MIM-72A/B/C/E/F[150] Chaparral		87kg	11kg	9000m	
9K35 Strela-10[151] (SA-13 Gopher)	70kg	40kg	3kg	5000m	517m/s

143 Page 146..148, History of the REDEYE Weapon System
144 Page 75, Техника и Вооружение No. 5-6 1999
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146 Page 80, Техника и Вооружение No. 5-6 1999
147 Page 80, Техника и Вооружение No. 5-6 1999
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149 Page 58, Техника и Вооружение No. 5-6 1999
150 Page 176-177, Jane's Land-Based Air Defence 2000-2001
151 Page 63, Техника и Вооружение No. 5-6 1999

Resources

All the materials compiled into this document are from open source and available to the public. I strongly encourage the reader to continue deepen his knowledge of this topic, by reading the referenced materials.

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Debasish Ghose
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Two-color infrared counter-countermeasure based on the signal ratio between two detection bands for a crossed-array tracker
SPIE Digital Library

Recognition of the Real Target in the Rosette Pattern Using Blind Source Separation and Hidden Markov Model
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Directed Infrared Countermeasures (DIRCM) Principles
Slides From ATI Professional Development Short Course Sampler
John L. Minor

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Contents

F/A-18E Super Hornet deploys flares