Military technology

Heat-seeking missile guidance

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THE HEAT-SEEKING OR INFRARED GUIDED AIR-TO-AIR MISSILE HAS BEEN A FEATURE OF FIGHTER ARMAMENT SINCE THE 1950s, and is likely to remain a key weapon for decades to come. In the nearly one half century that heat-seeking missiles have been in use, we have observed profound and often fundamental changes in the technologies used to construct such weapons, and in turn, significant improvements in performance, lethality and the ability to reject decoys and countermeasures.

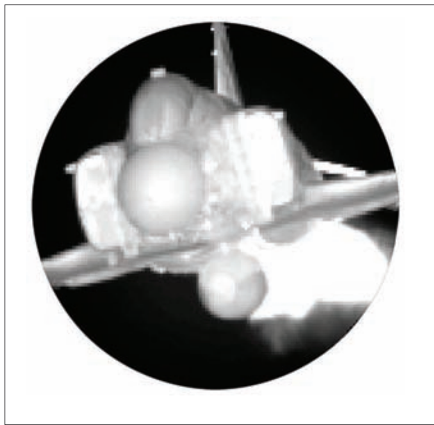
Heat-seeking missiles were the weapon of choice during the large air battles fought over North Vietnam during the late 1960s and early 1970s. In 1982, heat-seeking missiles were central to the Royal Navy's success against the Argentinian forces, as well as Israel's stunning victory over the Syrians in the skies above the Bekaa Valley of Lebanon. A shift to predominantly Beyond Visual Range combat using radar guided missiles came during the 1990s air battles over Iraq and later over Serbia and Kosovo. This change reflected the overwhelming superiority of Coalition forces, using Airborne Early Warning to choose the time and place of engagements.

Heat-seeking guidance is also the technique of choice in most short range surface-to-air missiles, and especially shoulder launched missiles. It has also found a niche in anti-ballistic missile guidance, examples being the US Air Force NCADE and US Navy SM-IV.

There are currently two schools of thought on the future of heat-seeking missiles. The view espoused by most Western defence bureaucracies is that the future will be dominated by long range missile combat, in which heat-seeking missiles will be largely displaced by radar guided missiles. This school of thought is predicated on some important assumptions, such as the view that opponents lack the sophistication to jam radars, datalinks and missile seekers. There is no evidence to actually support this belief but it nevertheless remains enormously popular in the Western world.

The other school of thought is that espoused by the Russians who see risks in radar guided missiles being jammed or evaded by stealth. The Russians see heat-seeking missiles as an alternative not easily overcome, and continue to equip their long range missiles with both heat-seeking guidance and radar guidance.

The science of aerial combat favours Russian thinking here, and as stealth and digital radar jamming technology evolves, and continues to compromise radar guided weapons, inevitably there will be more investment in infrared sensors and missile guidance.



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arget image produced by AIM-9X imaging seeker.
Wing tank damage inflicted by shoulder launched missile on DHL Airbus near Baghdad in 2003.
R-27ET2 Alamo Heatseeking BVR missile.

The origins of heat-seeking guidance fall into the murky latter years of the Second World War when Werner von Braun, later of Apollo moon landing fame, designed the first conically scanning infrared seeker. It was intended to be installed in the nose of the A-4/V-2 ballistic missile, to enable the missile to home in on urban target areas as it dived down from the apogee of its ballistic flight trajectory. It was thankfully not a success, largely due to the immaturity of the technology used in its construction.

Infrared radiation occurs in nature whenever an object is warm or hot. Invisible to the human eye, infrared radiation is essentially light, but with a wavelength just a little too large for the human eye to focus and detect. Otherwise, infrared light shares most of the same behaviours as visible light. Both can be focused, both can be detected using various technologies, both are blocked or absorbed by clouds, water vapour, dust or other obscurants.

Where infrared light differs from visible light is in how heavily it is absorbed by the atmosphere. Unlike visible light where colours through the spectrum from deep red to ultraviolet propagate through the atmosphere with minimal loss, infrared light of differing colours can be heavily absorbed, or propagate with little loss. Three infrared 'colours' can be detected at long ranges, these are known as the 'shortwave', 'midwave' and 'longwave' bands. Not surprisingly all infrared sensors such as thermal imagers, and missile seekers, are designed to 'see' these infrared 'colours'.

Aircraft and their jet exhaust plumes are more than often very bright infrared beacons to a infrared sensor such as a missile seeker.

The brightest and most colourful portion of any aircraft, in infrared terms, is its engine exhaust. The tailpipe cavity of a jet engine radiates most intensely in the infrared, and across all three infrared colour bands. This is also why the earliest heatseeking missiles with basic and not very sensitive seekers had to be fired at a target from dead astern, at close range and more than often killed their target by flying up the engine tailpipe and demolishing the aft section of the engine. Imagine a two metre long piece of four inch pipe hurled into the back of a jet engine at a relative speed of around 500 metres/sec.

The next brightest part of an aircraft is typically the exterior of the engine exhaust nozzle, and often the metal panels surrounding the engine bay. As these are much cooler than the interior of the exhaust, they are not as bright in the ‘shortwave’ band, but still very bright in the ‘midwave’ and ‘longwave’ colour bands.

The next step down in brightness is the exterior skin of the aircraft, cooler than the engine area, but also prone to reflect infrared light produced by the sun in daytime. Most aircraft are reasonably bright in the ‘midwave’ and often very bright objects in the ‘longwave’ colour bands. While low infrared reflectance paints and coatings have become commonplace since the 1970s, they at best reduce a problem which can never be entirely eliminated.

While the aircraft itself is always the target of choice for missile designers, the exhaust plume, the trail of hot gas behind an aircraft, remains a problematic source of infrared light, attached to an aircraft not unlike a fluffy tail attached to an animal. At best, an exhaust plume can be cooled and dissipated but never fully eliminated. If the aircraft has an afterburner, which injects and ignites fuel in the tailpipe to increase thrust several fold, then the infrared brightness of the plume will be several times greater than the rest of the aircraft, in all colour bands. Fighter pilots experienced in the use of Infrared Search and Track (IRST) sensors often observe that with an afterburner lit, a fighter’s exhaust plume can be detected at several times the range of the aircraft itself.

Stealth aircraft have in general the lowest heat signatures of combat aircraft, but this is achieved at considerable expense. The hot areas surrounding the engine are buried inside structure and actively cooled with airflow. The exhaust nozzle is rectangular, to flatten the exhaust plume into a harder to see beavertail shape, and to reduce the range of angles from which the tailpipe cavity can be seen. Cool air is mixed into the exhaust efflux to cool it down, and often the exhaust is buried in a channel. The F-117A, B-2A, F-22A and YF-23A are good examples of this practice.

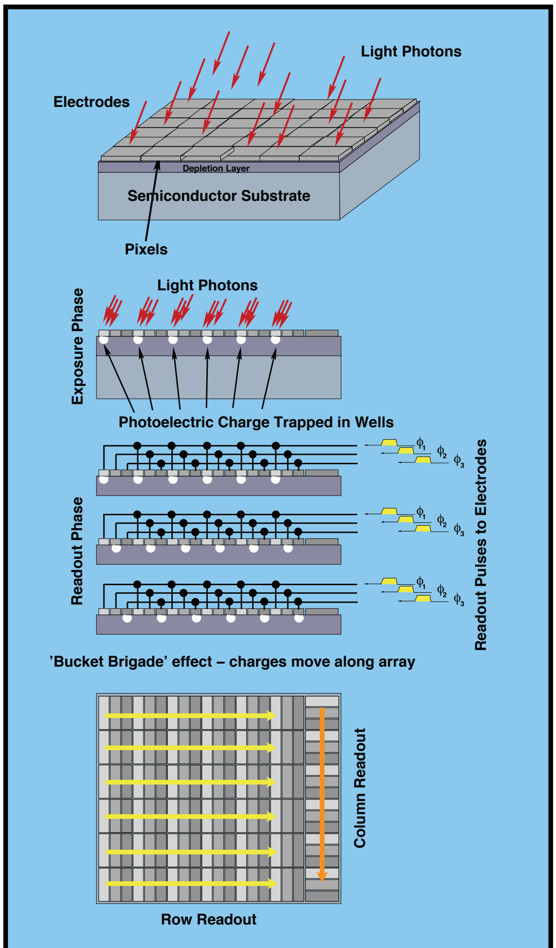
The basic idea in the design of all heat-seeking missile guidance is to fit a missile with an infrared sensor capable of detecting a target, and measuring the angular direction between the target and the direction the missile is pointing. The intent of the guidance system is to fly the missile until it collides with the target.

How good the guidance system is depends on its design. Shoulder launched missiles illustrate this well, since their hand grenade sized warheads are often unable to inflict immediately fatal damage to the target, so we then get to see interesting pictures of the damage after the aircraft has straggled back to a runway. The DHL Airbus freighter hit by a shoulder launched missile near Baghdad in 2003 is a good example – the missile was so inaccurate it missed the engine and speared through the wing, producing a shockwave in the fuel which ruptured the wing tank and nearly killed the aircraft.

The type of infrared sensor used has been a major area of evolution in heatseeking missiles, since their advent during the 1950s.

The earliest missiles used conical scanning (conscan) or rotating reticle designs, very simple and still widely used. In such designs, a spinning optical filter with patterns etched into its surface is placed in front of an infrared detector element, the detector usually cooled by expanding gas flow or a thermoelectric refrigerator – the latter being the same technology used in battery powered portable beer can coolers.

Reticle / conscan seekers were too complex and expensive for shoulder launched missiles, which mostly use a rosette scanning technique, where the missile spins around its axis in flight and the scanner nods away from the direction the missile is pointing in. The result is a rosette scan pattern.



Focal Plane Array Imager

These seeker types may be simple and cheap to construct, but they are quite susceptible to jamming, and more than often prone to seduction by bright objects. There are numerous anecdotes circulating about early heat-seeking missiles locking on to clouds or bright terrain features, or the orb of the sun. A not uncommon feature during 1960s aerial combat was the propensity of such seekers to shift lock if a brighter target than the one it was following passed near enough, the missile deciding to kill a wayward friendly instead of the intended hostile.

Suffice to say a whole science evolved around the technology of flares, designed to seduce heat-seeking missiles. The earliest Soviet shoulder launched Strela-2/SA-7 was so primitive, that a signal flare fired from a pistol could seduce it. Designers soon incorporated circuits and colour filters to reject flares, and Soviet flare designers innovated with low temperature burning flares in turn. Another technology which evolved to defeat flares was the ‘two colour seeker’, in which two detectors were employed, each with a different colour filter. The idea was to compare how bright the target was in both colour bands, flares behaving differently to real targets. US designers took this a step further in the Stinger missile, combining an ultraviolet detector with an infrared detector – the sky is usually bright in the UV colour band.

Scanning infrared seeker technologies are now being supplanted by imaging detectors, a variation on the theme of the CCD camera in mobile phone, webcam or digital camera. The detector chips used for such missile seekers are made from very different materials to the CCDs we use commonly, and must be cooled. What they offer is exceptional resistance to jamming and seduction, and also much better sensivity as the total area of the sensor is larger. The latest imaging detectors, based on Quantum Well technology, are actually capable of simultaneously imaging in two infrared colours.

Infrared colour sensitivity has also been an area of evolution through the history of such missiles. The earliest missiles were sensitive in the ‘shortwave’ colour band, but blind in the others. By the 1970s ‘midwave’ band detectors emerged, highly sought after since they provided an ‘all aspect’ capability to the missile, enabling it to lock on to its target from any aspect, not just the angles from where the hottest engine parts could be seen. Today, nearly all heat-seeking missiles operate in the ‘midwave’ colour band, with two colour seekers also covering the ‘shortwave’ band.

Defeating heat-seeking missiles is becoming increasingly difficult, as the detectors improve and the digital processing becomes smarter over time. While flares remain widely used they are increasingly ineffective, and we have seen a shift toward the use of infrared jammers, favoured for helicopters and transport aircraft. Such jammers flash an infrared lamp or laser to confuse the scanning missile seeker.

We have yet to see a shoulder launched missile with an imaging seeker, but it is now only a matter of time. A flashing infrared jammer will not defeat such a seeker, and a laser beam will be required to blind the seeker.

Where is this technology heading in the longer term? Imaging seekers will become dominant over the coming decade, that is now inevitable as jammers render older scanning seekers impotent. Many of these will be two colour seekers, and we are likely to see increasingly seekers sensitive in the ‘longwave’ colour band, as infrared suppressors become more widely used.

At this time infrared seekers are being used in shoulder launched missiles, and close combat air to air missiles by all nations, with only the French and Russians manufacturing beyond visual range missiles with heat-seeking guidance. That is also apt to change as digital radar jamming techniques and stealth proliferate.

What is clear is that heat-seeking missiles are likely to remain in use for decades to come.