Chapter 11

# Technology Issues: Munitions and Delivery Systems

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Chapter 11

# Technology Issues: Munitions and Delivery Systems

## INTRODUCTION

Munitions currently in the inventory and being procured, as described in chapter 9, are designed mainly to attack soft area targets (e.g., formations of trucks or lightly armored vehicles, or field command posts) and hard fixed targets (bridges, power stations). The technologies embodied in these munitions—cluster munitions for soft area targets, large unitary munitions for fixed targets-are straightforward; the munitions themselves are relatively inexpensive and are considered effective against their intended targets. An important question is whether new anti-armor munitions now under development can be made effective and affordable.

New anti-armor munitions under development, called "smart submunitions, make use of sensors that autonomously search a target area for a tank and are designed to strike the tank on its lightly armored top surface, in some cases using novel lethal mechanisms. If successful, these smart submunitions will clearly add a major new capability to attack armored vehicles beyond line of sight and without direct operator control, but their very "smartness" leads to greater cost, greater technical risk, and greater risk of being spoofed by countermeasures. Thus, if, as a matter of policy and analysis, it becomes clear that substantial effort should be devoted to attacking tanks, a number of technological questions come into play concerning these new munitions:

- Can they be made to operate reliably, under realistic conditions?
- Can they be made to resist likely countermeasures? Or will the deployment of effective countermeasures impose a substantial economic or military cost on the enemy?
- Can these goals be achieved at a reasonable cost?

At this stage of development, it is not possible to say with confidence whether such a practical balance among reliability, countermeasure resistance, and cost can be achieved in the design of smart submunitions, nor which designs are most likely to succeed. To date, tests of prototype smart submunitions have been carried out under artificial conditions that make targets easier to detect—clear weather, high contrast backgrounds, and, in some cases, artificially enhanced thermal signatures. Because of the considerable differences between U.S. and Soviet armored vehicles (Soviet vehicles generally are harder to detect) and between the climates and terrain of U.S. test ranges and potential European battlefields (more often obscured by fog, rain, and vegetation), it is essential that testing be carried out with realistic targets, under realistic conditions. A rigorous testing program, such as that provided now by the Chicken Little and Special Projects efforts at Eglin Air Force Base, may well be an essential continuing element in the development and evaluation of these submunitions.

A second issue is the role of mines. Historically, mines have been relatively ineffective weapons and have received correspondingly little analytical attention. A major limitation was that they had to be emplaced by hand, a slow process that allowed little flexibility to react to changing circumstances. New technologies that permit mines to be delivered by aircraft or artillery may allow mines to play a more immediate and responsive role in the attack of armored units. For example, mines might quickly be emplaced immediately in front of a moving unit, creating a concentration of vehicles that could then be directly attacked. Such mines are now being procured; however, the lack of a clear doctrine for their employment appears to be hindering plans for the acquisition of significant quantities. Mines that incorporate new lethal mechanisms-giving them a high probability not only of halting or delaying a tank but of actually destroying a tank-are farther down the road. Again, the role that such a weapon could play in follow-on forces attack is a key question that needs to be addressed.

## ANTI-ARMOR MUNITIONS

The development of effective anti-armor munitions for follow-on forces attack is complicated by two facts: First, the number of targets is large, and they are in enemy territory. An effective weapon will have to be able to engage multiple targets per pass, and will have to tolerate less than pinpoint delivery accuracy. Second, Soviet armored vehicles have over the past two decades undergone substantial improvements in armor protection, a trend that is continuing. Armor has become thicker, new materials such as ceramics which offer greater protection per pound than steel have been incorporated, and add-on reactive applique armors which are very efficient in deflecting high-explosive anti-tank munitions are being installed both on new tanks and as a retrofit on older tanks.[1]

All of this has meant that, to be effective, new anti-armor munitions must be able to penetrate greater thicknesses of armor and must have a higher probability of hitting the tank accurately—and ideally at a specific, vulnerable point on the tank's surface. Because armor protection has been concentrated on the front surfaces of tanks to meet the primary threat of direct fire from opposing tanks and infantry-fired anti-tank guided missiles, it is the top and bottom surfaces that are the most lightly protected and thus the most vulnerable. Almost all new anti-armor munitions designed to engage armored vehicles at some distance exploit these vulnerabilities. Increased probability of hitting a target is achieved, first, by making the munitions smaller so that more can be dropped over the target area; and second, in the case of "smart" munitions, by adding sensors that can detect the target and guide or aim the munition for an accurate hit.

There is, of course, nothing magic about top attack; indeed if the threat against tanks shifts substantially to top attack, future tanks may well be designed with added top armor protection. Clearly the most effective course in the long run–though likewise the most expensive—is to maintain a balanced variety of weapons that attack from all aspects, forcing the Soviets to make compromises in their tank designs. In the short run, however, top-attack weapons are likely to prove difficult to counter. As discussed below in the section on ballistic countermeasures, existing Soviet tank designs are not well suited to retrofitting with top armor because of the prohibitively large weight that effective armor would add and because of the need to maintain unobstructed air flow to the engine radiators.

The choice of warhead technology is another factor in armor/anti-armor competition. Armor which is most effective against one of the two principal types of warheads used in wide-area anti-armor weapons is not generally most effective against warheads of the other kind: Shaped-charge warheads typically penetrate greater thicknesses of armor than do explosively formed penetrators (EFPs) but can be more easily countered; EFPs typically penetrate less armor' but are harder to counter. If

[1] For more information, see vol. 2, app. 1 l-A, fig. 1 l-A-l.

'Not considered here is another important class of kinetic-energy warheads which are less suitable for submunitions: long, inert, preformed projectiles, such as are used today in armor-piercing, fin-stabilized, discarding-sabot (APFSDS) artillery rounds. They may be fired by an electromagnetic gun being developed by the Army, DARPA, and DNA. The Air Force's developmental high-velocity missile (HVM), although powered, is also a long, inert (i.e., nonexplosive), preformed projectile.

a proposed tank were expected to f ace a threat consisting primarily of warheads of a single type, its designers could optimize its armor against that type by trading off protection against the other type. An adversary's ability to use warheads of multiple types forces designers to forego ideal protection against one type in order to seek balanced protection against all.

## Top-Attack Munitions

Three generations of top-attack munitions could be used for FOFA. These are cluster munitions (the current generation), and two generations of "smart" submunitions now in development: sensor-fuzed and terminally guided submunitions.

### Cluster Munitions

Current-generation anti-armor munitions are unguided cluster bombs. They blanket a large area with a randomly dispersed shower of small bomblets. The air-delivered Rockeye, the Combined Effects Munition (CEM), the German MW-1 submunition dispenser system, and the artillery- or MLRS rocket-delivered Improved Conventional Munition (ICM, also called DPICM: dual-purpose improved conventional munition) all incorporate armor-piercing shaped-charge warheads. The armor-penetration capability of these munitions is, however, small, so they are most effective against trucks and lightly armored vehicles such as self-propelled artillery, armored personnel carriers, and infantry fighting vehicles. Against tanks, they are effective only if one of the bomblets strikes the vulnerable area over the engine compartment and the turret—which can be as little as 1 square meter out of 15 square meters of surface on the top of the tank. Because the typical pattern on the ground of these munitions is one bomblet per 20 square meters, the probability of stopping a tank is obviously not very great.[3] But against soft targets, cluster weapons have the potential to cause multiple kills per shot;[4] they are also relatively inexpensive (see table 11-1); and the technology and manufacturing experience are well in hand.

Possible countermeasures include the use of applique armor to add extra protection to lightly armored vehicles and armor skirts[5] to protect the vulnerable tires and radiators of trucks, dispersing vehicles, and emplacing vehicles such as self-propelled artillery in earth revetments.

### Sensor-Fuzed Munitions

A second generation of anti-armor munitions–the first generation of "smart" anti-armor submunitions—is now under full-scale development (see figure 11-1). These submunitions--called sensor-fuzed munitions-employ autonomous sensors that detect a vehicle and trigger the firing of an explosively formed penetrator, also known as a self-forging fragment, at the target. The use of a sensor to replace the random scattering of cluster munitions can increase the kill probability, so fewer munitions would be wasted on empty space, and fewer rounds have to be fired or fewer sorties flown to achieve the same result. The sensor can also select a particular, vulnerable aimpoint. Thus the air-delivered Skeet submunition uses an infrared sensor to find the hot engine compartment of a target vehicle; the artillery-delivered SADARM uses a combination of infrared (IR) and millimeter-wave (MMW) radar sensors to locate the center of the tank, where the turret is.

These warheads are expected to be effective in top attack against existing Soviet tanks; the retrofitting of top-attack protection armor to these vehicles would be very difficult.' The major lethal effect of the explosively formed penetrator against armor, however, results from spalling: bits of metal fly off the inside of the vehicle's armor at high speeds when the

[3] 1ncreasing the density of bomblets so as to increase the number of hits per tank becomes a losing proposition because the area of empty space between tanks is much greater than the area of tops of tanks.

[4] Some submunitions, such as GEM, DPICM, and the A PAM (anti-personnel, anti-material) also include fragmentation charges that can destroy a truck without hitting it.

[5] For more information, see note 1, app. 11-A, vol. 2.

[6] For more information, see note 2, app. 1 l-A, vol. 2.

**Table 11-1.—Anti-Armor Munitions**

| | Status | Delivery | Targets | Representative cost* |
|---|---|---|---|---|
| **TOP ATTACK MUNITIONS** | | | | |
| Cluster munitions (small shaped charge; unguided) | | | | |
| Rockeye | inv | air | trucks, self-propelled | $100 |
| MW-1 | inv | air | arty, other light armor | (20,000) |
| CEM | proc | air | | |
| ICM | proc | arty/MLRS | | |
| Sensor-fuzed munitions (explosively formed penetrator; sensor) | | | | |
| Skeet | FSD | air | same as above | 5,000<br>(200,000) |
| SADARM | FSD | arty/MLRS | same plus current infantry vehicles, some tanks | |
| Terminally-guided munitions (shaped charge; guided) | | | | |
| MLRS-TGW | R&D | MLRS | same plus | 50,000 |
| IRTGSM | R&D | ATACMS | tanks | (1,000,000) |
| **MINES** | | | | |
| Scatterable mines | | | | |
| GATOR | proc | air | armored vehicles | 500 |
| RAAM | proc | arty | | (50,000) |
| AT-2 | FSD | MLRS | | |
| Smart mines | | | | |
| ERAM | dead | air | armored vehicles | 10,000 |
| Army mine | R&D | arty, helo | | (100,000) |

*cost per individual submunition (cost per 1,000-lb load)

arty: artillery
inv: Inventory
light armor: armored combat vehicles, excluding tanks
proc: procurement
FSD: full-scale development
R&D: research & development prior to FSD

warhead strikes and have a high probability of killing the crew. Tanks being transported on trucks or trains to the front, without crews, fuel, or ammunition on board, may suffer little damage from these munitions. In some cases the munitions may do little more than drill a small hole that can later be patched or ignored.

In the long run, new tanks might be designed with armors that could defeat munitions of current designs without adding prohibitively to the overall weight of the vehicle.[7] To increase the penetrating capacity of explosively formed penetrators to match these improvements would mean increasing the caliber of these munitions, thereby undoing the key objective of carrying multiple munitions in each rocket, artillery shell, or aircraft dispenser load.[8] But these developments in Soviet armor are many years' away and of course do not come easily or cheaply: they will be expensive and will still likely add some weight to the tank. The paramount issue in considering countermeasures is not simply whether they are possible, but rather what cost they impose on the other side in terms of economics, weapon effectiveness, flexibility, and so on.

Because the search area of these munitions is small,[10] they are most effective when used against concentrated groups of vehicles. The small search area allows relatively unsophisticated sensors to be used, keeping costs down. But placing the job of detecting the target in the hands of an autonomous sensor, without human intervention, raises the obvious possibility that these weapons can be fooled,[11] possibly by standard camouflage techniques that

[7] For more information, see note 3, app. 11-A, vol. 2.

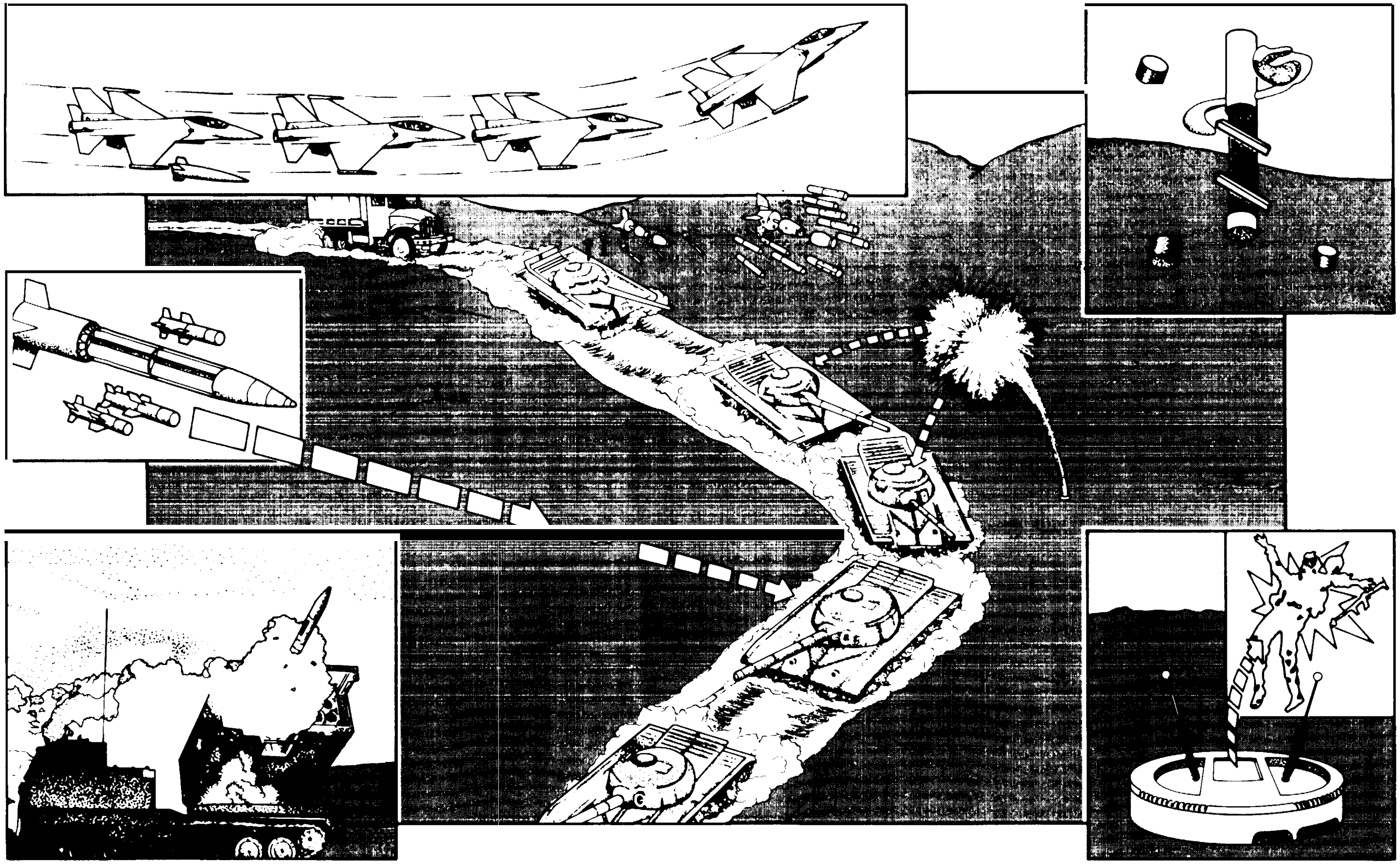
[8] Defense Science Board, Armor Anti-Armor Competition (Washington, DC: U.S. Department of Defense, OUSDRE, Final Report, October 1985), p. B-5; T. Hafer, Warhead Technology Options (Arlington, VA: System Planning Corp., Final Summary Report SPC 924, June 1983), p. 13.

[9] For more information, see note 4, app. 11-A, vol. 2.

[10] For more information, see note 5, app. 11-A, vol. 2.

[11] For more information, see note 6, app. 11-A, vol. 2.

**Figure 11-1.—Smart Anti-Armor Submunitions**



**Terminally guided submunitions (TGSMs):** More widely dispersed targets could be attacked by terminally guided submunitions, such as the Terminally Guided Warheads dispensed by MLRS rockets. These would search for, steer toward, and fly into tanks, detonating a shaped-charge warhead on impact. Three or six TGWs might be dispensed from each rocket (inset, left center), 12 of which could be carried and launched by each MLRS transporter-launcher (inset, below left), which could, alternatively, carry two longer range ATACMS missiles armed with TGSMs.

**Smart mines:** Two Skeet could also be lobbed toward the tanks by each of nine smart ERAM mines previously scattered along or beside the road (right center) from a TMD. As each Skeet descends, it spins and searches for tanks; if it detects one, it fires an explosively formed penetrator at the tank's engine compartment. Each mine (inset, below right) could also sense footsteps of approaching troops and lob three antipersonnel fragmentation grenades to hamper mine-clearing.

SOURCE: Office of Technology Assessment, 1987.

the Soviets are known to practice, such as placing fresh foliage or nets over the vehicle, which reduces the ability of these simple sensors to detect them against background "noise" or "clutter."[12]

Clutter is a particular problem when vehicles are in wooded or urban terrain, as they would be when halted in assembly areas; it is less of a problem when vehicles are on open roads. Camouflage becomes less practical as the tanks approach the area of the direct battle; camouflage piled on top of a tank to conceal it from overhead observation by humans or electronic sensors makes it more visible to direct line of sight observation. The use of smoke or metallic chaff to obscure sensors or decoys to distract them could be effective, but these methods are, from an operational point of view, far less practical.

The choice of sensor makes some difference in which countermeasures are likely to be most effective; however, both IR and MMW sensors have their vulnerabilities (see table 11-2).[13] Increasing the sensitivity of the sensors can help to detect camouflaged targets, but also drives up the false alarm rate. Use of multiple sensors in different wavelength bands ("dual-mode" sensors) can likewise help to discriminate between real targets and clutter; but that greater discrimination is paid for in greater cost and, possibly, reduced reliability. Extensive testing under realistic conditions will be needed to determine whether a practical balance between countermeasure resistance and cost can be achieved in the design of these munitions. The Army-Air Force Chicken Little and Special Projects test programs and the work of the Army Vulnerability Assessment Laboratory should provide much of this needed data.

The problem of dealing with countermeasures aside, costs are very uncertain at this stage. Although the fundamental technology involves no new concepts, no manufacturing experience exists for some key elements, particularly sensors.[14] Likewise, although the Assault Breaker project of the Defense Advanced Research Projects Agency demonstrated that the basic technology is feasible and available, it left unanswered the question of how much it will cost to produce a reliable total system. As shown in table 11-3, in none of the 14 flight tests carried out under Assault Breaker were all functions tested and found successful, although in three tests all functions tested were successful, including engagement of multiple targets by submunitions in one test. Successful demonstrations of prototype smart submunitions in Assault Breaker, and since, have taken place under artificial conditions-in clear weather, against low clutter backgrounds, and against targets with enhanced thermal signatures. Again, a thorough, realistic test program in the development stages could reduce this uncertainty.

### Terminally Guided Munitions

Top-attack munitions, which are now in the research and development phase, employ sensors to locate the target and guide the munition into a direct impact. The terminally guided munition is larger than the sensor-fuzed munition, containing a larger, shaped-charge warhead and a more sophisticated-and considerably more expensive-electronics package that is needed to translate sensor images into steering instructions for the tail fins that guide it.[15]

**Table 11-2.—Smart Submunition Sensors**

| | Sensor Mode | |
|---|---|---|
| | Infrared (IR) | Millimeter-Wave (MMW) |
| advantages | aimpoint accuracy | performance in weather |
| disadvantages | targets must be hot; Soviet tanks are IR-suppressed; affected by weather; decoys possible | jamming possible; multi-domain analysis necessary to reject simple decoys |

[12] Briefings from the "Chicken Little" program office, Eglin Air Force Base, and U.S. Army Vulnerability Assessment Laboratory, White Sands Missile Range.

[13] These are discussed in more detail below in the section on sensor countermeasures.

[14] Defense Science Board, op. cit., p. C-2.

[15] For more information, see note 7, app. 11-A, vol. 2.

**Table 11 -3.—Assault Breaker Results**

| Mission function | Missile — T-16, Test number: 1 2 3 4 5 6 7 8 •9 — T-22: 1 2 3 4 |
|---|---|
| Target acquisition (radar) | — — — U U S S S — — — — — S |
| Target position to missile | — — — U U S S S — — — — — S |
| Missile launch | S S S S S S S S S S S S S S |
| Precision guidance (inertial) | U S S S U S U — S S S S S S |
| Radar track target | — — — U U S S S — — — — — S |
| Radar acquire and track missile | — — — U U S S S — — — — — U |
| Radar provide guidance update | — — — U U S S S — — — — — S |
| Missile trajectory correction | — — — — — — S S — — — — — S |
| In flight dispense | — P S S P S S S S S S S P P |
| Payload pattern generation | — P S S P S S S S S u s U P |
| Payload descent functioning | — U U U S U — — — S U U U P |
| Payload target acquisition and lock-on | — — S U S U — — — S — — — — |
| Target engagement (single) | — — U U S U — — — S — — — — |
| Target engagement (multiple) | — — — — U U — — — S — — — — |
| Target engagement (moving) | — — — — — — — — — — — — — — |

S — successful test
P —partially successful test
U —unsuccessful test
— not tested
• — calibration test for fixed site radar used in test 9

SOURCE Steven L Canby, 'The Operational Limits of Emerging Technology, *International* Defense *Review*. August 1985, pp 875.880

This larger warhead is expected to have a greater kill capability than the explosively formed penetrator; it also has a much higher probability than the explosively formed penetrator warhead of causing catastrophic damage to a tank.

The search area of these munitions is greater than that of the sensor-fuzed munitions. Countermeasure issues are largely the same, but weather will be a greater problem because the terminally guided munitions begin their search at an altitude of 1 kilometer or so, and are therefore more susceptible to the absorbing effects of low-lying clouds.

A major issue is whether the larger search area and greater lethal effect of Terminally Guided Submunitions (TGSMs) as compared to sensor-fuzed weapons will justify their order-of-magnitude greater cost.

## Mines

New "scatterable" mines and "smart" mines could also be used for FOFA. Mines have historically been used to delay or harass enemy forces at best. The need to emplace mines by hand limited flexibility and imposed a large logistics burden as well. With the development of scatterable mines that can be deployed by aircraft or artillery (GATOR and RAAM, now being procured by the Air Force and Army, and the MLRS-delivered AT-2 under joint development by the United States and several European nations) and the incorporation of more effective lethal mechanisms, mines may play a more direct role in halting or destroying armored vehicles.

The major weakness of current remotely deliverable mines is that they are easily seen on roadways and can be easily cleared from roadways; in Warsaw Pact forces, several tanks per battalion have rollers or forks mounted in front for mine-clearing. The effectiveness of remotely deliverable mines will clearly be greater when used against a force moving off the roads.

"Smart" mines, which can sense and attack a tank at some distance, could command a road from concealed off-road positions.[16] They are,

[16] A more detailed description of these systems appears in OTA's earlier Technologies *for NATO's Follow-On Forces Attack Concept--Special Report, OTA-ISC-312* (Washington, DC: U.S. Government Printing Office, July 1986), pp. 33-34.

however, expensive, and they raise many of the same countermeasure, reliability, and cost issues raised by sensor-fuzed weapons. The Air Force recently decided against proceeding with full-scale development of its smart Extended-Range Anti-armor Mine (ERAM) for budgetary reasons; the Army is still studying the concept.

## Countermeasures

The competition between new anti-armor weapons and increased armor protection is a continuing one. The critical questions are whether quick, easy, and inexpensive countermeasures can defeat the new weapon, and, if not, what cost is imposed on the defender if he decides to develop and deploy an effective counter. For example, anew anti-tank weapon may require the defender to place heavier armor on his tanks, increasing their weight, thus requiring larger engines which consume more fuel (increasing the logistics burden or hindering mobility) and requiring a larger vehicle which is more easily seen and hit on the battlefield. In addition, there is a synergism among munitions: The greater the variety of munitions, the more difficult becomes the job of defending effectively against them all. If, however, a new weapon could be defeated by a trivial change in operations or hardware, there is clearly a strong case against developing it.

### Ballistic Countermeasures

A shaped-charge munition penetrates armor by detonating a precisely shaped explosive warhead which forms an intense jet of gas and molten metal. Explosively formed penetrators (self-forging fragments) are metal slugs which smash through armor by virtue of their high speed and mass—i.e., their kinetic energy. Although formed by explosives, they contain no explosives at the moment of contact with the target and are called kinetic-energy penetrators. The penetrating capabilities of these warheads are proportional to their calibers (i.e., diameters); a shaped-charge warhead can penetrate roughly 10 times deeper into ordinary steel armor than can a comparably sized explosively formed penetrator.[17]

On the other hand, shaped charges are much easier to defeat with current armors.[18] In the early 1960s, the only armors were aluminum alloys and steel. Increasing the thickness of such armors obviously increased protection, but at a considerable weight penalty. The trend in new armor development has thus been toward armors which achieve a level of protection equivalent to a given thickness of steel (usually expressed as millimeters of Rolled Homogeneous Armor Equivalent) with lighter new materials, such as ceramics, laminates, and reactive armors, which contain small explosive charges that detonate when struck by an incoming warhead, thereby deflecting the shaped-charge jet. These armors are not very effective against kinetic-energy penetrators, however.

Improved armor has been applied primarily to the front surfaces of tanks to protect them against the major threat on the battlefield—direct fire from enemy tanks and anti-tank weapons.[19] The tops of tanks remain relatively unprotected.

Thus the first-generation smart munitions (Skeet and SADARM), which contain explosively formed projectile warheads, are indeed sufficient to penetrate existing Soviet tanks with a top attack. Retrofitting existing tanks with additional top-attack protection does not appear feasible: a steel deck to protect the turret and engine deck of an existing tank would add a prohibitive amount of weight.[20]

Future tanks might use more efficient composite and hybrid armors to provide effective top-attack protection against Skeet and SADARM at a weight penalty less than that for steel armor.[21] Even so, there is always a

[17] A longer, preformed kinetic-energy penetrator (such as an APFSDS artillery round) can penetrate a thickness of homogeneous armor proportional to its length; it can be made to penetrate farther by increasing its length or velocity rather than caliber.

[18] For more information, see vol. 2, app. 11-A (note 8, table 1 l-A-2, and figure 1 l-A-2).

[19] For more information, see note 9, app. 11-A, vol. 2.

[20] For more information, see note 10, app.1 l-A, vol. 2.

"For more information, see note 11, app.1 l-A, vol. 2.

trade-off between using more efficient armor to add protection and using it to build a lighter tank with no additional protection. The hybrids and composites are not suitable for a retrofit to existing tanks because they must be made as an integral part of the armor; they cannot simply be bolted on top. Ceramics, for example, are brittle and have to be sandwiched between layers of steel in the manufacturing process. The effectiveness of these new armors against explosively formed penetrators cannot, however, be predicted with certainty by existing theoretical models; improvement of models is needed, as are simple controlled experiments.

### Operational Countermeasures

Because the sensors employed on smart munitions can search only a limited area, perhaps the most obvious countermeasure is to increase the spacing between vehicles both on the road and when halted in assembly areas. This would have a greater effect on sensor-fuzed weapons than on TGSMs, which can search much larger areas.[22]

Another operational tactic that could reduce the effectiveness of smart munitions would be to take advantage of terrain that produces high "clutter" (natural background camouflage), making it difficult for the sensors to pick out the target from a sea of confusing signals. Urban areas produce severe clutter in both the IR and MMW bands; using towns as assembly areas would make an attack with these munitions very difficult.[23]

Weather may be exploited to counter sensors. Dry snow provides a very high clutter background that can swamp the signature of a vehicle. The frequently occurring low-level clouds and fog in central Europe interfere with the performance of IR sensors. Rain affects both IR and MMW sensors. Moving when visibility is poor and halting when it improves results in reduced vulnerability, as well as rate of advance.

### Camouflage, Decoys, and Jamming

There are two basic technical approaches to fooling sensors. The target can be made to blend into the background, either by camouflaging the target or by artificially increasing the background noise or clutter level with electronic jamming, smoke, or chaff; alternatively, false targets can be created, either by deploying decoys or by broadcasting a carefully tailored signal which fools the sensor into thinking it has spotted a target.[24]

Counter-countermeasures for dealing with camouflage and clutter include the use of dual-mode (active and passive) and multi-spectral sensors (which are sensitive in more than one wavelength band), and the use of more sophisticated "multi-domain" analysis of the information obtained from a single-mode MMW sensor. For example, analysis of the delays of the echos of an MM W radar signal from different features of an object can yield information about the spacing of distinguishing features, which can help to distinguish a tank from background objects. Use of multiple wavelength bands increases the chances of finding one wavelength at which the background clutter at any given time will not be too bad.

These measures, of course, will increase the cost and complexity of the submunition and are not infallible. Multi-domain analysis, for example, reduces susceptibility to deception jamming but does not eliminate it, as discussed below.

Another approach to making target detection difficult is jamming. The aim can be simply to produce so much background noise that the target no longer stands out. To jam an active MMW sensor would require high power over a wide band of wavelengths and may be infeasible if the sensor has good counter-countermeasures.[25] The possible use of lasers

[22] For more information, see note 12, app. 1 l-A, vol. 2.

[23] Steven Canby, "The Conventional Defense of Europe: Operational Limits of Emerging Technology" Working Papers No. 55, International Security Studies Program, The Wilson Center, Smithsonian Institution, pp. 24-32; also briefing from Vulnerability Assessment Laboratory.

[24] For more information, see note 13, app. 1 l-A, vol. 2.

[25] Briefing from the U.S. Army Vulnerability Assessment Laboratory.

**Examples of Simple Countermeasures**

Camouflage paint

Smoke

*Photo credit: U.S. Department of Defense*

Camouflage nets

Foliage

to jam IR sensors has been raised; but tracking a rapidly moving submunition and aiming a laser at it is likely to be extremely difficult in practice.

Finally, smoke and chaff are standard deception devices. Soviet tanks are equipped with smoke generators, and the Soviets have considerable experience in using smoke to mask ground movements from visual observation. However, ordinary smokes are relatively transparent to IR and, especially, MMW radiation. Chaff might also be used.[26] To shield tanks against smart submunition sensors, the chaff would obviously have to be near the ground and would have to be renewed at least every few minutes; at the wavelengths in question, large quantities would be required. Both smoke and chaff suffer from the drawback that adequate warning of an attack is essential to their effective use.

Decoys in general pose less of a problem to sensors than do jamming or camouflage. Simple decoys, such as MMW corner reflectors, are easily rejected by multi-domain analysis. To fool multi-domain MMW sensors, decoys must resemble full-scale models, which obviously are of limited practicality. Simple IR decoys such as flares or fires **can** similarly be

[26] For more information, see note 14, app. 11-A, vol. 2.

rejected.[27] IR sensors may, however, be susceptible to decoys that more faithfully reproduce the power output and temperature of a tank engine.[28]

Even with multi-domain processing, active MMW sensors are susceptible to deception jamming–the broadcasting of signals which resemble the radiation reflected or emitted by a target, insofar as the sensor and its processor can determine. Deception jamming is not an inexpensive countermeasure, and it requires some knowledge of the operating wavelength of the sensor and its processing algorithm, but it is nonetheless straightforward from a technology point of view. The Soviets deploy a large variety of radar jamming equipment, and thus have the technical and operational base for developing and deploying such a system. Passive MMW sensors are also susceptible to deception jamming, which would require only modest power over a wide band of wavelengths simultaneously; while feasible, this would require several advanced-technology jammers.

[27]For more information, see note 15, app. 11-A, vol. 2.

[28]According to the Vulnerability Assessment Laboratory, such an I R decoy would require 1 kilowatt of primary power; a small propane bottle of the kind used for soldering torches or camping stoves could supply this power level for several hours.

# DELIVERY SYSTEM ISSUES

## Introduction

Aircraft today provide virtually the only means of delivering munitions to targets beyond the immediate battle area. Aircraft have a flexibility in deployment that ground-launched systems do not; they also place a human observer at the scene. They are limited, however, when used in direct attacks against follow-on forces: as discussed in more detail in chapter 9, few aircraft have a night or all-weather capability; all of the NATO aircraft that could play a role in attacking beyond the immediate battle area have other missions to perform as well; and the very heavy Warsaw Pact air defenses could result in significant losses of attack aircraft, particularly if those aircraft must fly very close to or directly over targets in enemy territory .29

The high cost, long development cycles, and long procurement programs for new aircraft mean that current aircraft-with the sole addition of the planned F-15E—will constitute NATO's ground attack air force at least until the turn of the next century.

The improvements in delivery capabilities that will occur over the next two decades or so can be expected to come principally from air-to-ground missiles that will allow attack aircraft to remain a safe distance from enemy air defenses,[30] and from ground-launched missiles that will complement aircraft in reaching deep targets, particularly at night and in bad weather or when aircraft are needed elsewhere. Missiles can incorporate precision guidance systems that offer substantial improvements in accuracy over that attainable with ground-based artillery, unguided rockets, or air-delivered free-fall bombs. High accuracy becomes crucial in attacking hard, fixed targets such as bridges and the increasing number of heavily fortified command, control, and communications facilities in Eastern Europe. And regardless of the type of target, to the extent that precision guidance can increase the probability of a kill, the use of missiles can reduce the number of sorties or rounds required to achieve a given objective.

## Missile Guidance Technology

The propulsion and airframe technologies of missiles are mature. The chief technology choice in these systems is between ballistic missiles and cruise missiles. Ballistic missiles fly faster and thus can reach moving targets before they move far; cruise missiles have the potential to achieve higher terminal accuracy on target,

"For more information, see note 16, app. 1 l-A, vol. 2.

[30]Improved means for suppressing enemy air defenses are another important approach to this problem.

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though they may take hours rather than minutes to reach their targets and will require inflight guidance updates or special seekers to hit moving targets. They may also be more vulnerable to interceptor aircraft and ground-based air defenses. The major area where new technology may play a role in airframe design is in the application of low-observable techniques to cruise missiles to reduce their vulnerability.

What distinguishes the major differing approaches to tactical missile design today and what most determines their differing capabilities is the technology used for guidance. Two different guidance functions-mid-course and terminal guidance—may be needed. These might use different technologies:

1. For guiding a missile to the general target *area-mid-course guidance-some* form of inertial guidance is almost always required. The only exceptions are very short range air-launched missiles that lock onto their targets before launch using one of the precision terminal guidance technologies described below,[31] or that fly their initial course in a pure ballistic trajectory. Although inertial guidance is a well-developed technology that has been used for decades aboard ships, aircraft, space vehicles, and ballistic missiles, the technology has historically been quite expensive; costs rise quickly with the increasing accuracy that is required for longer flight times. Thus, the major technical challenge in applying inertial systems to conventional missiles is reducing cost.

   The precise inertial systems used on nuclear-armed ballistic missiles or fighter aircraft, for example, cost far too much to justify their one-time use on low-cost, conventionally armed missiles. However, new technologies promise to reduce the cost of inertial guidance systems substantially, particularly for short-range applications. Inexpensive miniature inertial systems using fiber-optic gyros could be used in short-range weapons—and in longer range weapons, if complemented by any of several devices now available to recalibrate the system in flight (e.g., miniature Global Positioning System receivers). For the specific case of long-range attacks against moving targets, another important issue is whether the mid-course guidance system needs to include some means of receiving an in-flight update of the target's location.
2. For attacking hard fixed targets such as bridges or bunkers, mid-course guidance alone is not sufficient; precise *terminal guidance,* sometimes to within an accuracy of a meter or less, is needed. (For other types of targets, inertial guidance will as a rule suffice; if the missile can be delivered to within 100 meters or so of the target, cluster munitions can be used to attack soft area targets and smart submunitions to attack armored combat vehicles. See table 11-4 and, for a more

[31] To deliver such a missile, the aircraft must line itself up with a near straight-line path to the target. Inertial systems may be needed by short-range missiles that are to be able to fly to a target substantially off axis.

**Table 11-4.—Missile Guidance Technologies**

| Target Type | Range: Short | Range: Long |
|---|---|---|
| soft area fixed | Inertial | better Inertial |
| soft area moving | | |
| (unarmored unit) | inertial | better inertial ( + automatic target recogition or In-flight target update for cruise missiles) |
| (armored unit) | inertial + smart submunitions | better inertial + automatic target recognition or in-flight target update + smart submunitions |
| hard fixed | man in loop or automatic target recognition | better inertial + automatic target recognition |

SOURCE Office of Technology Assessment 1987

### Box A.—Delivery Error Budget

Missiles that carry nuclear warheads can get by with inertial systems, even at very long ranges (thousands of kilometers for ICBMs) and even when targeted against hard point targets, because the kill radius of the warhead is large enough to tolerate inaccuracies often of hundreds of meters in delivery. However, when conventional warheads are used against hard fixed targets such as bridges, accuracies on the order of a meter are often essential: a specific support element of a bridge may have to be struck. Inertial systems operate by guiding the missile to an absolute geographic coordinate. Even if the guidance system were perfectly accurate, it would be limited by the uncertainty with which the absolute geographic coordinate of a fixed target is known-and that uncertainty is too large to allow the required one meter or less accuracy,

detailed discussion of the limitation of inertial systems in attacking fixed-point targets, see box A. Precision terminal guidance on existing missiles is achieved through the use of a human controller—a "man in the loop' '—who, for example, might observe the target through a TV camera mounted on the nose of the missile and steer the missile into it by radio control.

A key issue in precision terminal guidance is how much effort should be given to developing a next-generation system that can operate autonomously. An automatic target recognition system could reduce the burden on a human controller; in the case of air-launched missiles, for example, it would allow the pilot to launch his missile and immediately exit the area. In certain proposed missions that could strain the capabilities of man-in-the-loop systems (e.g., long-range attack of hard fixed targets), automatic target recognition may be essential. Yet the development of such systems involves a high technical risk; so far, none of the many laboratory efforts or prototypes have proved reliable enough to justify procurement, and indeed critics suggest that automatic target recognition faces fundamental obstacles that may prove insurmountable.

#### Mid-course Guidance

Inertial.—An inertial navigation system continually recalculates its current position by adding up the many small changes it senses in the missile's acceleration and rotation. Even small errors in those measurements are quickly compounded, causing the accuracy of the system to decrease with time (drift). Measures to reduce drift quickly drive up the costs of traditional mechanical inertial navigation systems.

The new technologies of ring-laser gyroscopes and (especially) fiber-optic gyroscopes promise to reduce the costs of inertial systems substantially, although not necessarily to improve performance. Such inexpensive and less accurate inertial systems could have important applications in short-range missiles (e.g., a short-range air-launched stand-off missile carrying smart submunitions that have a large search area to compensate for delivery errors), and in longer range missiles if used in conjunction with techniques to periodically recalibrate the inertial system. These techniques include the Global Positioning System satellites, which can provide, via an on-board receiver, a geo-

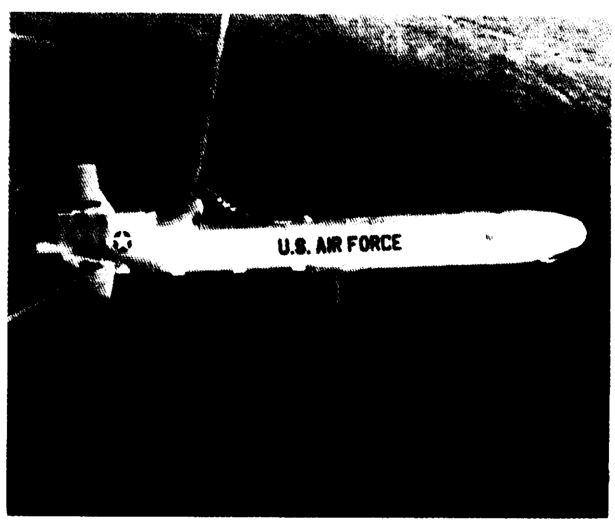


Photo credit U S Department of Defense

Air-launched cruise missile uses TERCOM and other precision guidance, graphic fix within 13 meters in absolute coordinates; and various map update systems such as terrain comparison (TERCOM) which, at set intervals, compares the terrain profile below with a stored map to correct any drift in the inertial system. GPS receivers are likely to be jammed in the immediate target area, so terminal accuracy is determined by the drift of the inertial system from the last (unjammed) update. The services have in addition been reluctant to place themselves in a position of having to rely on the survival of satellites in wartime. TERCOM, which is employed on existing U.S. cruise missiles, is an alternative technique, although mission planning is time-consuming, detailed maps are required, and thus retargeting flexibility is obviously very limited.

In-flight Target Location Update.–At longer range, a moving target will have moved farther by the time a missile arrives; this is especially the case for slow-flying cruise missiles. One possible solution, discussed below, is to equip a cruise missile with an automatic target recognizer so that it can search for the target as it flies a course along a likely route, such as a road. Another approach, employed in the Assault Breaker demonstration program (and applicable to both cruise and ballistic missiles) is to relay updated target location data to the missile in flight. This data would be developed by a radar surveillance and target acquisition system such as Joint STARS, and transmitted to the missile via a radio link.

Because of cost and technical problems, provision for an in-flight update was dropped from the design of at least initial versions of the Army Tactical Missile System (ATACMS); it maybe added later as a block improvement. Analysis has shown that the loss incapability due to lack of update is not severe for ATACMS. Technical issues that need to be considered are beaming of an update to a missile while lofted (or acquisition of the guidance signal by the missile at lower altitude in time to act on it) and the susceptibility of such an update link to jamming.

### Precision Terminal Guidance

Man in the Loop.–The current generation of precision-guided conventional missiles makes use of technology that was first employed by the U.S. Air Force in Vietnam some 20 years ago. Human control of the missile is maintained to acquire and select the target and, in some cases, to guide the missile throughout its entire flight. A variety of techniques are used (see table 11-5); for example, a laser seeker

**Table 11-5.—Guidance Technology—NATO Conventional Missiles**

| | Launch mode | Targets | Status | Guidance technology |
|---|---|---|---|---|
| **primarily inertial** | | | | |
| conv. Tomahawk | sea | area | proc | inertial/TERCOM |
| ATACMS | ground | area, armor | FSD | inertial (ballistic) |
| SRSOM | air | armor | R&D | inertial (+ sensor?) |
| IAM | air | fixed | R&D | inertial |
| **precision terminal (man in loop)** | | | | |
| **HVM** | air, ground | armor | FSD | laser command guidance (“beam rider”) |
| FOG-M | ground | armor | R&D | fiber-optic data link |
| MAVERICK | air | armor | inv | IIR lock-on before launch |
| COPPERHEAD | artillery | armor | inv | laser designator |
| PAVEWAY 2 | air | fixed | inv | laser designator |
| GBU-15 | air | fixed | inv/proc | TV/n R radio data link |
| AGM-130A | air | fixed | FSD | TV/n R radio data link |
| **precision terminal (automatic target recognition)** | | | | |
| **LRSOM** | air(/ground) | area | R&D | inertial/GPS/TERCOM + terminal seeker |
| CMAG | ground/air | all | R&D | LADAR, SAR, MMW |

targets: area: soft area targets (SSMS, SAMs, field command posts)
fixed: hard fixed targets (bridges, power stations, bunkers)
armor: moving armored combat vehicles

status: inv inventory
proc procurement
FSD: full-scale development
R&D research and development, prior to full-scale development

SOURCE Office of Technology Assessment, 1987 on the missile can guide the missile to a spot on the target illuminated by a laser beam, or a TV camera on the missile can send a picture back to the aircraft cockpit where a weapons officer is steering the missile via radio control.[32] All these techniques share some common characteristics. High accuracy—on the order of meters—is possible; the presence of a' 'man in the loop" may avoid many countermeasure problems such as electronic decoys or background clutter; the technology is for the most part mature and involves little technical risk; and costs are, very roughly, on the order of $100,000 per missile.

On the other hand, these missiles are all of relatively short range (tens of kilometers); most require a clear line-of-sight to the target; and thus most of the air-delivered models still require aircraft to fly close to their targets and to remain there throughout the flight of the missile. A general problem with laser-guided weapons is that the laser can be obscured by smoke around the target area; laser-guided weapons are also somewhat less accurate than TV-guided models. A general problem with radio data links, used to transmit TV pictures from the remotely guided GBU-15s, is that they can be jammed.

Despite these basic limitations, some improvements in this generation of weapons are possible without going to a radically new generation of technology. Range can be extended: for example, the AGM-130 has roughly double the range of the GBU-15 from which it is derived by the addition of a simple (but expensive) solid-fuel rocket motor. Jam-resistant data links are being developed for the GBU-15 and AGM-130. Fiber-optic data links could provide jam resistance for missiles launched from the ground.

Automatic Target Recognition.—Automatic target recognition, if successful, clearly could increase the effectiveness of missiles in all missions, and could increase the survivability of aircraft by allowing them to leave the area immediately after launching the missile. However, as indicated in table 11-4, automatic target recognition may bean enabling technology for attacking hard fixed targets at long range with nonnuclear missiles.

At long distances, attacking hard fixed targets would strain the capabilities of the man-in-the-loop guidance systems that are now the only means of providing the required precise terminal accuracy. Establishing radio contact with the missile as it approaches the target area is difficult at long range. The control aircraft would have to arrange to be in position at the right instant to have a clear line of sight to the missile, unobscured by terrain or vegetation, and jamming of the radio data link presents an increasing threat at greater range from the control aircraft. Automatic target recognition, which could free the missile from the need for human control while providing high terminal accuracy, is the only practical alternative.

For a second mission-long-range attack of moving armored combat vehicles whose location will have changed substantially during the flight time of the missile-a possible solution, discussed above, is to provide an in-flight update of the target location from a system, such as the Joint STARS radar, with weapon guidance capability. Alternatively, the missile could be equipped with an autonomous capability to search for the targets while flying along a likely route such as a road.

Both of these missions would also require a mid-course guidance system capable of delivering the missile to the general target area (see discussion of inertial systems above).

The technology for automatic target recognition has proved problematic to date. The sensor (e.g., a TV camera or radar) must provide a high-quality image of the target area for recognition; even then, picking out the target from a complex image, and distinguishing it from similar objects (e.g., a tank from a truck) is a very challenging computational task, especially because it must be carried out in real time. Mobile targets pose a special problem in that they may be facing any direction-and

[32]These specific technologies are described more thoroughly in OTA's special report, *Technologies for NATO's Follow-On Forces Attack Concept,* July 1986, pp. 24-27.

Photo credit' McDonnell Douglas Corp

F-15E equipped with LANTIRN pods.

a tank looks quite different when viewed from different angles.

All sensors are subject to countermeasures, including decoys and camouflage as discussed above in the section on smart submunitions; signatures of fixed targets may be quite variable depending on the season and weather as foliage and snow cover change. Although elements of an automatic target recognize have been demonstrated in the laboratory, complete working systems have remained elusive. For example, continuing problems in achieving reliable automatic target recognition in the Low Altitude Navigation and Targeting Infrared for Night (LANTIRN) infrared targeting system for fighter aircraft may lead to that feature being dropped from LANTIRN. An automatic target recognize for an autonomous missile would have to perform even more reliably: LANTIRN was designed to identify the target but still allow a human to make the final launch decision; an autonomous missile would be entrusted to perform the entire job on its own.

Even if the technology can be made reliable, placing an automatic target recognize on a cruise missile poses some engineering challenges as well. An imaging sensor and its associated computer processor would add a considerable power requirement over that of existing cruise missile electronics; this will require heavier generators and, with the extra heat generation, a cooling system for the electronics." Advances in the miniaturization of electronics may solve this problem. The use of currently available sensor technology—millimeter wave radar and imaging infrared—would also pose a packaging problem, because an additional system would be required for terrain following. A more advanced sensor, $CO_2$ laser radar, is being pursued by several contractors; both target-acquisition and terrain-following/obstacle-avoidance functions could be carried out by this single sensor. Much additional development of this sensor will be required; however, it is also likely to be the most expensive option.

The lowest technical risk approach to automatic target recognition might involve clever combination of existing capabilities to perform a limited mission. For example, low-cost inertial/GPS guidance could be used to steer a cruise missile close to a road or railroad, and a relatively simple imaging sensor could identify the road and keep the missile precisely on track; it could also detect trains or groups of vehicles. An autonomous capability against fixed targets might be provided in the near term similarly by demanding less than complete autonomy or flexibility. A short-range standoff missile could be guided from a preset launch point to the target area by a simple inertial system; a sensor system, supplied with information about the orientation of the target and its general characteristics (e.g., type of bridge, number of spans), might then be able to perform the somewhat simplified target recognition task.[34]

[33]Capt. R.B. Gibson, USAF, et al., *Investigation of the Feasibility of a Conventionally Armed Tactical Cruise Missile, Vol. I* (Wright-Patterson Air Force Base, OH: Air Force Institute of Technology, report AFIT/GSE-81D-2, December 1981), p. 7.

[34]This concept is being pursued in the Autonomous Guided Bomb program of the Air Force Armaments Laboratory.