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Report to the Honorable Charles E. Bennett, House of Representatives

September 1987

ANTITANK WEAPONS

Current and Future Capabilities

RELEASED

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GAO

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Program Evaluation and
Methodology Division

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September 17, 1987

The Honorable Charles E. Bennett
House of Representatives

Dear Mr. Bennett:

This report responds to your April 16, 1986, letter requesting that we assess the capabilities of infantry antitank weapons now in the field or under development and describe the information on future weapons that has been communicated within the Department of Defense and to the Congress.

To guide our analyses, we devised a framework covering several factors that are critical to antitank weapon performance. These include five effectiveness factors—the probability of hitting the target, probability of kill (weapon lethality), rate of fire (number of rounds fired per unit of time), sustainability of fire (number of rounds available during an engagement), and survivability of the gunner and weapon. We also considered three factors that can reduce effectiveness. These degradation factors include the mission environment (elements such as rain and dust), enemy countermeasures (such as camouflage), and human factors (such as combat stress and the quality of gunner training). For each current and future infantry antitank weapon in our study, we assessed effectiveness under benign conditions and then assessed the extent to which possible sources of degradation might reduce effectiveness in actual combat.

We have proposed that the Congress consider using this framework to guide and help specify its future reviews of infantry antitank weapon effectiveness. We have also recommended that the secretary of Defense ensure that the data generated by DOD regarding antitank weapon performance cover the five effectiveness factors and three degradation factors in the framework.

We note that this is an unclassified version of the classified GAO report C-PEMD-87-2. As we agreed with your office, unless you publicly announce the contents of this report earlier, we plan no further distribution of it until 30 days from the date of the report. At that time, we will send copies to those who are interested and will make copies available to others upon request.

Sincerely yours,

Eleanor Chelimsky
Director

Executive Summary

Purpose

The lethality of antitank weapons available to the U.S. infantry is [material deleted]. According to Department of Defense (DOD) estimates, our small antitank rockets are [material deleted]. The Honorable Charles E. Bennett asked GAO to (1) assess the effectiveness of U.S. infantry antitank weapons now in the field or under development and (2) determine what information on future antitank weapons has been communicated within DOD and by DOD to the Congress.

Background

For this study, GAO devised an analytical framework including five effectiveness factors: the probability of hitting the target, probability of kill (weapon lethality), rate of fire (number of rounds fired per unit of time), sustainability of fire (number of rounds available during an engagement), and survivability of the gunner and weapon. The framework also covers three factors that can degrade effectiveness: the mission environment (elements such as rain and dust), enemy countermeasures (such as camouflage), and human factors (such as combat stress and the quality of gunner training).

The U.S. inventory of infantry antitank weapons includes the tube-launched optically tracked wire-guided (TOW) missile, the Dragon missile, and two short-range rockets—the M72 and the AT4. Because of their small warheads, the Army no longer classifies the two rockets as antitank weapons. However, Army doctrine still promotes use of those weapons against tanks for self-defense. TOW and Dragon are both wire-guided. Gunners keep the crosshairs of their sight on target while the missile automatically makes the necessary course corrections.

GAO's evaluation covered each of these current weapons, as well as upgraded versions of the TOW, Dragon, and M72. The evaluation also covered two of several possible weapons that exploit new technologies. One of these weapons is a short-range rocket, the shoulder-launched multipurpose assault weapon with its new high energy antiarmor warhead (SMAW-HEAA). The other weapon uses fiber optics, a generic guidance technology with several possible applications. DOD may field a fiber-optic guided missile (FOG-M) to replace TOW or Dragon. FOG-M will house a television or infrared camera linked to a gunner's viewing screen by fiber-optic cable. As the missile flies above the battlefield, gunners will locate a target on the screen, then select automatic or manual guidance.

The assessment describes the demonstrated or projected effectiveness of each weapon under benign conditions (such as the probability of hitting the target on a clear testing range) and then estimates the extent to which possible sources of degradation (such as smoke and fog) may reduce effectiveness in actual combat. Data sources include technical documents and antitank-weapon experts inside and outside DOD.

Results in Brief

DOD does not routinely measure the performance of infantry antitank weapons on each effectiveness factor under all of the degraded conditions the weapons are likely to encounter. However, even the partial information available from DOD suggests that combat conditions can severely degrade effectiveness. For example, one measure of effectiveness is the probability of kill, given a shot. (This measure is the product of two factors in our framework—the probabilities of hit and kill). According to DOD, under benign conditions the probability of kill, given a shot, is [material deleted] for the current TOW (called TOW2) against a [material deleted]. Under various combat conditions (such as smoke and evasive maneuvering by the target), [material deleted]. (See pages 54-57, 62, and 75.)

New technologies may improve the effectiveness of infantry antitank weapons in some respects. The new high energy antiarmor warhead used in SMAW-HEAA could provide a higher probability of kill than the M72 or AT4 warhead. Fiber-optic technology makes it possible to relay an overhead view of the battlefield from the missile's camera to the gunner's screen. Consequently, FOG-M may be more accurate than the current wire-guided missiles, especially in the presence of fog, smoke, or other obscurants. Fiber-optic technology provides other capabilities, such as added range, that may improve sustainability and survivability. Without extensive testing and field experience, these possibilities remain uncertain. (See pages 35-63.)

Program staff for the future weapons were well aware of the effectiveness issues identified in this study. However, DOD has communicated little information on the expected performance of these weapons under benign or degraded conditions to the Congress. (See pages 62-72.)

Principal Findings

To quantify weapon performance under degraded conditions, DOD relies on simulations of combat between forces (weapons in combination), plus tests of individual weapons. Overall simulation results do not indicate the extent to which combat conditions reduce the effectiveness of individual weapons in the force. Even when the simulation provides some measure of effectiveness for each weapon, the results can vary widely, depending on combat scenario. Tests of individual weapons generate estimates of degraded performance, but the comparability across weapons is quite limited. Tests have not included the same degrading elements or varied the elements in the same way. (See pages 24-32.)

It is difficult to estimate a weapon's probability of kill even under benign conditions. Lethality depends in part on interior tank damage, which cannot be predicted with adequate precision. Moreover, the thickness and composition of modern Soviet armor remain uncertain. (See pp. 32-33.)

Consequently, GAO had to base its findings on nonquantitative information (for example, descriptions of a weapon's technical characteristics and capabilities). GAO used the quantitative data available from DOD to demonstrate the degree of performance degradation possible for each weapon if those data are correct. (See pages 33-36.)

Because of its new warhead, SMAW-HEAA may offer a better probability of kill than our current M72 or AT4. However, because it is difficult to predict penetration and interior damage, the actual lethality of the new SMAW-HEAA warhead remains uncertain. (See pages 36-44.)

Fiber-optic technology makes it possible to house a camera in the nose of a missile flying above the battlefield and to relay the picture to gunners who are as far away as 10 kilometers. Fiber optics may therefore improve the probability of hit, as well as sustainability of fire and survivability. Fiber optics may also provide a higher probability of kill by enabling gunners to attack tanks from above. (See pages 44-60.)

Technicians responsible for developing the future weapons were well aware of issues that DOD and non-DOD experts consider crucial. Despite this, the information that DOD provides to the Congress, such as the annual antiarmor master plan, contains little information on weapon effectiveness under either benign or degraded conditions. (See pages 64-72.)

Matter for Congressional Consideration

To assess the relative effectiveness of weapon alternatives, reviewers need performance data that are comprehensive (covering all effectiveness factors and all likely and predictable sources of degradation) and comparable (derived under similar test conditions and measured in similar ways). GAO believes that its framework can assist in these assessments and therefore proposes that the Congress consider using the framework to guide and help specify its requests for information regarding infantry antitank weapon performance. (See pages 75-77.)

Recommendation

Data on weapon performance may be quantitative or descriptive, as appropriate, and may be based on a variety of sources including lab tests, live fire, and computer simulation. But regardless of data types and sources, congressional reviews of weapon performance will be more efficient if DOD generates and organizes its performance data with GAO's framework in mind. GAO therefore recommends that the secretary of Defense ensure that the data generated by DOD regarding antitank weapon performance are comparable across weapon alternatives and cover the five effectiveness factors and three degradation factors contained in GAO's framework. (See pages 77-78.)

Agency Comments

DOD fully or partially concurred with the findings in this report. DOD's reservations center chiefly on two issues. First, DOD accepted the relevance of the five effectiveness factors and three degradation factors but argued that system reliability should also have been considered. As noted in the report, weapon assessments may cover several factors not in GAO's framework—cost and logistics requirements, for example, as well as reliability. But such factors do not directly measure the effectiveness of a weapon. Instead, they measure the inputs and processes that determine its effectiveness. GAO believes that the factors covered in this study represent all those that are directly relevant to weapon effectiveness. Second, DOD noted that quantifying each effectiveness factor and degradation factor would oversimplify the analysis and obscure many contingencies. As the report makes clear, GAO recognizes that quantification is not always feasible or necessary. The framework is merely a device for organizing the available information—quantitative or nonquantitative—and highlighting possible problems and trade-offs. (See page 78 and appendix II.)

DOD concurred with GAO's recommendation that performance data on infantry antitank weapons be comparable across weapon alternatives and cover all factors in the framework. (See page 92.)

DOD's comments are in appendix II. GAO's responses appear there and in chapter 5.

Contents

Abbreviations

AAWS	Advanced antiarmor weapon system
AAWS-H	Advanced antiarmor weapon system-heavy
AAWS-M	Advanced antiarmor weapon system-medium
ACCP	Short-range antitank missile (French anti-char courte portée)
AMSAA	Army Materiel Systems Analysis Activity
BRL	Ballistics Research Laboratory
DOD	U.S. Department of Defense
FOG-M	Fiber-optic guided missile
FST	Future Soviet tank
GAO	U.S. General Accounting Office
HEAA	High energy antiarmor
MPIM	Multipurpose individual munition
RHA	Rolled homogeneous armor
RHAE	Rolled homogeneous armor equivalence
SMAW	Shoulder-launched multipurpose assault weapon
TOW	Tube-launched optically tracked wire-guided missile

Introduction

[Material deleted.] According to DOD estimates, our lighter weapons [material deleted]. The Army and Marine Corps have begun efforts to improve our antitank capabilities, efforts expected to cost over $6.5 billion by 1995 (in fiscal 1987 dollars), including upgrading our current weapons and employing new technologies.

At the request of Congressman Charles E. Bennett, we reviewed information on infantry antitank weapons, now available or in development, to determine

- what the known or projected capabilities of these weapons are and
- what information about the capabilities of future weapons has been communicated within the Department of Defense and to the Congress.

In chapter 1, we review first the threat posed by Soviet doctrine and armor and then the planned U.S. infantry response. We describe next the antitank weapons—current, upgraded, and future—covered by the study. Finally, we present in more detail our objectives, scope, and methodology and identify some study strengths and limitations.

The Threat

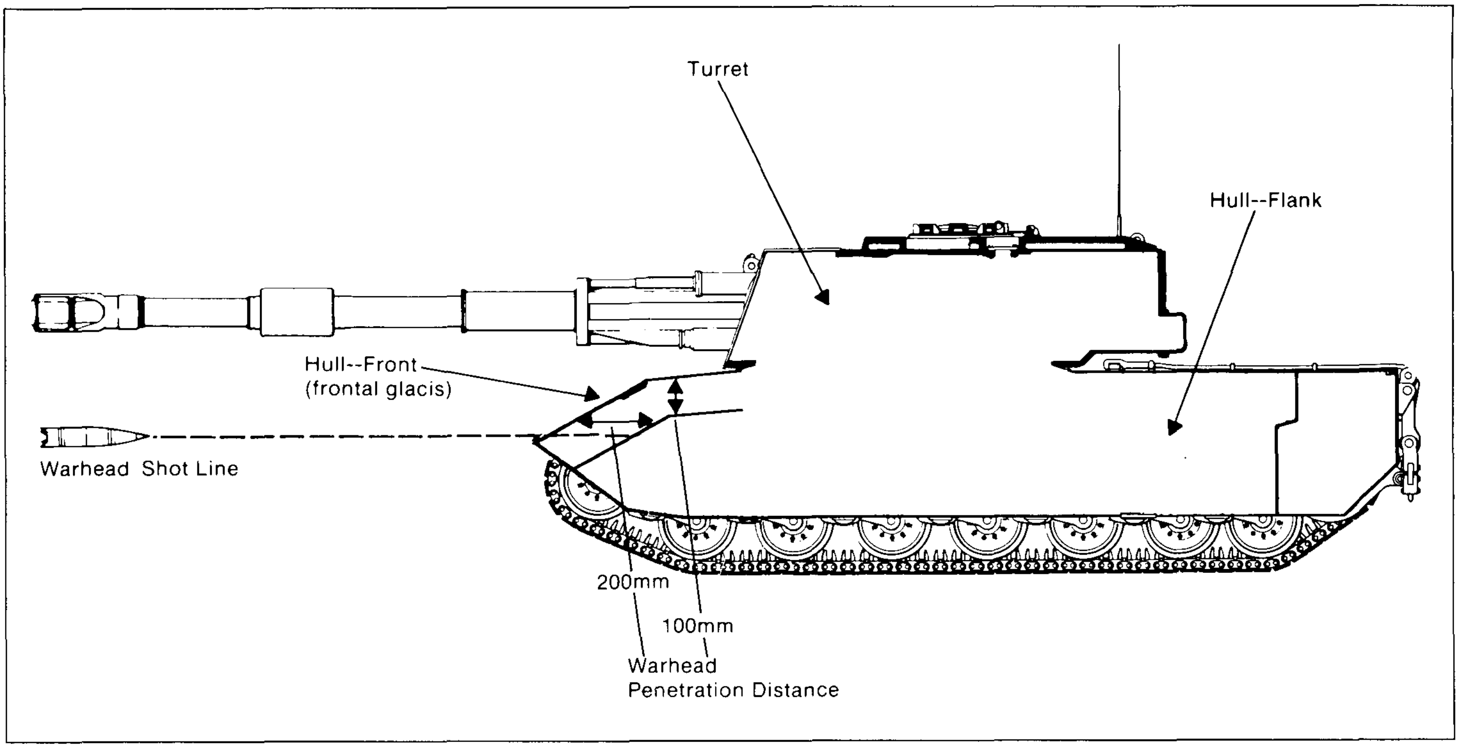
Soviet Doctrine and Armor

If war occurs in Europe, analysts believe that the Warsaw Pact will rely on applying its superior numbers of tanks and lighter vehicles (such as armored personnel carriers) in a continuous and rapid advance. The enemy may move first along a wide front to conceal its axes of primary effort while pinning down defensive forces. Once across the border, the enemy may move forward along a few axes as rapidly as possible, then press for a quick consolidation of its gains.

A critical component of this threat is the enemy's tank fleet. According to DOD, the Soviet inventory now totals approximately 52,000 tanks worldwide and is expected to [material deleted]. In Europe, the Soviet Union and other nations of the Warsaw Pact have approximately 29,000 tanks, and [material deleted].

These figures include three generations of Soviet tanks. The first generation includes one model of World War II vintage (the T34) plus others (the T54, T55, and T62) that entered production after 1945. These first-generation tanks constitute 55 percent of the Soviet Union's current worldwide fleet. [Material deleted], as we illustrate in figure 1.1. Of course, if the shot hits at an oblique angle, the penetration required is [material deleted].

Figure 1.1: Distance Required for Warhead Penetration of a Frontal Glacis From a Flat Trajectory[a]



[a]This illustration is generic. It does not represent the Soviet T-62 or any other tank model.

The Soviet Union began a second generation of tanks in the 1960's, starting with the T64 and later adding the T72 and the T80. [Material deleted.]

DOD expects to see a third generation—[material deleted].

By 1995, over one half of the worldwide Soviet inventory will reportedly be second generation; approximately 10 percent, third generation. In Europe, Warsaw Pact forces will be more thoroughly modernized: 20 percent of the inventory will be third generation and well over one half will be second generation.

The Infantry's Response

According to U.S. Army doctrine, the infantry works in conjunction with other ground and air forces to disable enough enemy "armor" (tanks and other fortified vehicles) to stop an advance. This task is easier if the defense can channel enemy forces onto terrain that favors the infantry (such as narrow passes or urban areas) and if the defense can strip enemy armor of its own infantry support. To ambush individual tanks and move through difficult terrain, the infantry may leave their vehicles, or "dismount," and move on foot.

Tanks are a formidable element in the enemy's arsenal. Their combination of size, mobility, firepower, and noise produces a fearsome shock effect, but they are not invulnerable. Even the most modern Soviet tanks are thinly armored at the flanks, top, and rear. Further, if crew members must stay "buttoned up" (inside the tank with the hatch closed), the infantry can exploit blind spots at the flanks and rear.

Accordingly, tactics for infantry operations against tanks include mutual support, flank shots, and use of cover and concealment. Whenever possible, infantry will set up overlapping fields of fire. The overlap provides mutual support: gunners protect other gunners nearby and subject advancing tanks to multiple hits from more than one direction. Also, flank shots are preferable because a tank is more vulnerable on the flanks—the armor is thinner, and tank crews are less likely to see gunners who fire from that angle. Finally, whenever possible, infantry gunners maneuver for positions that provide concealment (so tank crews cannot see gunners) and cover (so tank crews cannot hit the gunners they do see).

Such tactics are of limited value if our antitank weapons are not sufficiently accurate and lethal. Without confidence in the ability to hit and disable enemy tanks, infantry gunners will be hard pressed to withstand the shock effect that tanks create.

Outside Europe, U.S. forces are more likely to face older tanks. Objectives and operational procedures may shift, particularly in the Marine Corps's mission of amphibious assault. But the same tactics of antitank warfare still apply, as do armor's fundamental strengths and weaknesses.

Infantry Antitank Weapons

The antitank weapons now available to infantry have chemical-energy warheads, which detonate near the armor surface to form a penetrating jet of metal. These weapons are part of a wider ground-based capability against tanks and lighter armor. Other ground weapons include tank guns and artillery. Tank guns can use kinetic-energy warheads, which convert high speed into penetrating power.

Congressman Bennett asked us to focus on infantry antitank weapons for two reasons. First, those weapons are critical to combat effectiveness. Army simulations indicate that in the close-battle portion of any major European engagement, infantry antitank weapons will disable between 18 percent and 89 percent of Soviet armor; a more precise estimate within that range depends on the terrain, the combination of weapons available, and other factors. (With regard to other ground weapons, the Army expects that tanks will disable 10 percent to 42 percent of enemy armor; mines, 0 to 42 percent; and artillery, 0 to 5 percent.) Second, while lighter armor targets pose some challenging technological problems (such as how to maximize casualties), the most serious and immediate problems lie in defeating tanks.

A key characteristic of infantry antitank weapons is their deployment level. Light weapons are distributed to soldiers individually. Medium weapons are heavier and require more training, so a platoon or company must assign, or "dedicate," members to carry and handle them. Heavy antitank weapons may be carried by soldiers but are usually mounted on vehicles and operated by a trained crew. DOD's current infantry antitank inventory comprises light, medium, and heavy weapons, and we organized our research accordingly. In chapter 3, we raise some questions regarding this current mix of weapons.

Light Antitank Weapons

The infantry uses light antitank weapons at close range. Some of these unguided weapons are effective to 150 meters; others, to 400 meters. For portability, most weigh no more than 15 pounds.

Light weapons currently in the U.S. inventory are the M72 LAW and the AT4. In 1986, M72 stocks totaled approximately 525,000; AT4 stocks, approximately 150,000. (See figures 1.2 and 1.3 on pages 14 and 15.)

The M72 carries a 66-millimeter warhead (2.6 inches); AT4, an 84-millimeter warhead (3.4 inches). Both warheads are conical; their metal liners are shaped like an inverted cone. Upon detonation, the rear tip is driven forward to form the front end of a penetrating jet.

According to Army policy, which was revised in 1983, the AT4 and M72 are no longer classified as antitank weapons. The infantry carries them

Figure 1.2: M72A3

Source: Department of Defense.

mainly to defeat lighter armor, bunkers, and other "soft" targets. But both the M72 and the AT4 can be lethal against tanks if fired at the flanks or rear, and both the Army and the Marine Corps will use them at these attack angles in self-defense.

A new E4 model of the M72 has been developed in Norway. DOD has not fully tested the M72E4 and has not decided whether to deploy it. The M72E4 warhead is conical and has the same diameter, 66 millimeters, as its predecessor.

Future light weapons include the multipurpose individual munition (MPIM) and an antitank warhead for a current weapon, the shoulder-

Figure 1.3: AT4

Source: Department of Defense.

launched multipurpose assault weapon (SMAW). The Army has not selected a MPIM design but hopes to develop a single round that will be effective against both light armor and soft targets. The SMAW, which has a reusable launcher and spotting rifle, requires a dedicated gunner. The current SMAW has a warhead that can defeat bunkers and other soft targets. The Marines are developing a new high energy antiarmor (HEAA) warhead for the SMAW that is 83 millimeters (3.3 inches) in diameter. According to program representatives, this new warhead will be able to defeat some tanks with a frontal shot. The SMAW equipped with the HEAA warhead (SMAW-HEAA) incorporates recent advances in warhead technology, primarily the trumpet-shaped liner, a design that increases the mass of a chemical-energy jet. According to current plans, SMAW-HEAA will be fielded in 1987. MPIM may be deployed in the early 1990's.

Medium Antitank Weapons

Some medium weapons can reach targets as far away as 600 meters; others can hit targets at 2,000 meters. The round of ammunition may be guided or unguided.

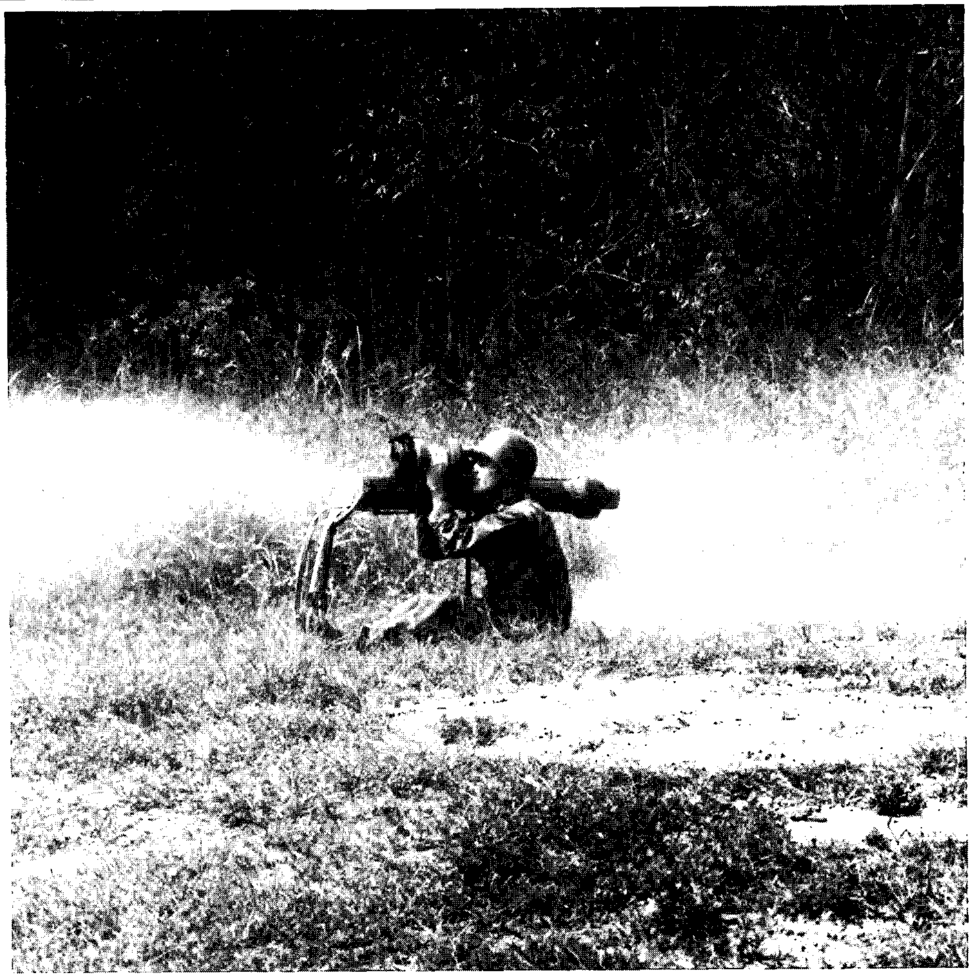
When the infantry dismount, especially in difficult terrain, medium weapons are their primary resource for ambushing tanks. For this reason, medium weapons must be light enough for soldiers to carry. Weighing between 25 and 45 pounds, such weapons are carried intact by one gunner or split into components carried by two- or three-member teams.

The U.S. medium weapon is the wire-guided Dragon (see figure 1.4), which has a 102-millimeter (4-inch) warhead. As of 1986, Army and Marine Corps inventories totaled about 54,000 of these weapons. To operate the Dragon, a gunner simply keeps the crosshairs of the telescopic day or night sight on target while the launch device automatically computes course corrections and feeds them to the missile through a copper wire.

The Marine Corps is upgrading the Dragon in two steps, called generations II and III of the Dragon product improvement program. Generation II will reportedly improve lethality with a trumpet-shaped liner. Generation III will improve the sight, add range, and increase missile speed.

While supporting the short-term Dragon product improvement program (generation II), the Army is also pursuing the advanced antiarmor weapon system-medium (AAWS-M). The Army hopes to deploy AAWS-M [material deleted]. At present, there are three guidance designs under consideration. In one design, called the laser beam rider, a gunner keeps the crosshairs on target while the missile "rides" the beam to impact. In the second design option, known as the tank breaker, an infrared sighting and tracking device detects the thermal energy emitted by a target, enabling a gunner to locate the target through the sight and lock onto the target before firing. The third design option uses fiber optics, a generic guidance technology with several possible applications. In a medium antitank role, a fiber-optic guided missile (FOG-M) replaces the sight with a viewing screen linked by a fiber-optic cable to an infrared camera in the nose of the missile. A gunner could fire the missile on a flat or lofted trajectory and then lock onto the target or guide the round manually until impact. (The Army is already developing a FOG-M for use against ground targets beyond the gunner's line of sight and against helicopters.) With a lofted trajectory, the medium FOG-M would dive toward the top of a tank, where the armor is not so thick.

Figure 1.4: Dragon



Source: Department of Defense.

Heavy Antitank Weapons

These weapons present the infantry's most lethal antitank capability. The guided rounds can hit targets as far away as 4,000 meters. For tactical flexibility, launchers can be carried on a vehicle or set up on a tripod for use by infantry who have dismounted.

Our current heavy weapon is the tube-launched optically tracked wire-guided (TOW) missile (see figure 1.5). As of 1986, the Army and Marines held approximately 160,000 TOW missiles, including basic TOW, improved TOW, and TOW2. Like the Dragon, the TOW is connected to its launcher by copper wire. The gunner keeps the crosshairs on target while the launcher transmits course corrections to the missile. TOW2's tracking and sighting have been upgraded to maximize resistance to [material deleted]. Its warhead diameter is 150 millimeters (6 inches). (Infantry have also used heavy antitank guns such as the 106-millimeter recoilless rifle. We did not include such weapons in this study.)

Figure 1.5: TOW

Source: Department of Defense.

DOD plans two further improvements in TOW missiles by [material deleted]. TOW2A will reportedly increase lethality with a tandem warhead that, as the name implies, attempts to defeat modern armor by sending a second charge through a path cut by the first. TOW2B may further increase lethality by shifting the attack to the top of enemy tanks.

The missile will follow a horizontal flight path slightly above the gunner's "aimpoint" (the area centered in a gunner's sight). The warhead will be set at an angle, so that it fires downward as it passes a tank underneath. Thus, even a head-on shot will attack the thinner top armor, not the frontal glacis. Planners may also put two charges on the same TOW2B round to fire simultaneously at different angles.

Beyond these TOW2 upgrades, DOD is also developing the advanced antiarmor weapon system-heavy (AAWS-H) for deployment in [material deleted]. There are several design options now under consideration, including the AAWS-M candidates (the fiber-optic guided missile, the infrared tank breaker, and the laser beam rider), a new version of TOW, and a kinetic-energy weapon. DOD may pursue one or more of these options. In some respects, a heavy FOG-M may resemble the medium FOG-M. Gunners may be able to select a flat or lofted trajectory, then lock onto targets or guide rounds manually. In other respects, a heavy FOG-M could resemble the current TOW—a launcher and several rounds carried on a vehicle or, when gunners dismount, on foot. According to current plans, the range for a heavy FOG-M would be at least 5 kilometers—over 1 kilometer past TOW's maximum range. Another alternative is a heavy line-of-sight weapon resembling the FOG-M already under development. This FOG-M will use television or infrared guidance to reach targets at least 10 kilometers away—well beyond line-of-sight range. After being launched vertically, from behind cover, rounds will pitch over for the flight downrange. Planners believe that the gunner could control as many [material deleted] in the air simultaneously.

Table 1.1 lists the current, upgraded, and future weapons in each category.

Table 1.1: U.S. Infantry Antitank Weapons[a]

Size	Current weapon	Upgrade	Future weapon
Light	M72A3 (66) AT4 (84)	M72E4 (66)	MPIM[b] SMAW-HEAA (83)
Medium	Dragon (102)	Dragon (122) (generations II and III)	AAWS-M[c]
Heavy	TOW2 (150)	TOW2A (150) TOW2B (150)	AAWS-H[c]

[a]Numbers in parentheses represent the warhead size in millimeters.

[b]Not covered in this study. Warhead size not yet specified.

[c]Warhead size not yet specified.

Objectives, Scope, and Methodology

Objectives

As noted above, the objectives of this study were to assess the capabilities of infantry antitank weapons and to describe the information regarding future antitank technologies that DOD has communicated. To meet these objectives, we addressed five questions.

1. What factors are relevant to the effectiveness of infantry antitank weapons?

2. What is the relative effectiveness of infantry antitank weapons now in the field, planned weapon upgrades, and future weapons intended to exploit new technologies?

3. What issues are pertinent to the effectiveness of infantry antitank weapons using new technologies?

4. What information regarding new antitank technologies has been communicated across technical levels in DOD, such as labs, test centers, and program offices?

5. What information regarding new antitank technologies has been communicated by DOD to the Congress?

Scope

We covered all the current and upgraded weapons listed in table 1.1. But we were constrained by the limited information now available on future weapons—the SMAW with its HEAA warhead, the MPIM, and the medium and heavy versions of AAWS. For all of these antitank weapons except SMAW-HEAA, several design options are still being considered. Moreover, MPIM may not be built as an antitank weapon, and DOD has not yet formulated MPIM performance projections. For the category of light future weapons, we therefore covered SMAW-HEAA but not MPIM.

For the medium and heavy categories, study resources did not permit coverage of each design option. Instead, we focused on one possible design, fiber optics. With FOG-M, the link from missile camera to the gunner's screen is expected to provide a clear picture of the battlefield, defeat many possible countermeasures, and extend heavy-weapon ranges to at least 5 kilometers. Because FOG-M promises these new capabilities and is under consideration in both the medium and the heavy categories, our discussion of the future AAWS-M and AAWS-H centers on that design option. Readers should not infer that DOD has already decided to field a FOG-M in either the medium or the heavy category.

We also collected limited data on several guided and unguided European antitank weapons to illustrate a somewhat different approach to lethality taken outside of the United States. We discuss the European weapons in chapter 3.

Methodology

Our first question concerns the factors to be considered when analyzing effectiveness. We consulted published sources, weapons development documents, and defense experts and then devised a framework for analysis that represents systematically the factors that we identified.

We used this framework to answer our second and third questions: What is the relative effectiveness of infantry antitank weapons and what issues are pertinent to the effectiveness of future weapons? In our data collection, conducted from April 1986 to February 1987, we obtained estimates of weapon performance pertinent to factors in the framework. Some of the estimates are quantitative—for example, a probability of 0.85 that the round will hit the target. Others are qualitative, such as a description of the technical problems that a weapon must overcome to be effective. Some estimates reflect only the benign conditions of a lab test or a clear firing range. Others take into account various battle conditions—smoke, enemy countermeasures, gunners' stress, and so on—that can seriously degrade performance. Use of the framework also enabled us to identify, in a systematic way, the effectiveness issues for which data are and are not available.

We obtained quantitative estimates of weapon performance under benign and various battlefield conditions from the Army Materiel Systems Analysis Activity, the Ballistics Research Laboratory, and the Army and Marine Corps program offices. DOD's estimates for current weapons are based on data that have accumulated over a long series of live and simulated firings. For future weapons, DOD uses performance projections based on weapon requirements or on the known or anticipated capabilities of a technology. We also conducted a systematic search of documents reporting the performance of weapons and technologies in battle or under specific test conditions. These documents described performance in quantitative or qualitative terms. Finally, we interviewed experts (both within and outside of DOD) in the capabilities of these weapons and the relevant technologies.

In the search for pertinent data, we covered not just antitank weapons but also other weapons that apply certain technologies used in antitank weapons—television and infrared tracking and wire guidance. (These other weapons are listed in chapter 4.) By widening our search in this way, we incorporated useful findings and expertise from sources throughout DOD.

Our fourth question involves communication regarding future antitank technologies among technical elements within DOD. We assembled a set of issues regarding the two future weapons—SMAW-HEAA and the medium and heavy versions of FOG-M. Among these issues were specific performance capabilities and trade-offs identified by programs, labs, and test centers inside and outside DOD. For example, one possible problem for an infrared-guided FOG-M is "thermal clutter." It can be difficult to identify tank targets through infrared devices when a battlefield is crowded with hot objects—burning trees and vehicles, for example, as well as functioning enemy tanks. Information from our search of technical documents, including those for nonantitank weapons, was especially useful in assembling these issues. We then interviewed program office personnel for the future weapons, asking whether and how the issues have been or will be addressed. We did not attempt to evaluate decisions regarding any issue or the information on which decisions were based. Our purpose was more limited: to determine the degree to which program personnel were aware of issues discovered elsewhere in DOD and outside of DOD.

To answer our final question, regarding communication by DOD to the Congress, we examined DOD's annual antiarmor master plans (provided to the Congress since 1984) and congressional testimony of DOD officials on the two future weapons. Working from the effectiveness framework devised for this study, we extracted any statement regarding those weapons and analyzed its contribution within that framework. For example, one effectiveness factor is the probability of hitting a target. We scanned the master plans and congressional testimony for statements on probability of hit for both future weapons, including statements concerning the potential performance of relevant technologies and the battlefield conditions that can affect performance.

Study Strengths and Limitations

The study offers a systematic framework for assessing the effectiveness of infantry antitank weapons and demonstrates the utility of that framework by applying it to a set of weapons to determine their effectiveness. The study also demonstrates, in a generic way, the wide range of battle conditions that can degrade weapon performance.

The study has two limitations inherent in the data available to us. First, our findings on the effectiveness of upgraded and future weapons are of necessity based on projections or requirements, not actual performance, since these weapons do not yet exist. The findings are therefore quite tentative and cannot be refined without extensive testing. Second, the quantitative effectiveness estimates we obtained for all weapons (current as well as upgraded and future) are not comprehensive, and their accuracy is uncertain, for reasons that we discuss in chapter 2.

These problems are not particular to this study. Only after long experience with weapons in the field can it be fully understood how well weapons perform and why. Short of data derived from such experience, we must use estimates of performance that are subject to revision and adjust our analytical procedures accordingly. The analysis of DOD's data in this study is one step in that process.

Organization of the Report

In chapter 2, we introduce five factors in our framework for assessing effectiveness, describe the battle conditions that can degrade effectiveness, and review the procedures used by DOD to measure each factor. In chapter 3, we use that framework to assess the capabilities of infantry antitank weapons now in the field or under development. In chapter 4, we describe the communication of information on the SMAW-HEAA and the fiber-optic guided missile within DOD and by DOD to the Congress. In chapter 5, we review our findings, propose one matter for congressional consideration, and make one recommendation to the secretary of Defense. We also summarize DOD's comments on a draft of this report and our response to those comments.

Chapter 5 is followed by two appendixes: (1) an outline of generic issues to be covered when assessing antitank weapon effectiveness and (2) the full text of DOD's comments on the draft report and our response. We also provide a bibliography of published sources from which we took performance data and background information and a glossary of terms used in this report.

Weapon Effectiveness

In this chapter, we answer our first question:

What factors are relevant to the effectiveness of infantry antitank weapons?

To accomplish this, we developed an analytical framework that identifies relevant factors and the battle conditions that can reduce effectiveness. We will use this framework in chapter 3 to assess weapon capabilities and in chapter 4 to examine communication by DOD to the Congress. In this chapter, we also review DOD's methods for measuring the effectiveness of weapons when used alone and in "forces," or combinations of weapons.

Effectiveness Factors

Our framework covers five factors assessing weapon effectiveness:

- probability of hit,
- probability of kill,
- rate of fire,
- sustainability of fire, and
- survivability.

For broader purposes, we could have incorporated some additional factors. For example, to evaluate a weapon's cost-effectiveness, we might have considered procurement quantities and the expenditures associated with building, deploying, and maintaining the weapon. To evaluate the effectiveness of weapons used in combination, we might have considered each weapon's likely availability, logistics requirements, and possible synergistic effects.

But our purpose is to assess the capabilities of particular weapons, with an emphasis on the strengths and weaknesses of technologies applied in the development of new weapons. After consulting with experts in antitank technologies and doctrine, we believe that these five factors cover the full range of information relevant to that purpose. Since the relative importance of the five factors depends on tactics and circumstances that vary across scenarios, we have not attempted to rank these factors.

Degradation Factors

Weapons may not perform as well in battle as they do under the benign conditions of the laboratory or the test range. Consider the first effectiveness factor, probability of hit. Gunners may miss only rarely in practice but when faced with counterfire and evasive targets not do nearly so well.

Our framework covers three degradation factors that can weaken the effectiveness of infantry antitank weapons:

- mission environment—the visibility conditions and terrain in which a weapon is employed;
- enemy countermeasures—the efforts to toughen their materiel, conceal movement, and jam U.S. communications; and
- human factors—the gunners' ability to handle a weapon, especially under the stress of combat.

In table 2.1, we have listed several elements pertinent to each factor. These elements do not cover all possible sources of degradation, but they do cover those often discussed in antitank program documents, test reports, and other relevant sources.

Table 2.1: Elements That Can Degrade Effectiveness

Effectiveness factor	Degradation factor: Mission environment	Degradation factor: Countermeasure	Degradation factor: Human factor
Probability of hit	Rain, fog, and haze; smoke and dust; terrain and lines of sight; darkness	Decoys, camouflage, and aerosols; [material deleted]; evasive movement; counterfire	Gunners' skill, training, and mental and physical attributes
Probability of kill	[a]	Reactive armor; [material deleted]	[a]
Rate of fire	[a]	[a]	Gunners' skill, training, and mental and physical attributes
Sustainability of fire	[a]	Counterfire	[a]
Survivability	[a]	Counterfire	[a]

[a]We did not consider the possible reduction in effectiveness due to this degradation factor.

We cover each effectiveness factor in detail below and describe how the elements under each degradation factor can reduce effectiveness.

Effectiveness and Degradation Factors

Probability of Hit

The probability of hit is a function of accuracy and target size. Depending on a weapon's technical characteristics, shots may systematically miss the intended aimpoint and may scatter randomly around the actual aimpoint, even when the weapon is stable and the air is still.

Probability of hit diminishes under actual combat conditions. Obscurants in the mission environment, such as rain or dust, reduce visibility. If the terrain is flat and open, targets may be fully exposed for extended periods. But if the terrain is hilly, urban, or wooded, moving targets may stay at least partially hidden for much of the time.

Obscurants and terrain degrade probability of hit in two ways. First, they make it more difficult to guide weapons to a target. Smoke and trees, for example, can interfere with the tracking device. Second, they make it more difficult to find targets in the first place—a problem for unguided as well as guided weapons.

Countermeasures, another important degradation factor, include camouflage, aerosol obscurants, [material deleted], and counterfire. Notably, counterfire can degrade probability of hit without hitting the gunner; it is only necessary to disrupt the gunner's aim.

Human factors can also degrade probability of hit. These include a gunner's weapon-handling skills, such as the ability to assemble the weapon quickly and to aim it accurately, and more general attributes of gunners, such as their ability to handle stress and the quality of their training.

At the outer reach of most weapons, the probability of hitting a target declines. According to various projections, most tank-antitank engagements in a European conflict will occur within 500 meters; and 80 percent, within 1,500 meters. Some medium and heavy guided weapons can be accurate beyond 1,500 meters, but terrain and foliage restrict the lines of sight, and other environmental elements and countermeasures reduce visibility. Light, unguided weapons are also less accurate at their outer reaches, regardless of battlefield conditions. For these reasons, soldiers speak of an unguided weapon's maximum effective range, the distance at which probability of hit equals 0.50.

Antitank weapons are also characterized by a minimum range. Until the round is some distance away, detonation can endanger the gunner. Moreover, for a guided weapon, initial tracking errors can be sizable. Thus, within a certain minimum distance, the probability of hit is relatively low.

In short, elements that interfere with target detection can degrade the probability of hit for unguided weapons. Elements that interfere both with target detection and with the ability to track targets can degrade the probability of hit for guided weapons.

Probability of Kill

The probability of kill measures a weapon's likelihood of disabling a tank. This likelihood depends not just on penetrating the outer armor but also on doing further damage once inside the tank. A chemical-energy weapon achieves its behind-armor effect by creating fires, overpressure, and "spall," or fragments.

DOD defines at least three types of kill: a mobility kill—damage to the engine, tracks, or other components or driver injury; a firepower kill—damage to the tank-gun systems or turret or gunner injury; and a catastrophic kill—a combined mobility and firepower kill with damage too extensive for quick repair.

There are three steps in estimating probability of kill. The first step is to determine the likelihood of penetrating armor at various "azimuths," or hit points, and the potential damage to components or injury to personnel. These outcomes depend on the armor type (solid steel or composite); the location of fuel tanks, ammunition, and other components; and the presence of interior screens or liners that reduce spall damage. The second step requires some assumptions about the likely distribution of azimuths: simply put, how many shots will hit the front, flanks, and rear of the tank? The third step combines data derived from the first two steps to arrive at an overall probability of kill. Steps 1 and 3 rely, in part, on computer modeling, which we describe below.

With regard to step 2, DOD does not use the same azimuth distribution of hits for all antitank weapons. For most antitank weapons, DOD uses a cardioid (heart-shaped) distribution. In addition, DOD uses a close-combat distribution for light weapons. Both distributions are based partly on experience in war. The cardioid distribution assumes that more shots will be taken at the front of the tank than at the flanks or rear. Close-combat assumes that fewer shots will be taken at the front of the tank than at the flanks or rear. DOD also estimates probability of kill for shots hitting within the 60-degree frontal arc, the most heavily armored part of a tank.

A weapon's probability of kill is a function of various technical characteristics of the warhead such as its size, composition, and type (chemical energy or kinetic energy). If a tank has features not accounted for in the models, a weapon's actual probability of kill may not equal its estimated probability of kill. One possible countermeasure is [material deleted] that can degrade probability of kill by inducing detonation too far from the tank surface. Another countermeasure, reactive armor, reduces penetration by exploding outward when it is hit, disrupting the formation of a chemical-energy jet. (Experts describe two sorts of reactive armor: applique, which is attached to the hull; and integral reactive armor, not yet deployed, which will be part of the hull.)

Rate of Fire

The number of rounds a gunner can fire per minute, or rate of fire, is a function of the time that it takes to find a target, aim, and fire, and (for guided weapons) to track the round until impact. If the launcher is reusable, we must also consider the time that it takes to reload it. Under battle conditions, human factors such as combat stress or inadequate training can slow the rate of fire.

Sustainability of Fire

Sustainability of fire is the number of rounds that a unit can carry into the field and fire. Under benign conditions, "carry weight" and deployment level determine sustainability of fire.

Carry weight affects sustainability of fire in that the lighter the system is, the more rounds a unit can carry. Carry weight can include not just the round and launcher but also the day and night sights, battery, coolant, platform (bipod or tripod, for example), cleaning equipment, and storage containers. There is, of course, an advantage to weapons with reusable pieces.

Also relevant is the level at which the weapons are deployed—individual soldier, squad, or battalion, for example. Larger units can carry more weight by assigning weapons to specialized subunits.

Under combat conditions, suppressive counterfire can also reduce sustainability. As with probability of hit, the enemy need not achieve direct hits; if gunners must keep their heads down or move after firing, they may not be able to sustain fire even when rounds of ammunition are still available.

Survivability

Survivability is the likelihood of attrition—that is, the chance that either gunner or weapon will be disabled during battle. Variables that affect survivability include the extent of gunner exposure and the weapon's range and firing signature. Various conditions complicate the relationship between range and survivability. But, in general, if a weapon has more range, the enemy is less likely to pinpoint its location. Noise, muzzle flash, smoke, and dust can contribute to a weapon's firing signature.

These variables may be measured in technical terms, such as decibel level, but their importance lies in their effect on concealment and cover. Concealment keeps the enemy from identifying a gunner's location. Cover, provided by terrain or by the launch platform itself, keeps the enemy from hitting the gunner even after the gunner's location has been disclosed. In short, gunner and weapon are more survivable if they can maintain concealment and cover, thereby reducing the likelihood of attrition.

The relevant degradation factor for survivability is counterfire—in this case not disruptive or suppressive counterfire but disabling counterfire.

DOD Methods for Estimating Effectiveness

Aside from actual combat, there are three sources of information regarding the effectiveness of a weapon:

- actual firings during live tests, training, and field exercises,
- laboratory tests, such as a series of warhead detonations against a steel plate, and
- computer-aided simulations of combat or of physical events such as the spalling pattern inside of a tank.

Working from these sources, DOD estimates weapon performance under benign conditions (such as in clear weather) and degraded conditions (such as in heavy fog or smoke).

Estimates Under Benign Conditions

Estimates for probability of hit are derived from the results of tests and training exercises. The Army Materiel Systems Analysis Activity (AMSAA) accumulates and tallies these results, generally making separate estimates for stationary and moving targets.

To estimate probability of kill, DOD derives data from warhead tests in the laboratory and then enters the data in computer simulations of multiple shots at specific tanks. The Army's Ballistics Research Laboratory (BRL) tests antitank warheads against "range targets," plates of steel or composite armor that duplicate the known or presumed characteristics of an enemy tank. (There may be 10 or more range targets per tank to represent its armor characteristics on the frontal glacis, turret, flanks, and so on.) After measuring the penetration achieved against each range target, BRL uses mathematical models to estimate the likelihood of punching through the tank's armor at any spot and hitting the materiel or personnel inside. The result is a large set of probability-of-kill estimates, covering shots from any angle. These estimates are fed into other models with the assumed shot distribution (the cardioid or close-combat distribution, for example) to produce an overall estimate for the weapon against a particular tank.

DOD bases its rate-of-fire estimates on field tests and training exercises. AMSAA keeps a record of the time it takes to load, aim, and fire antitank weapons and the time between firing and impact.

Regarding sustainability of fire, DOD measures the weight of the round, the launcher, and any other components to be carried on foot or in a vehicle. Since larger units can carry more weight, deployment level also governs this effectiveness factor by determining the number of rounds of ammunition available during combat.

Finally, DOD measures various technical characteristics pertinent to survivability, including range and firing signature. As already noted, the importance of these characteristics lies in their effect on attrition—another variable measured by DOD.

Estimates Under Degraded Conditions

How does DOD assess the effects of the mission environment, countermeasures, and human factors on these benign estimates? For the most part, DOD assesses degraded performance for forces of weapons, not for each weapon in isolation. Benign estimates serve as input to mathematical models that simulate battle, given various weapon combinations and quantities. In any scenario, the lines of sight, weather conditions, countermeasures, and human factors can vary in accordance with known features of the battle area and assumptions regarding enemy capabilities and tactics. Outcomes include the number of red (enemy) and blue (friendly) tanks disabled and the loss-exchange ratio (red to blue).

For example, input to BRL's "tank wars" model covers characteristics such as probability of hit, probability of kill, and rate of fire for tanks and antitank weapons, as well as terrain conditions that affect the lines of sight. Able to simulate a battle involving as many as 20 tanks, the model estimates the numbers of blue and red tanks killed, loss-exchange ratios, and overall win probabilities.

Other models estimate outcomes at higher force levels. "Carmonette," a battalion-level model, simulates the combined performance of ground and helicopter units. Input includes weapon characteristics, countermeasures, weather, smoke, and the effect of terrain on lines of sight. Output includes the number of weapons lost by each side and the loss-exchange ratio. Carmonette also estimates the contribution of each weapon to the overall results—for example, the number of red targets killed by the weapon, the number of blue weapon units killed, and the weapon's loss-exchange ratio.

DOD also estimates degraded effectiveness for some weapons in isolation, using field tests and simulations. For example, in 1979 the Army's Human Engineering Laboratory conducted a study of the influence of noise, blast, and threat on Dragon's tracking accuracy. Gunners fired against mock targets while subject to simulated explosions and counterfire. Under these conditions, Dragon's probability of hit at 1,000 meters decreased from [material deleted]. In 1983, the Institute of Defense Analyses conducted an assessment of antiarmor munition technology goals. This study projected an attrition rate of 3.5 percent to 5 percent for each shot taken by dismounted TOW gunners.

In summary, DOD measures the five effectiveness factors under benign conditions but does not routinely and systematically measure the performance of individual weapons under degraded conditions. Force-on-force outcomes for several weapons in combination do not indicate the extent to which the conditions simulated in the model degrade the performance of each weapon. Even when a model produces loss-exchange ratios per weapon, those ratios can vary widely depending on the scenario (terrain, tactics, synergistic effects of other weapons, and so on).

Furthermore, occasional tests of particular weapons do generate useful degraded estimates, but the comparability across weapons is limited. Tests have not included the same degrading elements or varied the elements in the same way.

Problems in Measuring the Probability of Kill

It is difficult to estimate the impact of degrading elements on any of the effectiveness factors, but estimates of probability of kill are difficult even under benign conditions, for three reasons. First, as noted above, the likelihood of disabling a tank depends not just on penetration but also on interior damage. At present, DOD sources do not believe it possible to build models that adequately simulate the effects of blast, fire, and shock behind the armor or that predict the paths of spall fragments and the resulting damage to components.

Second, warhead penetration capabilities have, until recently, been expressed in millimeters of solid steel (called rolled homogeneous armor, or RHA). Weapons experts evaluated the performance of different warheads by comparing the depths of RHA penetration. However, developments in armor technology have complicated matters. Composite and reactive armors and interior tank liners present penetration problems not directly comparable to those presented by solid steel. Weapons experts now measure various armors in RHA equivalence (RHAE), as if the modern armors provide a degree of protection equal to so many millimeters of plain steel. But the degree of protection depends heavily on the depth and materials of each composite layer, as well as on characteristics of the attacking warhead. The degrading effect of reactive armor depends on warhead characteristics and the angle of impact. Hence, it is difficult to generalize beyond a particular pairing of armor and warhead.

Third, [material deleted]. BRL uses this intelligence to construct range targets for warhead tests and, in its models for simulating the probability of kill, to fix the location of internal tank components. [Material deleted.] There is, in addition, the tendency to overestimate—to assume for safety's sake that the enemy is "10-feet tall," or in this case, 10-feet thick. [Material deleted.]

A more detailed discussion of DOD's models for estimating the probability of kill appears in Live Fire Testing: Evaluating DOD's Programs (GAO/C-PEMD-87-1).

Application of the Framework

Table 2.2 presents our analytical framework as a matrix. Using the matrix to sort the available data for any weapon, we can summarize

- the weapon's current or projected performance on each effectiveness factor (column 1) under benign conditions (column 2),
- the quantitative effect of each degradation factor, known as the degradation term (columns 3 through 5), and
- the combined quantitative effect of all degradation factors for which data are available (column 6).

Table 2.2: Analytical Framework[a]

		Degradation term			
Effectiveness factor (1)	**Benign estimate (2)**	**Mission environment (3)**	**Countermeasure (4)**	**Human factor (5)**	**Degraded estimate (6)**
Probability of hit	0.90	0.80	0.70	0.85	0.43
Probability of kill					
Rate of fire					
Sustainability of fire					
Survivability					

[a]Values given in this table are for illustrative purposes only.

To illustrate our use of the matrix, we can adopt the hypothetical estimates for probability of hit given in table 2.2. For example, suppose that the probability of hit for a weapon is 0.90 under benign conditions and that, according to tests, elements in the mission environment can degrade the weapon's probability of hit by 0.80. We refer to this quantity, 0.80, as the "degradation term," which represents the degree to which a degradation factor can reduce effectiveness. The weapon's probability of hit after degradation by the mission environment is 0.72 (the product of 0.90 and 0.80). Suppose that additional tests show that countermeasures can degrade probability of hit by 0.70 and that human factors can degrade it by 0.85. Multiplying the probability of hit by all three degradation terms, we conclude that the degraded probability of hit for this weapon is approximately 0.43:

$$0.90 \times 0.80 \times 0.70 \times 0.85 = 0.43.$$

Note that a lower degradation term means a more severe impact on effectiveness. If the degradation term for mission environment equals 0.50 instead of 0.80, the weapon's probability of hit after degradation is only 0.45, not 0.72.

This approach is subject to unavoidable limitations. First, we have assumed that each element degrades effectiveness independently—for example, that smoke and dust degrade the probability of hit by 0.80, regardless of gunners' ability and training. However, highly skilled gunners might be able to overcome the problems posed by battlefield obscurants. Conversely, the performance of less skilled gunners might decline drastically (far more than the 0.85 term suggests) when their vision is obscured. In short, the effects of various elements are subject to contingencies and interactions that are beyond the scope of our study.

Second, we have not tried to evaluate the accuracy of data provided by DOD. Performance projections and requirements for future weapons are, of course, impossible to verify without extensive testing and field experience. Even the performance data for current weapons are incomplete and tentative, reflecting measurement problems that our study cannot resolve.

The framework is valuable despite these limitations. When quantitative data are available, the framework sorts current DOD expectations regarding the effects of various conditions, taken singly. It also suggests the possible and approximate extent of overall degradation when these conditions combine on the battlefield.

Even without quantitative data, the framework remains valuable. Using it to organize nonquantitative descriptions of a weapon's capabilities, we can determine approximately how a weapon may perform under benign and degraded conditions.

Finally, the framework highlights the performance issues on which data, quantitative or not, are still missing.

Chapter Summary

In this chapter, we have established the framework that we will use to analyze the performance of infantry antitank weapons. For each of five factors in weapon effectiveness, we can describe performance under benign conditions and the approximate degree to which the mission environment, countermeasures, and human factors may degrade performance.

DOD generates information to which we can apply this framework. But information on many degradation elements is incomplete and some inherent difficulties render DOD's estimates inconclusive.

Effectiveness of Infantry Antitank Weapons

Introduction

In this chapter, we address our second and third questions:

What is the relative effectiveness of infantry antitank weapons now in the field, planned weapon upgrades, and future weapons intended to exploit new technologies?

What issues are pertinent to the effectiveness of infantry antitank weapons using new technologies?

Our descriptions of relative effectiveness cover all current and upgraded weapons in table 1.1, plus two future weapons: the light shoulder-launched multipurpose assault weapon with its new antitank warhead (SMAW-HEAA) and the fiber-optic guided missile (FOG-M). As noted in chapter 1, DOD has not specified the design for the medium and heavy advanced antiarmor weapon systems. FOG-M is an option for both.

Chapter 3 also provides information regarding the probability of kill for several antitank weapons developed in Europe. It concludes with observations on our current mix of infantry antitank weapons.

Descriptions of Relative Effectiveness

Working from our framework of effectiveness factors and degradation factors (see table 2.2), we describe the actual or projected capabilities of each weapon under benign conditions and various battlefield conditions. Given the issues posed by question 3, we pay particular attention to future weapons, focusing on the new technologies being applied and the issues pertinent to their effectiveness.

Quantitative Effectiveness Estimates

We supplement our descriptive account with the quantitative data that we were able to obtain from DOD—for example, numerical estimates for the probability of hitting and killing specific targets. These data, sorted into our analytical framework, indicate the approximate degree to which various elements, singly and combined, may degrade effectiveness.

As noted in chapter 2, DOD does not routinely cover all possible degradation elements when estimating weapon effectiveness. Moreover, for weapons still in development, DOD can supply only projections or requirements, which may not correspond to actual performance. To cover some of these cases, we derived estimates by collating expert judgment, performance projections and requirements, and the results of available laboratory or field tests. In other cases, we were unable to find or derive the necessary quantitative data.

Whenever possible, we report a quantitative "degradation term" (defined in chapter 2) to indicate the degree to which a factor can reduce effectiveness. For some weapons, we adopted degradation terms directly from DOD documents. If terms were not available, we calculated them by comparing benign and degraded performance data.

The accuracy of quantitative effectiveness estimates is limited by the quality and availability of data. Even when current and precise, estimates for some factors are of unknown validity (for reasons cited in chapter 2) and are subject to revision as more information becomes available. For these reasons, we base our findings on descriptive information regarding antitank technologies and field experience with actual weapons. The value of quantitative estimates lies, we believe, in illustrating the approximate degree to which performance may be degraded under battle conditions.

Effectiveness

The discussion covers each weapon category in turn: light, medium, and heavy. We begin with a descriptive (nonquantitative) comparison of capabilities and then supply the quantitative estimates that we obtained. Coverage is brief for the current weapons and their upgrades but more extensive for future weapons using new technologies.

More detailed descriptive and quantitative data were available for weapons in the medium and heavy categories than for weapons in the light category. As a consequence, the cumulative effects of various degrading elements and the value of the analytical framework itself become clearer as the discussion proceeds.

Light Antitank Weapons

Weapons in this category include the current M72A3 and AT4, the M72E4 upgrade, and the future SMAW-HEAA. These weapons are unguided. The gunner merely aims and fires without having to track the round until impact.

Probability of Hit

Under benign conditions, the current M72A3 demonstrates a low probability of hit beyond short ranges. Its relatively large dispersion (random distribution of hits around the aimpoint) contributes to the problem, as does its relatively slow flight velocity. Because of the AT4's smaller dispersion and higher velocity, its probability of hit well exceeds the M72A3's. According to projections, the M72E4 upgrade should be more accurate than the M72A3 but will not be as accurate as the AT4.

SMAW-HEAA promises a better probability of hit than any of these weapons. The spotting rifle, though not a new technology, may enable SMAW-HEAA gunners to get a close fix on their targets before firing.

What can be said about probability of hit under adverse conditions? All three degradation factors—the mission environment, countermeasures, and human factors—present critical problems.

Elements such as smoke and terrain may not degrade probability of hit against detected targets but will make it more difficult to see targets in the first place. None of the light weapons was designed in a way that overcomes this problem.

Probability of hit is also subject to countermeasures such as evasive target movement and counterfire. When targets are moving, the probability of hitting the target decreases considerably for the M72A3. The problem is less severe for the AT4 because of its higher velocity and smaller dispersion. It may be less severe for the M72E4 and SMAW-HEAA as well, since their rocket velocities exceed the M72A3's. Enemy counterfire can degrade probability of hit by disrupting the gunners' aim. None of the light weapons was designed for a unique ability to overcome the counterfire problem.

Finally, at close range, human factors—specifically gunners' skill and combat stress—can also degrade probability of hit.

Overall, SMAW-HEAA may improve the probability of hit offered by the M72 series. Various battlefield conditions degrade probability of hit for any of these weapons, but the ability to estimate the extent of degradation depends on data quantity and quality.

Probability of Kill

Constrained by weight and size, our current light weapons provide limited lethality against Soviet armor. With its small warhead diameter (66 millimeters) and conical design, the M72A3's probability of kill is low. The probability of kill for the M72E4 is subject to the same constraints.

The AT4 provides a greater probability of kill than either M72 version. The improvement is due largely to the warhead diameter of 84 millimeters.

The new SMAW-HEAA warhead is virtually the same size as the AT4 but switches from a conical liner to a trumpet-shaped liner. Preliminary tests indicate improved penetration into solid steel. But, as noted in chapter 2, we cannot assume that penetration into solid steel accurately predicts penetration into modern composite armor. Further, since lethality depends on behind-armor effects (such as spalling) as well as penetration, we cannot assume that more penetration will mean a commensurate improvement in probability of kill. Further testing and field experience are required.

A critical degradation element is reactive armor—explosive plates that disrupt jet formation. None of the light weapons was designed to have a unique ability to defeat this countermeasure.

Rate of Fire

Our current and upgraded light weapons are disposable and intended to be used as rounds of ammunition. Gunners do not reload the launcher before firing more rounds. Thus, the maximum possible rate of fire is determined by the time it takes gunners to prepare (pull the safety pin, uncover the sight, and shoulder the round), aim and fire, and then repeat the process. The M72A3 and its E4 upgrade offer a relatively high rate of fire. The AT4 is more cumbersome—heavier and longer—so gunners need more time.

SMAW-HEAA will not be disposable. Gunners will reload the launcher and, to improve their aim, can fire spotting rounds (as many as 6 are available) before they fire the rocket. After using the spotting rifle, gunners must switch the firing mechanism to initiate the main round. The reloading procedure includes expending the launch tube for the first round, attaching another clip of spotting rounds, and locking in another rocket.

Actual rates of fire will vary greatly, depending on the circumstances, but these more complicated procedures may drive the benign rate of fire for SMAW-HEAA well below that for disposable weapons.

Human factors can degrade the rate of fire for any light weapon. Average gunners cannot match the rate of fire achieved by expert gunners, and the stress of combat degrades the ability to aim and fire accurately.

(Counterfire will often force gunners to move before refiring. We discuss this element in the following section on sustainability of fire.)

Sustainability of Fire

Under benign conditions, sustainability of fire is a function of carry weight. When gunners fire from prestocked positions, carry weight is not so critical. But when gunners carry rounds on foot over considerable distances, it is critical. With a lighter weapon, a squad can carry more rounds and therefore sustain fire for a longer time.

The M72A3, M72E4, and AT4 weigh 5.5 pounds, 7.2 pounds, and 14.6 pounds, respectively. Thus, when a squad's weight load is constrained (for example, when it is defending its position while moving between two battle areas), it can carry more M72A3 rounds than E4 rounds and more E4 rounds than AT4 rounds.

SMAW-HEAA will weigh 30 pounds. Since the launcher is reusable, gunners can get more than one shot per launcher. An extra round will weigh 14 pounds, so two rounds will impose a weight requirement of 44 pounds.

We have not compared sustainability of fire for disposable and reusable weapons because SMAW-HEAA will be carried by dedicated gunners. But weight differences may not affect sustainability of fire nearly so much as suppressive counterfire—a severely degrading element at short ranges. In many circumstances, counterfire will force gunners to move before they refire. Whether they move or not, gunners at these ranges will often be forced to keep their heads down.

Vulnerability to counterfire is similar for the M72A3, M72E4, and AT4. With the greater range of SMAW-HEAA, gunners may be somewhat less detectable. However, if they use the spotting rifle, they could be exposed longer and therefore find it more difficult to sustain fire.

Survivability

This factor is a function of attrition rates—how many gunners are likely to be disabled during an engagement. At short ranges, gunners for any light weapon are highly vulnerable to direct hits.

Light-weapon gunners are often detected while getting into their firing positions. If SMAW-HEAA gunners use the spotting rifle, they could be in firing positions longer than gunners using disposable weapons.

Quantitative Estimates

Quantitative data from DOD help to clarify the degree to which various elements can degrade the effectiveness of light weapons. We have entered data for the probabilities of hit and kill and for the rate of fire in tables 3.1 through 3.3. (Data for sustainability of fire and survivability are not extensive enough to permit tabular presentation.)

Probability of hit. The Army Materiel Systems Analysis Activity (AMSAA) reports a probability of hit of 0.20 for the M73A3 and 0.67 for the AT4, when used at 250 meters under benign conditions (see table 3.1). The "effective range" (that is, the range at which probability of hit under benign conditions equals 0.50) is approximately 180 meters for the M72A3 and 290 meters for the AT4. Probability of hit for the M72E4 upgrade will reportedly be 0.35 and its effective range, 220 meters.

Table 3.1: Probability of Hit for Light Weapons

		Degradation term			
Weapon	Benign estimate	Mission environment	Countermeasure	Human factor	Degraded estimate
M72A3	0.20	[a]	<0.56[b]	[a]	<0.11[b]
AT4	0.67	[a]	<0.82[b]	[a]	<0.55[b]
M72E4	0.35	[a]	[a]	[a]	<0.35[b]
SMAW-HEAA	[material deleted][c]	[a]	[a]	[a]	[material deleted][b]

[a]Data are unavailable.

[b]Data do not cover all elements that can degrade effectiveness. We have used the "<" (less than) symbol to indicate that the figure could decrease if missing elements were taken into account.

[c]Estimates are based on weapon requirements. Other estimates are based on actual or projected performance.

SMAW-HEAA requirements stipulate a probability of hit of [material deleted] at 250 meters. Its effective range will be approximately 370 meters. Its minimum-range requirement is 17 meters, comparable to the minimum range for our current light weapons. In 1983 tests by the Marine Corps Operational Test and Evaluation Agency, the current SMAW achieved a probability of hit of [material deleted] against targets smaller than tanks, so SMAW-HEAA representatives believe that their probability-of-hit requirement is feasible.

What do the available data tell us about probability of hit when conditions are not benign? AMSAA has estimated that probability of hit for the M72A3 is 0.11 against a moving tank at 250 meters, which suggests a degradation term of 0.56 for that weapon. (Degrading the 0.20 benign probability of hit by 0.56 produces a probability of hit of 0.11.) AMSAA's estimate for the AT4 is 0.55 against moving targets, suggesting a degradation term of 0.82. We found no estimates for probability of hit against moving targets for the M72E4 or SMAW-HEAA. We found no quantitative data on the effect of environmental elements, counterfire, or human factors for any of these weapons.

Because of the unquantified elements, we cannot compare degraded probability of hit estimates for light weapons. But DOD's partial data indicate that the degraded probability of hit may fall well below 0.11 for the M72A3, below 0.35 for the M72E4, below 0.55 for the AT4, and below 0.75 for the SMAW-HEAA.

Probability of kill. Estimates in table 3.2 represent the probability of a firepower or mobility kill at 250 meters, given a close-combat distribution of shots. (These terms are defined in chapter 2.) DOD often combines its estimates of probability of kill and probability of hit by reporting the probability of kill, given a shot. Since we have covered probability of hit separately, table 3.2 reports probability of kill, given a hit.

Table 3.2: Probability of Kill, Given a Hit, for Light Weapons[a]

		Degradation term			
Weapon	**Benign estimate**	**Mission environment**	**Countermeasure**	**Human factor**	**Degraded estimate**
M72A3					
T62	[material deleted]	b	c	b	[material deleted][d]
T72	[material deleted]	b	c	b	[material deleted][d]
AT4					
T62	[material deleted]	b	c	b	[material deleted][d]
T72	[material deleted]	b	c	b	[material deleted][d]
M72E4	c	b	c	b	c
SMAW-HEAA	c	b	c	b	c

[a]Estimates are based on actual or projected performance.

[b]For probability of kill, the study did not consider data on this degradation term.

[c]Data are unavailable.

[d]Data do not cover all elements that can degrade effectiveness. We have used the "<" (less than) symbol to indicate that the figure could decrease if missing elements were taken into account.

AMSAA's estimates of [material deleted]. AT4 appears more lethal. AMSAA's probability of kill estimates for the AT4 are [material deleted].

According to a 1985 AMSAA evaluation, the M72E4 upgrade may offer some improvement over the M72A3, but apparently it will not match the AT4.

SMAW-HEAA requirements do not stipulate a probability of kill against any particular target. Instead, there is a general requirement for depth of penetration—[material deleted] into rolled homogeneous armor (RHA). (SMAW developers wanted to avoid having to redesign and retest the weapon in response to changes in the estimated characteristics of threat tanks. The standing requirement for RHA penetration circumvents such changes.) Conclusive data are not yet available, but preliminary assessments indicate that SMAW-HEAA [material deleted]. As noted above, we cannot assume that penetration into RHA accurately predicts penetration into modern composite armor or that added penetration affords a commensurate improvement in probability of kill. For these reasons, we cannot enter a probability-of-kill estimate for SMAW-HEAA.

The AMSAA figures and the SMAW-HEAA requirement do not take into account the effect of reactive armor.

Rate of fire. Table 3.3 reports the limited data available. In a 1983 evaluation by the Army Missile Laboratory, the average time required for firing an M72A3 was 13.6 seconds, so the rate of fire was 4.4 rounds per minute. In the same evaluation, average gunners took 22.5 seconds to

Table 3.3: Rate of Fire for Light Weapons[a]

		Degradation term			
Weapon	Benign estimate	Mission environment	Countermeasure	Human factor	Degraded estimate[d]
M72A3	[b]	[c]	[c]	[b]	<4.40 per minute
AT4	[b]	[c]	[c]	[b]	<2.70 per minute
M72E4	[b]	[c]	[c]	[b]	<4.40 per minute
SMAW-HEAA	1.30 per minute	[c]	[c]	<0.46[d]	<0.60 per minute

[a]Estimates are based on actual or projected performance.

[b]Data are unavailable.

[c]For rate of fire, the study did not consider data on this degradation term.

[d]Data do not cover all elements that can degrade effectiveness. We have used the "<" (less than) symbol to indicate that the figure could decrease if missing elements were taken into account.

fire the AT4, a rate of fire of 2.7 rounds per minute. The M72E4 upgrade does not make any changes to our current A3 version that can be expected to increase rate of fire. (No estimates were available for the benign rate of fire—that is, the rate achieved by expert gunners. Since counterfire can force gunners to move before refiring, even these average rates of fire will often not be feasible in combat.)

As noted above, firing the SMAW-HEAA is a more complicated process. Gunners may load and fire the spotting rifle before they fire the main round. To refire, they lock another main round into the launcher. Marine Corps tests conducted in 1983 indicated that gunners who did not use the spotting rifle needed 16 seconds to prepare, aim, and fire. Reloading took another 60.3 seconds. Thus, to fire two rounds, gunners who do not need the spotting rifle would take 92.3 seconds—a rate of fire of 1.30 rounds per minute. Average gunners are more likely to need spotting rounds, which can add as many as 54 seconds to the firing time, reducing the rate of fire to 0.60 per minute.

Sustainability of fire. We have already reported the benign sustainability of fire, which is a function of carry weight. A critical degradation element is counterfire. In a 1985 field simulation at the Army Infantry School, 49 percent of the gunners carrying light weapons (the M72A3 or the AT4) were detected by a tank crew while getting into position to fire. The other 51 percent were detected after firing one round. Thus, even if gunners can get off one shot, it is likely that they will have to move before taking another shot. We found no corresponding data for SMAW-HEAA.

Survivability. In the 1985 Infantry School simulation, laser devices pinpointed the positions of 67 percent of M72A3 gunners and 59 percent of AT4 gunners, indicating a high probability of lethal counterfire.

Conclusions for Light Weapons

Table 3.4 summarizes our descriptive data, comparing light weapons on each effectiveness factor.

Table 3.4: Comparison of Light Weapons

Effectiveness factor	Comparison
Probability of hit	With the spotting rifle, SMAW-HEAA may be more accurate than the AT4 or either M72
Probability of kill	SMAW-HEAA, with its relatively large warhead and trumpet-shaped liner, may provide greater lethality than the AT4 or either M72
Rate of fire	The rate of fire may be lower for SMAW-HEAA than for the AT4 or either M72
Sustainability of fire	We have not compared sustainability for SMAW-HEAA, AT4, and either M72; counterfire can severely degrade sustainability for any light weapon
Survivability	There are no clear differences in survivability; gunners for the SMAW-HEAA, AT4, and either M72 face low survivability

SMAW-HEAA gunners will be able to use a spotting rifle. Thus, compared to other light weapons—the AT4 and the current and upgraded M72—SMAW-HEAA promises an improvement in probability of hit. However, the SMAW-HEAA rate of fire may be less than the rate of fire attainable with the other light weapons.

SMAW-HEAA may provide a higher probability of kill. Its trumpet-shaped warhead, larger than the warheads on either M72, will replace the conical warheads used with both M72's and the AT4. Tests indicate that the SMAW-HEAA warhead may be more lethal against solid-steel targets. We cannot be sure that it will be more lethal against modern-armor targets.

At short ranges, gunners using any of these weapons are highly vulnerable to counterfire, which can degrade both sustainability of fire and survivability.

Quantitative data on degradation effects were not available for most elements in the mission environment, nor for most countermeasures or human factors.

Medium Antitank Weapons

The weapons in this category include the current Dragon, its two upgrades (Dragon II and Dragon III), and the possible fiber-optic design (FOG-M) for the advanced antiarmor weapon system-medium.

Probability of Hit

With guided antitank weapons, the task is not simply to aim and fire; gunners must also track their targets until the rounds hit. Environmental elements, countermeasures, and human factors can interfere at any point in this sequence, making it more difficult to detect targets and to hit those already detected.

Probability of hit for our current medium weapon, Dragon, can be degraded severely under real or simulated battle conditions. A major difficulty is keeping the crosshairs of the sight on target. This "jitter" problem is compounded by evasive target movement and the disruptive effects of counterfire. It is further compounded by battlefield obscurants, which degrade both guidance and target detection. The thermal night sight is only a partial solution to this problem. The first Dragon upgrade (generation II) makes no guidance modifications, so we cannot expect any change in the probability of hit. Dragon III will reportedly improve the sight and add another 500 meters of range.

In a medium FOG-M, the fiber-optic cable will transmit signals from an infrared camera in the missile to the gunner's viewing screen. After sighting the target on the screen, the gunner can either lock onto that target or guide the missile to impact. A gunner may also select a flat- or lofted-trajectory launch. A flat trajectory will enable gunners to hit targets that are protected overhead (under a bridge, for example). The maximum range for a lofted-trajectory launch will be [material deleted]; for a flat-trajectory launch, 1,000 meters.

The lofted trajectory would take FOG-M above the battlefield and so may reduce the degradation from obscurants—what Dragon cannot see through, FOG-M may see over. Heavy fog and smoke may still degrade FOG-M somewhat, especially when the launch trajectory is flat. Counterfire may degrade FOG-M as well, more so when the trajectory is flat because gunners would be within 1,000 meters of their targets. But if the lofted trajectory reduces the effects of obscurants and counterfire, FOG-M may improve the likelihood of detecting and hitting targets.

Probability of Kill

Dragon appears [material deleted].

The medium FOG-M [material deleted] against these targets, because of changes in the attack angle. With a lofted trajectory, FOG-M will dive steeply toward its target. Thus a shot from any direction, even head-on, will hit the thinner armor on top of the tank. [Material deleted], however. The medium FOG-M may face new countermeasures, possibly an [material deleted] that degrades top-attack and tank fuels and munitions that are less likely to explode.

Rate of Fire

Medium FOG-M requirements call for a minimum rate of fire of 1.50 shots per minute with a goal of 3.00 shots per minute if possible. The mission environment problems that can degrade FOG-M's probability of hit, such as thermal clutter, can also break its lock. Thus gunners may have to guide many shots manually until impact, slowing the firing process and making it unlikely that FOG-M will exceed the minimum requirement of 1.50 shots per minute.

The rate of fire achieved by expert Dragon gunners, under benign conditions, exceeds the FOG-M requirement. But both FOG-M and Dragon are subject to human factors—combat stress and variability in gunners' skills—that degrade the benign rate of fire. With the limited information available, we were not able to determine whether either weapon is less susceptible than the other to these elements.

Sustainability of Fire

As mentioned earlier in the text, this effectiveness factor is a function of carry weight. For Dragon and Dragon II, the tracker and one round weigh approximately 50 pounds. For Dragon III, equipped with an integrated day-night sight, those components will weigh approximately 43 pounds. Other components such as the coolant and battery add at least another 5 pounds. Thus, if a medium FOG-M meets its requirement of 45 pounds, it will weigh 10 pounds less than Dragon or Dragon II.

Suppressive counterfire can degrade sustainability of fire by forcing gunners to keep their heads down and move before taking another shot. Firing is particularly difficult for Dragon and Dragon II gunners since they must remain exposed, at a maximum range of 1,000 meters, while they aim, fire, and guide the round to impact. The effect on Dragon III, with its longer range and faster missile, may be less severe.

FOG-M gunners will be able to stay prone and fire from [material deleted], but they will not be invulnerable, especially if they need a flat-trajectory shot. Developers are considering a "remote launch" design in which the gunner and launch platform can be set some distance apart. This capability could reduce the suppressive effect of counterfire but could add another 30 pounds to the carry weight.

If FOG-M can meet its weight and range requirements, its sustainability of fire under degraded conditions may surpass the sustainability of fire for any version of Dragon.

Survivability

The same problems govern survivability for both Dragon and FOG-M. At the ranges afforded by Dragon, gunners are subject to attrition from direct fire as well as indirect fire. Dragon II makes no changes in range likely to affect survivability. However, Dragon III, by adding range and increasing the missile's flight velocity, may reduce attrition to some degree.

Survivability may improve with FOG-M, if gunners fire from longer ranges and have a remote-launch capability. But survivability will suffer if counterfire is intense.

Quantitative Estimates

Quantitative data from DOD are, as noted above, tentative and subject to revision, but they indicate the approximate degree to which degradation factors may reduce the effectiveness of medium weapons. We have entered data for the probabilities of hit and kill and for rate of fire in tables 3.5 to 3.7.

Probability of hit. As shown in table 3.5, the latest AMSAA estimates of probability of hit under benign conditions are [material deleted] for Dragon and [material deleted] for FOG-M. Specifications for current and future medium weapons set the minimum range at 65 meters.

Table 3.5: Probability of Hit for Medium Weapons

		Degradation term			
Weapon	**Benign estimate**	**Mission environment**	**Countermeasure**	**Human factor**	**Degraded estimate**
Dragon	[material deleted]	[material deleted][a]	[material deleted][a]	[material deleted][b]	[material deleted][a]
Dragon II	[material deleted]	[material deleted][a]	[material deleted][a]	[material deleted][b]	[material deleted][a]
Dragon III	c	c	c	c	c
FOG-M	[material deleted]	[material deleted][a]	[material deleted][d]	[material deleted][b]	[material deleted][a]

[a]Data do not cover all elements that can degrade effectiveness. We have used the "<" (less than) symbol to indicate that the figure could decrease if missing elements were taken into account.

[b]Estimates are based on weapon requirements. Other estimates are based on actual or projected performance.

[c]Data are unavailable.

[d]Estimates are specified in the weapon requirements. Data do not cover all elements that can degrade effectiveness. We have used the "<" (less than) symbol to indicate that the figure could decrease if missing elements were taken into account.

To what degree can the mission environment degrade probability of hit for these weapons? In a 1981 study by the Institute for Defense Analyses, dust from artillery fire reduced Dragon's probability of hit to [material deleted], suggesting a degradation term of 0.63 for this element. (Degrading [material deleted] by 0.63 produces a probability of hit of [material deleted].) We found no other quantitative data on obscurants for either Dragon or FOG-M.

Elements such as these can also render target detection problematic. We found no data on this point for Dragon. A 1986 AMSAA analysis for FOG-M projected a [material deleted] probability of finding a specific target. If FOG-M's benign probability of hit is [material deleted], then the degradation term for elements in the mission environment is [material deleted], reduced further by unquantified elements.

How severely can countermeasures degrade effectiveness? A 1979 study by the Army's Human Engineering Laboratory found that simulated counterfire decreased Dragon's probability of hit against moving targets to [material deleted]. FOG-M requirements allow degradation terms no worse than 0.70 for [material deleted] and 0.80 for "target signature suppression," or the attempt to mask characteristics of the target. If we consider the effects of [material deleted] and other unquantified elements, we can expect the countermeasure degradation for FOG-M to be worse than 0.56.

The effect of human factors may also be substantial. We found no quantitative data for Dragon. FOG-M requirements set a degradation term of [material deleted] for human factors; we adopted that figure for FOG-M and Dragon.

When we multiply benign estimates by their degradation terms, we begin to see the degree to which battlefield conditions may degrade the performance of medium weapons. Without quantification of all possible elements, we cannot compare weapons directly, but the degrading effect on each is drastic. As shown in table 3.5, Dragon's probability of hit drops from [material deleted], even assuming that the gunners can find targets. When we take into account the target detection problem, as well as other degrading elements, FOG-M's probability of hit drops from [material deleted].

Probability of kill. Table 3.6 shows DOD's estimated probabilities of getting a mobility or firepower kill, assuming a cardioid distribution of shots. [Material deleted.] In each case, reactive armor will [material deleted]. The few data available on probability of kill against the frontal glacis (not shown in table 3.6) [material deleted].

Table 3.6: Probability of Kill, Given a Hit, for Medium Weapons[a]

		Degradation term			
Weapon	Benign estimate	Mission environment	Countermeasure	Human factor	Degraded estimate
Dragon					
T54	[material deleted]	[b]	[c]	[b]	[material deleted][d]
T62	[material deleted]	[b]	[c]	[b]	[material deleted][d]
T72	[material deleted]	[b]	0.76	[b]	[material deleted]
Dragon II					
T72	[material deleted]	[b]	0.70	[b]	[material deleted]
T80	[material deleted]	[b]	0.68	[b]	[material deleted]
Dragon III					
T72	[material deleted]	[b]	0.72	[b]	[material deleted]
T80	[material deleted]	[b]	0.70	[b]	[material deleted]
FOG-M					
T72	[c]	[b]	[c]	[b]	[material deleted]

[a]Estimates are based on actual or projected performance.

[b]For probability of kill, the study did not consider data on this degradation term.

[c]Data are unavailable.

[d]Data do not cover all elements that can degrade effectiveness. We have used the "<" (less than) symbol to indicate that the figure could decrease if missing elements were taken into account.

For FOG-M, AMSAA has estimated a cardioid probability of hit of [material deleted].

Rate of fire. It takes 16 seconds for expert gunners to fire Dragon and Dragon II, including approximately 11 seconds for the flight to maximum range (1,000 meters). Reloading takes at least 25 seconds. Thus, the maximum rate of fire for Dragon is 1.84 rounds per minute under benign conditions (see table 3.7). With a faster missile, Dragon III may improve the rate of fire to 2.25 rounds per minute at 1,000 meters. (Its maximum range requirement is 1,500 meters.)

Table 3.7: Rate of Fire for Medium Weapons

Weapon	Benign estimate	Degradation term: Mission environment	Degradation term: Countermeasure	Degradation term: Human factor	Degraded estimate[a]
Dragon	1.84 per minute	[b]	[b]	<0.23[a]	<0.43 per minute
Dragon II	1.84 per minute	[b]	[b]	<0.23[a]	<0.43 per minute
Dragon III	2.25 per minute	[b]	[b]	<0.20[a]	<0.45 per minute
FOG-M	1.50 per minute[c]	[b]	[b]	[d]	<1.50 per minute

[a]Data do not cover all elements that can degrade effectiveness. We have used the "<" (less than) symbol to indicate that the figure could decrease if missing elements were taken into account.

[b]For rate of fire, the study did not consider data on this degradation term.

[c]Estimate is based on weapon requirements. Other estimates are based on actual or projected performance.

[d]Data are unavailable.

Program office estimates for gunners with average skills decrease the maximum rate of fire to 0.43 rounds per minute for Dragon and Dragon II and to 0.45 rounds per minute for Dragon III. We found no data quantiying the effect of combat stress.

As noted above, FOG-M gunners may often need to guide rounds manually—a task that will, according to DOD projections, [material deleted]. We found no data on degradation by human factors of FOG-M's rate of fire.

Sustainability of fire. We have already reported the carry weight for each weapon. We found no quantitative data on the degree to which suppressive counterfire can degrade sustainability for Dragon or FOG-M gunners.

Survivability. A 1983 study by the Institute for Defense Analyses estimated direct-fire attrition for Dragon gunners in European scenarios to be between 20 percent and 33 percent for each shot. Indirect fire could add to this figure. We found no estimates of possible FOG-M attrition due to counterfire.

Conclusions for Medium Weapons

As indicated by our descriptive data, FOG-M may offer improvements in four effectiveness factors (see table 3.8). These conclusions are, of course, tentative. If DOD decides to develop a medium FOG-M, its capabilities will become more clear with testing and field experience.

Table 3.8: Comparison of Medium Weapons

Effectiveness factor	Comparison
Probability of hit	Flying above the battlefield, FOG-M may provide a higher probability of hit than the current or upgraded Dragon
Probability of kill	FOG-M will attack the thinner armor on top of enemy tanks and may therefore provide a higher probability of kill than any Dragon
Rate of fire	Under benign conditions, Dragon's rate of fire exceeds the FOG-M requirement; we cannot compare the degraded rates of fire for these weapons
Sustainability of fire	With more range and a remote launch, FOG-M may be less susceptible to suppressive counterfire
Survivability	With more range and a remote launch, FOG-M provides more survivability than any Dragon

FOG-M may enable gunners to detect and hit targets more often than Dragon gunners can because of FOG-M's flight above the battlefield. A steep-dive angle may also improve lethality since FOG-M will attack the thinner armor on top of tanks. However, when gunners select a flat-trajectory launch to hit targets protected by overhead cover, FOG-M loses these advantages.

Under benign conditions, Dragon's rate of fire exceeds the FOG-M requirement. We were not able to compare rates of fire for these weapons under degraded conditions.

Finally, FOG-M's added range and the possible remote launch may leave gunners less susceptible to counterfire and thereby provide a higher sustainability of fire and survivability than any version of the Dragon.

DOD's quantitative estimates are, to reiterate, partial and tentative. We have no data on the degradation of probability of hit for some elements in the mission environment or for some countermeasures. Regarding human factors, we have only the AAWS-M requirements. Still, even the partial data indicate that battlefield conditions may severely degrade probability of hit for any weapon in this category.

Data concerning probability of kill and rate of fire were more complete and again suggest that the relevant degradation elements may reduce performance substantially.

For the last two effectiveness factors, sustainability of fire and survivability, we found few quantitative data.

Heavy Antitank Weapons

The weapons in this category are the TOW2, its planned upgrades (TOW2A and TOW2B), and the fiber-optic (FOG-M) design for an advanced antiarmor weapon system-heavy.

DOD has not fully specified its requirements for the future heavy weapon. In this analysis, we assumed that a heavy FOG-M might resemble the medium version, or the non-line-of-sight FOG-M already in development, or some combination of the two. It may also retain some features of the current TOW. Specifically, we considered these design options for a heavy FOG-M:

- range at least 5 kilometers or as many as 10 kilometers;
- guidance technology—television or infrared;
- launch trajectory—flat, lofted, or vertical; and
- firing doctrine—single or multiple rounds.

Probability of Hit

The TOW2 thermal tracker was designed specifically to improve probability of hit when subject to smoke and enemy jamming, but these and other problems have not disappeared entirely. Environmental elements such as dust and haze, as well as smoke, degrade TOW2's probability of hit to some extent. Line-of-sight problems make it difficult to find targets. Countermeasures—[material deleted]. Since neither of the TOW2 upgrades will change the tracker, these problems will continue.

On a lofted trajectory, FOG-M may see over some battlefield obscurants and improve the lines of sight. The same advantage accrues to a FOG-M that is launched vertically and then pitches over for the flight downrange. A further advantage is that the fiber-optic signal cannot be jammed. Nevertheless, the mission environment may at times pose problems. If the heavy FOG-M uses a television camera, it will be difficult to find and hit targets through smoke, haze, or fog—and very difficult at night. An infrared camera can ameliorate these conditions but will also be affected by heavy smoke and fog. In urban areas or broken terrain, gunners might not find suitable targets with either type of camera.

At a range of at least 5 kilometers (compared to a TOW2 range under 4 kilometers), FOG-M gunners may be somewhat less vulnerable to counterfire. The non-line-of-sight FOG-M will reportedly provide at least 10 kilometers in range, and its vertical launch will enable gunners to maintain cover and concealment. If a FOG-M replacement for TOW2 can take advantage of these capabilities, gunners might be considerably less vulnerable to counterfire.

Overall, FOG-M may improve the probability of hit. Its flight above the battlefield may improve gunners' ability to hit targets already detected and their ability to find targets in the first place. Deployment at ranges well beyond TOW2 ranges could reduce the gunners' susceptibility to counterfire.

Probability of Kill

TOW2's warhead is reportedly [material deleted]. DOD hopes to maintain TOW lethality into the 1990's with TOW2B, which will aim at the tops of enemy tanks, thus avoiding the heavily armored frontal glacis.

FOG-M will also hit the top of the tank. For this reason, FOG-M, like TOW2B, might improve heavy-weapon lethality. However, these weapons may face new countermeasures, such as [material deleted] and tank fuels and munitions that are less likely to explode.

Rate of Fire

Developers have not specified a rate of fire for the future heavy weapon, so we cannot compare TOW2 and the heavy FOG-M on this factor. Current plans for the non-line-of-sight FOG-M call for a launch platform accommodating at least 10 rounds, to be fired in volleys. If the TOW2 replacement also fires in volleys, can a gunner effectively control the multiple rounds? There are at least four possible problems.

First, the tracker's lock may be broken by mission environment elements such as thermal clutter and by countermeasures such as [material deleted]. A gunner who has locked onto a target may have to reacquire it and lock on again. Thus, an orderly sequence of hits at short intervals could break down.

Second, television trackers can use a zoom lens, providing an unbroken transition from wide to narrow field of view, but they are not effective at night. To compound the problem, infrared trackers that can be used at night cannot use a zoom lens, forcing gunners to switch abruptly from wide to narrow fields of view, possibly losing targets. In short, neither option always provides a rapid and orderly targeting sequence.

Third, the gunner can use the later rounds of a volley to survey the battlefield and to assess damage. While such a capability is feasible and desirable, it may force gunners to space their rounds farther apart.

Finally, the rate of fire depends partly on whether gunners will know where to find suitable targets. If targets are within the line of sight, this may not be a problem. But if the heavy weapon takes advantage of the extra range afforded by fiber optics, suitable targets could be well beyond the line of sight, and gunners would need target information from other sources—a scout vehicle or forward observer, for example. In actual combat, this information may be inaccurate, late, or unavailable.

None of these problems is unlikely, and as they mount, a FOG-M gunner may find it difficult to juggle rounds. Careful testing will provide estimates of the effects of these problems.

Sustainability of Fire

A dismounted TOW (all versions) weighs approximately 270 pounds. Requirements for the future heavy weapon set a maximum of 175 pounds—a considerable advantage in sustainability of fire if gunners dismount.

At TOW's maximum range (under 4 kilometers), counterfire can degrade sustainability of fire by forcing gunners to move, even if they have not dismounted. Deployed at 10 kilometers, FOG-M gunners may be less subject to counterfire than TOW gunners, and a vertical launch would allow FOG-M gunners to maintain cover and concealment. If FOG-M's maximum range is 5 kilometers and its launch is not vertical, its advantage in sustainability of fire over TOW will decrease.

Survivability

TOW gunners are vulnerable to attrition from direct and indirect counterfire. FOG-M gunners may be less vulnerable if they fire from under cover at extended ranges.

Quantitative Estimates

To illustrate the degree to which degradation factors may reduce effectiveness, we provide the available data on the probabilities of hit and kill and rate of fire in tables 3.9 to 3.11.

Probability of hit. The latest AMSAA estimate of probability of hit for TOW2 is [material deleted] under benign conditions; for the heavy FOG-M, [material deleted] against stationary and moving targets (see table 3.9). TOW2's minimum range is reportedly 65 meters. The minimum-range specification for the future heavy weapon has not been set.

Table 3.9: Probability of Hit for Heavy Weapons

		Degradation term			
Weapon	Benign estimate[a]	Mission environment[b]	Countermeasure[b]	Human factor	Degraded estimate[b]
TOW2	[material deleted]	[material deleted]	[material deleted]	[material deleted]	[material deleted]
TOW2A	[material deleted]	[material deleted]	[material deleted]	[material deleted]	[material deleted]
TOW2B	[material deleted]	[material deleted]	[material deleted]	[material deleted]	[material deleted]
FOG-M	[material deleted]	[material deleted]	[material deleted]	[material deleted]	[material deleted]

[a]Estimates are based on actual or projected performance. Other estimates are based, in part, on weapon requirements.

[b]Data do not cover all elements that can degrade effectiveness. We have used the "<" (less than) symbol to indicate that the figure could decrease if missing elements were taken into account.

To what degree can the three degradation factors reduce these figures? Regarding the mission environment, TOW2 requirements allowed a probability of hit of [material deleted] in smoke. A 1986 AMSAA analysis considered the effect of environmental elements on target detection for TOW2 and FOG-M. The analysis indicated that, given 60 seconds to find a fully exposed target, TOW2's chances at 3,000 meters—in smoke, fog, or haze—are [material deleted]. Flying above the battlefield, FOG-M's chances of hitting a target at any range are, according to AMSAA, [material deleted].

Regarding countermeasures, TOW2 requirements set a probability of hit of [material deleted] under various jamming conditions. Relevant requirements for the future medium weapon will be applied to the heavy weapon as well. Those requirements allow a probability of hit as [material deleted] and target signature suppression. AMSAA estimates a probability of hit of [material deleted] against moving targets for TOW2. (AMSAA's benign estimate for FOG-M already covers moving targets.) For other countermeasures, such as decoys and counterfire, we found no quantitative data.

The medium-weapon requirements allow a degradation term of [material deleted] for human factors such as gunner's skill and stress. We applied this term to all TOW2 versions and FOG-M.

Taken together, the degradation terms decrease TOW2's probability of hit to less than [material deleted] under benign conditions. Since TOW2 upgrades will not change the tracker, we entered the same figures for TOW2A and 2B. FOG-M's probability of hit decreases [material deleted]. Because of data limitations, we cannot use these figures for any precise comparison of degraded capabilities. But the figures do indicate, once again, the severe degree of possible degradation.

Probability of kill. Degraded probabilities of a mobility or firepower kill, given a cardioid distribution of hits, fall between [material deleted] for TOW2 and TOW2A (see table 3.10). Because it will attack the thinner armor on top of Soviet tanks, TOW2B may provide a higher probability of kill.

Table 3.10: Probability of Kill, Given a Hit, for Heavy Weapons

		Degradation term			
Weapon	**Benign estimate**	**Mission environment**	**Countermeasure**	**Human factor**	**Degraded estimate**
TOW2					
T72	[material deleted]	[a]	0.72	[a]	[material deleted]
T80	[material deleted]	[a]	0.79	[a]	[material deleted]
FST	[material deleted][b]	[a]	[b]	[a]	[material deleted]
TOW2A					
T72	[material deleted]	[a]	0.83	[a]	[material deleted]
T80	[material deleted]	[a]	0.84	[a]	[material deleted]
FST1	[material deleted][b]	[a]	[b]	[a]	[material deleted]
TOW2B					
T80	[material deleted]	[a]	[c]	[a]	[material deleted]
FST1	[b]	[a]	[b]	[a]	[material deleted]
FOG-M					
T72	[d]	[a]	[d]	[a]	[material deleted]
FST1	[b]	[a]	[b]	[a]	[material deleted][e]

[a]For probability of kill, the study did not consider data on this degradation term.

[b]Data are not relevant.

[c]No degradation is expected for this weapon.

[d]Data are unavailable.

[e]Estimate is based on weapon requirements. Other estimates are based on actual or projected performance.

We can also report probability-of-kill estimates for shots at the frontal glacis of a future Soviet tank (FST1). The estimates (not shown in table 3.10) are [material deleted]. Again, because of its ability to hit the tops of enemy tanks, TOW2B may be [material deleted]. These estimates are highly tentative, since [material deleted]. However, frontal-kill estimates for TOW2 against the current T72 and T80 are [material deleted].

We obtained figures for FOG-M's cardioid probability of kill against two of these targets. The figures in table 3.10 [material deleted].

Rate of fire. It takes at least 24.2 seconds for gunners to fire the TOW2, including a flight time of 20 seconds to TOW2's maximum range (3,750 meters). The reload time is at least 22.5 seconds. These figures suggest a maximum rate of fire of 1.53 rounds per minute for expert gunners (see table 3.11). The rate of fire for average gunners is about 0.59 rounds per minute. We found no data on the effect of stress.

Table 3.11: Rate of Fire for Heavy Weapons

		Degradation term			
Weapon	Benign estimate	Mission environment	Countermeasure	Human factor	Degraded estimate[b]
TOW2	1.53 per minute	[a]	[a]	<0.39[b]	<0.59 per minute
TOW2A	1.53 per minute	[a]	[a]	<0.39[b]	<0.59 per minute
TOW2B	1.53 per minute	[a]	[a]	<0.39[b]	<0.59 per minute
FOG-M	3.00 per minute	[a]	[a]	[d]	<3.00 per minute

[a]For rate of fire, the study did not consider data on this degradation term.

[b]Data do not cover all elements that can degrade effectiveness. We have used the "<" (less than) symbol to indicate that the figure could decrease if missing elements were taken into account.

[c]Estimates are based on weapon requirements. Other estimates are based on actual or projected performance.

[d]Data are unavailable.

Sustainability of fire. We have already reported weights for TOW and FOG-M. We found no quantitative data on the suppressive effects of counterfire.

Survivability. A 1986 AMSAA analysis set the attrition rate for vehicle-mounted TOW2 "fire units" (gunners and platforms) at between 20 percent and 85 percent, depending on force ratios and visibility conditions.

Conclusions for Heavy Weapons

Our descriptive (nonquantitative) data suggest that a heavy FOG-M may improve performance in four effectiveness factors (see table 3.12). These conclusions remain tentative. If DOD decides to develop a heavy FOG-M, its capabilities will become more clear with testing and field experience.

Table 3.12: Comparison of Heavy Weapons

Effectiveness factor	Comparison
Probability of hit	With more range and a flight above the battlefield, FOG-M may provide a higher probability of hit than the current or upgraded TOW2
Probability of kill	FOG-M and TOW2B will attack the thinner armor on top of enemy tanks and may therefore provide a higher probability of kill than TOW2 or TOW2A
Rate of fire	We cannot compare rates of fire for TOW2 and FOG-M; but battlefield conditions and tactics may degrade FOG-M's rate of fire
Sustainability of fire	FOG-M may weigh less than any version of TOW2; it may be less susceptible to suppressive counterfire, especially if gunners can fire under cover from extended ranges
Survivability	FOG-M may provide more survivability than any version of TOW2, especially if gunners can fire under cover from extended ranges

With its greater range and its ability to fly above the battlefield, FOG-M may enable gunners to find and hit targets more often than TOW gunners can. A steep dive angle may also improve lethality since FOG-M will attack the thinner armor on top of tanks. (TOW2B will also be designed to attack the tops of tanks.)

We cannot compare rates of fire for FOG-M and the current or upgraded TOW. Battlefield obscurants and tactics could make it difficult for FOG-M gunners to keep track of multiple rounds.

Finally, DOD is designing the non-line-of-sight FOG-M to reach targets well past 5 kilometers. Its vertical launch will reportedly enable gunners to fire when under cover. If these capabilities prove feasible for the TOW2 replacement, gunners would be less susceptible to counterfire. In short, the heavy FOG-M may provide a higher sustainability of fire and survivability than any version of TOW.

Turning to DOD's quantitative estimates, we found no data on the degradation of probability of hit by some elements in the mission environment or by some countermeasures. For human factors, we had to base our estimates on weapon requirements, not performance estimates. The partial data indicated that battlefield conditions can markedly degrade probability of hit for FOG-M as well as for other heavy weapons.

Data concerning probability of kill, though still tentative, were more complete; for all weapons deployed or in development, we found estimates for probability of kill.

Using TOW test results, we were able to estimate the degree to which TOW's rate of fire may be degraded. But we found no comparable projections or test results specific to FOG-M.

For the last two effectiveness factors, sustainability of fire and survivability, we found few quantitative data.

European Weapons

In the attempt to maximize probability of kill, some countries have adopted light and medium weapons with larger warheads than current U.S. weapons. The Federal Republic of Germany has built an unguided rocket, Panzerfaust 3, with a 110-millimeter warhead. France has several weapons of this sort in production or development. Its unguided weapon, Apilas, has a warhead measuring 112 millimeters. The guided short-range antitank (Anti-Char Courte Portée or ACCP) missile, which has a 135-millimeter warhead, is now in development, along with two unguided weapons.

We obtained lethality data on larger European weapons from contractors' reports and DOD test reports. Table 3.13 lists the weapons on which the data were sufficient for our purpose.

Table 3.13: European Infantry Antitank Weapons

Weapon and producer	Warhead size (millimeters)	Weight (in pounds)	Penetration (in millimeters)
Current weapons			
Panzerfaust 3, West Germany	110	26	[material deleted]
Apilas, France	112	20	[material deleted]
Weapons in development			
Jupiter, France	115	26	[material deleted]
Dard 120, France	120	32	[material deleted]
ACCP, France	135	47	[material deleted]

Do larger warheads provide more lethality? The indicator of lethality for which we have current data on all weapons is the depth of penetration into solid steel, or rolled homogeneous armor. RHA is the material used in first-generation Soviet tanks (the T34, T54, and T62). [Material deleted.]

The added penetration has its price—larger warheads are heavy. In the unguided category, all of these weapons outweigh our disposable M72A3 and AT4. In the guided category, ACCP will reportedly weigh about the same as Dragon and Dragon II but outweigh Dragon III.

Does added penetration mean a higher probability of kill? As we noted in the SMAW-HEAA assessment, performance against RHA is not a reliable indicator of performance against modern composite armors. Further, warhead lethality depends partly on effects behind the armor (such as fire and spalling), so added penetration does not guarantee a commensurate increase in probability of kill. Finally, since a warhead's performance against modern targets depends on the depth and composition of each layer of armor, we cannot assume that a higher probability of kill against one target guarantees a higher probability of kill against another.

In summary, larger warheads add weight to achieve more penetration into solid steel, but this added penetration does not necessarily increase lethality. We have no current data that can be used to assess the performance of these European weapons against modern armor or their probability of kill against particular Soviet tanks.

Weapons Mix

The distinction between light, medium, and heavy weapons has evolved in the attempt to maximize the capabilities of current technology within the constraints imposed by infantry operations. DOD wanted a light tank-killer, issuable as a round of ammunition. As modern armors became tougher, the M72—already inaccurate past point-blank range—lost punching power as well. It became a "last ditch" self-defense weapon. DOD also developed a medium weapon, the Dragon, so soldiers would have an effective, portable tank-killer. Reportedly, the Dragon [material deleted]. The vehicle-mounted TOW has become our primary tank-killer. [Material deleted.]

New technologies offer not only a possible "leap ahead" against Soviet armor but also an opportunity to rethink the current weapons mix.

First, the Army does not consider the M72A3 and AT4 to be antitank weapons for any purpose other than self-defense because they cannot penetrate the frontal glacis of modern Soviet tanks and produce lethal behind-armor effects. It is unlikely that any foreseeable light, flat-trajectory weapon will be able to do so. This observation holds true even if we increase the weight allowance to 20 pounds and take full advantage of warhead technologies such as trumpet-shaped liners. However, some light weapons appear quite capable of penetrating the flanks or rear of modern tanks, as well as the frontal armor under the glacis. Gunners consider flank shots to be ideal and often get an opportunity to shoot at the flanks or rear. Over half of the shots in the cardioid and close-combat distributions—both based partly on combat experience—hit outside the tank's 60-degree frontal arc. Moreover, Army and Marine Corps tactics still promote the use of light weapons against tanks when circumstances are favorable—when gunners can fire at the flanks, at close range, or, in urban fighting, from upper stories.

If we pursue the unlikely prospect of frontal kills, we must design light weapons for maximum penetration. In the past, we have done so by designing warheads to produce a long, thin jet of metal. The drawback to this approach is that the jet, after it penetrates, may do relatively little damage inside of the tank.

If, instead, we forgo frontal kills, we can design light weapons with thicker jets, composed of materials that create more spall fragments, fire, and overpressure. Such weapons could still penetrate modern tanks at spots other than the frontal glacis but could also cause more damage behind the armor. This may enhance their lethality over current light weapons—perhaps enough to go beyond mere self-defense. In developing future weapons, such as MPIM and the possible adaptation of SMAW's antitank round to the AT4, we will need to consider fully the trade-offs between penetration and behind-armor effects and the technical potential for increasing behind-armor damage.

Second, the capabilities of a heavy FOG-M may prompt a reconsideration of doctrine. According to plans for the non-line-of-sight FOG-M, gunners will fire volleys from full cover, remaining several kilometers beyond line-of-sight ranges. Rounds will fly above battlefield obscurants and provide reconnaissance useful in targeting later rounds. What will such capabilities mean for the future mix of U.S. infantry antitank weapons? Should our heavy line-of-sight weapon take advantage of those capabilities? Should we drop it altogether? In either case, what will be the infantry's future role in fighting tanks, and how will infantry and noninfantry operations be coordinated? Anticipating these questions, some DOD sources speak of deploying fiber-optic weapons well within the maximum possible range—perhaps at [material deleted]—costing those weapons much of their potential. Although we cannot get answers to these questions now, it is important to recognize that a heavy FOG-M has implications for a wide range of doctrinal and procurement decisions.

Chapter Summary

It has not been possible to develop quantitative estimates of effectiveness for each weapon under the full range of battlefield conditions. Precise estimates were not available for many degradation elements, and we cannot be sure that estimates are accurate. Projections of future capabilities pose particular problems.

The data indicate, nonetheless, how severely battle conditions degrade a weapon's performance. Even without data on all elements, we found that performance estimates for our current medium and heavy weapons decreased substantially. For Dragon, the product of the probabilities of hit and kill decreased from a benign estimate of [material deleted].

This drastic degradation in performance may be inevitable. Data for the medium and heavy versions of the future FOG-M suggest a degraded estimate of performance of [material deleted]. Clearly, we cannot expect to deploy antitank weapons that are immune to these adverse elements. The goal is to design weapons that resist degradation more effectively than our current weapons.

Because the quantitative data are partial and tentative, we based our conclusions on descriptive (nonquantitative) information. What enhancements are promised by the future weapons? The SMAW-HEAA spotting rifle—not a new technology—may provide a higher probability of hit than our current light weapons. We may also see an improved probability of kill against older tanks because of the trumpet design of the warhead. Without testing and field experience, though, we cannot be fully confident of SMAW-HEAA's probability of kill against modern tanks.

The same restriction applies to our assessment of weapons being developed outside the United States. Larger warheads reportedly achieve more penetration into solid steel than our current light and medium weapons, but we were unable to assess their lethality against modern tanks.

A medium or heavy FOG-M may improve performance in four of the effectiveness factors. Television or infrared guidance is not unique to FOG-M but when combined with FOG-M's capability to fly above the battlefield may increase the likelihood of detecting targets. In addition, the steep dive angle enables the missile to attack the thinner armor on top of the tank. (TOW2B also promises a higher probability of kill with a top-attack strategy.) On the negative side, limitations imposed by the guidance technology, obscurants, and countermeasures may reduce the rate of fire by forcing FOG-M gunners to reacquire targets and guide rounds manually. Battlefield tactics may further reduce rate of fire. However, if the medium FOG-M exceeds TOW2's range and has a remote-launch capability, gunners may be less susceptible to enemy fire. Finally, if the heavy FOG-M is deployed at ranges out to 10 kilometers, gunners may be considerably less vulnerable to counterfire.

Communication

The development of new weapons requires communication among the many DOD elements working with advanced technologies. In addition, management and oversight require that lessons learned during development be relayed not just to elements inside DOD but also to congressional reviewers. Such communication can reduce duplication of effort and, more importantly, reduce the time spent on technical alternatives that ultimately do not perform up to specification in the intended environment. In this chapter we cover our final two questions:

What information regarding new antitank technologies has been communicated across technical levels in DOD, such as labs, test centers, and program offices?

What information regarding new antitank technologies has been communicated by DOD to the Congress?

For reasons covered under "scope" in chapter 1, we focus on communication regarding two future weapons—the fiber-optic guided missile (FOG-M) and the shoulder-launched multipurpose assault weapon equipped with its high-energy antiarmor warhead (SMAW-HEAA).

Procedures

Communication in DOD

To gather technical information relevant to fiber optics and warhead technologies, we consulted DOD and non-DOD sources. The DOD sources include

- reports from service labs—for example, the Army's Ballistics Research Laboratory and the Army's Missile Command, Guidance, and Control Directorate;
- reports from testing organizations such as the operational test and evaluation agencies for the Army and Marine Corps, the Army Materiel Systems Analysis Activity, and the Center for Naval Analyses;
- program-office materials including test plans and results and weapon requirements;
- technical experts at the Institute for Defense Analyses, the Defense Advanced Research Projects Agency, and other organizations; and
- requirements analysts and weapons acquisition administrators.

Our sources outside of DOD include

- technical journals,
- nontechnical defense journals,
- weapons developers formerly with DOD,
- contractors, and
- experts in fiber optics and warhead design.

These sources provided information on previous, current, and future infantry antitank weapons, plus generic information on relevant technologies such as infrared guidance and fiber optics. (Our information on fiber optics covered several possible versions of FOG-M—medium, heavy, line-of-sight, and non-line-of-sight.) The sources also covered weapons that use technologies relevant to infantry antitank weapons but intended for other purposes, such as the television- and infrared-guided Maverick missiles and the GBU-15 glide bomb. Table 4.1 lists these additional weapons.

Table 4.1: Additional Weapons and Relevant Technologies

Service	Weapon	Type	Guidance technology[a]
Army	Hellfire	Missile	Infrared
Navy	Mark 48 ADCAP	Torpedo	Copper wire
	Condor	Missile	Television
	Harpoon	Missile	Infrared
	Walleye	Glide bomb	Television, infrared
Air Force	AGM-130	Glide bomb	Television, infrared
	GBU-15	Glide bomb	Television, infrared
	Maverick	Missile	Television, infrared

[a]In some cases, a technology was considered or tested during development, but the weapon deployed did not apply that technology.

After collating the information and consulting further with DOD and non-DOD technical experts, we compiled three sets of issues widely considered critical to weapon effectiveness: issues specific to SMAW-HEAA, issues specific to FOG-M, and issues pertaining to both weapons (the issues are listed under the headings below). We then reviewed technical reports for each weapon (primarily design documents and test plans) to find passages covering these issues. Specifically, we looked for any discussion of relevant technical problems, alternatives, and trade-offs indicating that the issues have been or will be addressed. In interviews with technical staff for each program, we asked for clarification when necessary and for further information on each issue. The interviews were part of our overall procedure for collecting the effectiveness data that we reported in chapter 3.

SMAW-HEAA Issues

Probability of Hit

- Fast-burning propellants can increase a rocket's muzzle velocity and range, but they can also be unreliable, expensive, and unsafe to store.
- A small lifting surface provides a low, flat trajectory, reducing guidance problems.
- There are durability problems with the sights for some light weapons, and some are not fitted with night sights.

FOG-M Issues

Probability of Hit

- Infrared seekers cannot use a zoom lens. When gunners switch abruptly from wide to narrow fields of view, targets can be lost.
- With television seekers, target shadows can degrade accuracy, especially near dawn or dusk. Television seekers also have problems in fog, smoke, and other adverse conditions and are very limited (though not useless) at night.
- Infrared seekers are degraded by thermal clutter, heavy fog or smoke, and high humidity.
- [Material deleted.]
- Small bends in the fiber and low temperatures can cause signal attenuation, or weakening.
- FOG-M may have an automatic target recognition and cuing component, but this technology may not be mature enough to utilize at the time of deployment.

Probability of Kill

- Performance of a single-cone warhead is degraded if it must fire through the seeker.

Rate of Fire

- Reliability can be degraded by grease, sand, or dirt at the cable connectors.
- To minimize fiber breaks, FOG-M needs a spool winding technique that allows a fast but smooth unreeling of fiber.
- Target coordinates may not be accurate or timely, and target-identification data links to the FOG-M gunner may not be reliable.
- The fiber-optic cable cannot easily be replaced in the field.

Shared Issues for SMAW-HEAA and FOG-M

Probability of Kill

- Composite and reactive armors can severely degrade shaped-charge warheads.
- Various liner shapes and materials offer trade-offs among reliability, manufacturability, behind-armor effects, and penetration.
- The optimum "standoff" distance for warheads (distance from the target's surface at detonation) depends on weapon characteristics such as warhead size and liner type.
- [Material deleted] can degrade warhead performance.
- Some warheads do not perform well when they strike a target obliquely.
- The explosive used in the warhead is important to lethality. Some explosives perform better than others in certain warhead designs, and some explosives are less reliable than others.
- Imperfect alignment of the explosive charge and the warhead liner degrades performance.
- In a biconal shaped charge, performance can be degraded if the transition between angles of the cones is too abrupt.

Survivability

- Smokeless propellants can reduce the likelihood of exposure and counterfire but may reduce velocity to an unacceptable level.
- Field-weight noise suppressors may increase survivability.

Because of the complex nature of these issues, our goal was not to determine whether technical decisions for these weapons have been optimal nor to determine whether there are sufficient data and expertise available to support the decisions still pending. Our approach was more limited. We wanted to determine only whether program representatives were aware of these technical issues and could discuss the relevant trade-offs.

Communication by DOD to the Congress

To determine what information has been communicated to congressional reviewers, we examined DOD antiarmor master plans prepared for the Congress in 1984, 1985, and 1986. (1984 was the first year in which DOD prepared antiarmor master plans for the Congress.) We also examined congressional hearings for fiscal years 1979 to 1987. We selected these years for study because the Army expressed interest in FOG-M as early as 1979 and SMAW-HEAA development began in 1983.

These sources provide an extensive, documented record of formal communication by DOD to the Congress. Additional information moves through informal channels such as private meetings, but communication of this sort is usually not documented, nor is it open to systematic review. We therefore were unable to include it in our analysis.

We scanned these sources for statements relevant to weapon effectiveness and categorized statements by the effectiveness and degradation factors to which they referred. We did not include statements that were too general to categorize or that did not mention effectiveness against armor. Consider, for example, this statement in DOD's 1986 antiarmor master plan: "The Marine Corps plans to expand the flexibility of the SMAW by creating a family of rounds that includes an antiarmor round that will [material deleted]." The penetration estimate is relevant to SMAW-HEAA's probability of kill but does not indicate the possible effects of any degradation factors. We therefore counted it as a reference to SMAW-HEAA's probability of kill under benign conditions.

In another example, taken from authorization hearings on the fiscal year 1986 DOD budget, the director of Army research and technology stated that

> ". . . a view of a tank that is actually seen from the TV camera on board the fiber optic guided missile [is] passed back to the controller on the ground . . . [he] can maneuver the missile, select his target . . . determine which target he wants to engage . . . and then . . . [make] a direct hit right on top of the target tank."

This statement describes FOG-M's potential probability of hit in nonspecific terms but does not discuss any factors that may degrade the controller's ability to hit the target; thus we counted this as a reference to FOG-M's probability of hit under benign conditions.

It is important to recognize that the Congress has not explicitly requested information in this framework. Our purpose was to assess whether information that the Congress has actually received provides a comprehensive view of weapon effectiveness.

Results

Communication in DOD

Technical staff for the SMAW-HEAA and FOG-M were aware of the issues (discussed earlier in this chapter) pertaining to their programs. Program documents explicitly covered some of the issues. In program office interviews, respondents discussed these and the remaining issues in detail, citing possible technical and operational problems, alternatives, and trade-offs. Many of the issues were no longer considered to be problems by program office representatives. Where issues were still unresolved, program staff were considering or testing various technical alternatives.

As previously mentioned, we did not attempt to determine whether the design decisions already made have been optimal or whether the information and expertise on hand in the program offices provide an adequate basis for future decisions. Our purpose was simply to assess the degree to which technical staff were aware of the issues.

How have program staff for future weapons kept abreast of the issues pertaining to their programs? A variety of sources, inside and outside DOD, were cited. For example, program office staff have conducted technical surveys of DOD labs and private contractors. They have reviewed raw data, technical reports, and analytical models provided by industry. They have also maintained frequent contact with other organizations in DOD, including the Army's Ballistics Research Laboratory, the Army Materiel Systems Analysis Activity, the Army Materiel Command, technical organizations in the Department of Energy (such as the Lawrence Livermore and Sandia national laboratories), and program offices for weapons using the same technologies or facing similar operational problems. Communication occurs informally as well—in briefings by private industry and at professional meetings and conferences.

Communication by DOD to the Congress

Major sources of formal communication (the antiarmor master plans and DOD testimony) have provided little information, quantitative or descriptive, on the specific capabilities of these weapons. Communication regarding the SMAW-HEAA has covered performance under benign conditions for three effectiveness factors—the probabilities of hit and kill and survivability—and has described possible degradation of probability of kill due to enemy countermeasures (see tables 4.2 and 4.3).

Table 4.2: Information on SMAW-HEAA Communicated by DOD to the Congress in DOD Antiarmor Master Plans[a]

		Degraded performance		
Effectiveness factor	Benign performance	Mission environment	Countermeasure	Human factor
Probability of hit	[b]	[b]	[b]	[b]
Probability of kill	1984, 1985, and 1986	[b]	1985 and 1986	[b]
Rate of fire	[b]	[b]	[b]	[b]
Sustainability of fire	[b]	[b]	[b]	[b]
Survivability	[b]	[b]	[b]	[b]

[a]Entries represent the year of the antiarmor master plan that discusses the effectiveness factor.

[b]Information was not discussed in antiarmor master plans.

Table 4.3: Information on SMAW-HEAA Communicated by DOD to the Congress in Congressional Hearings[a]

		Degraded performance		
Effectiveness factor	Benign performance	Mission environment	Countermeasure	Human factor
Probability of hit	1985 and 1986	[b]	[b]	[b]
Probability of kill	1985, 1986, and 1987	[b]	[b]	[b]
Rate of fire	[b]	[b]	[b]	[b]
Sustainability of fire	[b]	[b]	[b]	[b]
Survivability	1986	[b]	[b]	[b]

[a]Entries represent the fiscal years of the hearings in which information on an effectiveness factor was communicated to the Congress.

[b]Information was not discussed in the congressional hearings.

Communication on FOG-M has covered probability of hit under benign conditions and some sources of degradation for the probabilities of hit and kill and survivability (see tables 4.4 and 4.5).

Table 4.4: Information on FOG-M Communicated by DOD to the Congress in DOD Antiarmor Master Plans[a]

		Degraded performance		
Effectiveness factor	Benign performance	Mission environment	Countermeasure	Human factor
Probability of hit	1985 and 1986	1985	1985 and 1986	[b]
Probability of kill	[b]	[b]	1985 and 1986	[b]
Rate of fire	[b]	[b]	[b]	[b]
Sustainability of fire	[b]	[b]	[b]	[b]
Survivability	[b]	[b]	[b]	[b]

[a]Entries represent the year of the antiarmor master plan that discusses the effectiveness factor.

[b]Information was not discussed in antiarmor master plans.

Table 4.5: Information on FOG-M Communicated by DOD to the Congress in Congressional Hearings[a]

Effectiveness factor	Benign performance	Degraded performance: Mission environment	Degraded performance: Countermeasure	Degraded performance: Human factor
Probability of hit	1986 and 1987	1987	1987	1987
Probability of kill	[b]	[b]	[b]	[b]
Rate of fire	[b]	[b]	[b]	[b]
Sustainability of fire	[b]	[b]	[b]	[b]
Survivability	[b]	[b]	1987	[b]

[a]Entries represent the fiscal years of the hearings in which information on an effectiveness factor was communicated to the Congress.

[b]Information was not discussed in the congressional hearings.

A closer look at tables 4.2 through 4.5 indicates that DOD's coverage of the specific capabilities of weapons in the antiarmor master plan or in testimony has been sparse. For example, the antiarmor master plans for 1984, 1985, and 1986 each contain only one statement on one SMAW-HEAA effectiveness factor—probability of kill—mentioning potential penetration (see table 4.2).

Moreover, these statements have not provided enough detail or explanation to indicate the degree to which elements can degrade performance. For example, in the 1985 antiarmor master plan, DOD stated,

> "The current [FOG-M] concept will be improved by the addition of IIR [imaging infrared] technology to provide day/night capability, and by range improvements."

This statement provides no information, either quantitative or descriptive, about the extent to which night operations and obscurants limit a television-guided FOG-M or the extent to which an infrared version minimizes these limitations.

The 1985 and 1986 master plans provided information on advanced armors and electro-optical countermeasures (for example, smoke, aerosols, [material deleted]) but did not tie the information to specific weapon capabilities such as SMAW-HEAA's lethality against advanced armor or FOG-M's potential for overcoming electro-optical countermeasures.

Even the statements on benign performance provided only limited information. For example, in the 1984 antiarmor master plan, DOD stated, "Development of an antiarmor round for the SMAW is underway to give it a capability against tanks." The statement neither specifies the nature of this capability (for example, SMAW-HEAA's projected probability of hit or kill) nor identifies or describes the intended target (critical information because of the important differences between generations of Soviet tanks).

In summary, information received by the Congress offers only general projections of performance for these weapons and very little on their specific capabilities and limitations. However, it is also the case that DOD has not been specifically required to present information to the Congress on the five effectiveness factors and three degradation factors that we used to assess weapon performance. Therefore, it is not our purpose to infer that DOD has intentionally evaded congressional reporting requirements.

Conclusion

[Material deleted.] In this chapter, we review our findings on weapon effectiveness and DOD communication. We also propose one matter for congressional consideration and one recommendation for action by the secretary of Defense.

Findings

To summarize our substantive findings, we review the effectiveness of infantry antitank weapons (question 2) and highlight issues specific to the future weapons only (question 3). Because we did not attempt to assess the accuracy of DOD's quantitative performance estimates, these findings are based on the nonquantitative data that we obtained from DOD and non-DOD sources. Next, we review the contents of DOD communication regarding the future weapons (questions 4 and 5). We conclude with methodological findings on the usefulness of the framework that we devised and the availability of data from DOD (question 1).

SMAW-HEAA Capabilities

The probability of hitting targets may be higher for the SMAW-HEAA than for other light, unguided weapons. The reusable spotting rifle—not the product of a new technology—allows gunners to get a better fix on their targets, brings SMAW-HEAA's weight to 30 pounds (about 25 pounds more than the M72A3), and requires a dedicated gunner.

Will SMAW-HEAA be more lethal than our current or upgraded light weapons? The new trumpet-shaped warhead liner may provide more penetration into the solid steel of first-generation Soviet tanks. However, the probability of kill depends on behind-armor effects as well as penetration, and DOD is not yet able to estimate these effects with precision. Moreover, penetration against solid steel is not a reliable indicator of penetration against the composite armor of second- and third-generation Soviet tanks. Thus, probability of kill for SMAW-HEAA remains uncertain.

SMAW-HEAA gunners may not achieve the rates of fire that are possible with one-shot, disposable weapons. At short range, gunners using any light weapon are quite vulnerable to suppression and attrition.

FOG-M Capabilities

FOG-M is among the options being considered by DOD in the medium and heavy weapon categories and may provide several advantages over current weapons and upgrades. For instance, television or infrared guidance is not unique to FOG-M and will not enable FOG-M to see through the obscurants that blind other electro-optical weapons, but a lofted or vertical launch will take FOG-M above the battlefield to see over possible obscurants, and the fiber-optic cable will allow the gunner to guide the missile to impact. These capabilities may substantially improve the likelihood of finding and hitting targets, particularly in the face of battlefield obscurants or electro-optical countermeasures. The medium FOG-M may also offer the option of a flat-trajectory launch. Using this option, gunners will sacrifice the ability to see over the battlefield but gain an opportunity to hit targets that have overhead cover.

FOG-M may also offer a better probability of kill. Developers are not applying any new warhead technology, but FOG-M's steep dive should hit the top of tanks where the armor protection is thinner. TOW2B also promises improved lethality. With its angled warhead and horizontal but elevated flight path, TOW2B will pass directly over the tank and fire downward. In short, the design for each weapon reflects a similar strategy—to regain sufficient lethality not by building a warhead that can punch through the thickest frontal armor but by attacking tanks at trajectories that avoid the frontal armor altogether.

We cannot project the rates of fire for a medium or heavy FOG-M. But obscurants and countermeasures may force the FOG-M gunner to reacquire targets previously locked onto. Target-identification problems and the use of later rounds for damage assessment may cut further into FOG-M rates of fire.

Finally, FOG-M may be less vulnerable to counterfire, since both versions are expected to have more range than Dragon and TOW. Moreover, in the medium version of FOG-M, the gunner and launch platform may be some distance apart. If the heavy FOG-M can reach targets 10 kilometers away, its sustainability of fire and survivability may be considerably better than TOW's. Keeping the heavy FOG-M inside line-of-sight ranges, for doctrinal or tactical reasons, will reduce its standoff range and increase vulnerability.

Communication

Working from technical documents and interviews with weapon experts, we assembled a large set of issues pertinent to the development of the light SMAW-HEAA and the medium and heavy versions of FOG-M. Program office personnel for these future weapons were aware of the issues and described plans for testing and resolving them.

The Congress has not, in the past, required that DOD provide information on the five effectiveness factors and three degradation factors in our analytical framework. But when we applied that framework to the information provided through formal DOD sources, we found that DOD had not provided comprehensive estimates of weapon effectiveness under benign and degraded conditions. These sources contained only a few references to specific factors, such as the probability of hit or kill, and did not indicate the reasons for and degree of any anticipated improvement in effectiveness.

Data Availability

To develop our analytical framework, we first identified key factors in antitank weapon effectiveness and then systematically considered various elements that can degrade it.

The framework offers three advantages. First, it demonstrates the degree to which performance under benign conditions may decline under the actual conditions of battle. As shown in chapter 3, performance degradation for infantry antitank weapons may be severe. For example, consider the probability of kill, given a shot. According to DOD, under benign conditions this probability is [material deleted] for TOW2 against a [material deleted].

Second, by comparing this framework to the information available on a weapon, reviewers can determine precisely what is known and what is not known regarding the weapon's effectiveness. With a systematic awareness of issues for which data are not available, reviewers can then more easily set priorities for the generation of supplemental data.

Third, our framework can support the evaluation of possible trade-offs in the capabilities of alternative weapons. After sorting the available information into this framework, reviewers might conclude, for example, that one alternative offers an improved probability of hit, even under degraded conditions, but renders survivability unacceptably low. (Appendix I specifies in a question format the weapon-effectiveness issues that constitute our framework.)

The best use of the framework requires data that are comprehensive, covering all effectiveness factors and all likely and predictable sources of degradation, and comparable, derived under similar test conditions and measured in similar ways. With such data in hand, reviewers would be better able to reach conclusions regarding the possible degree of degradation and the advisability of various trade-offs.

When possible, the data should be quantitative because such data are more precise. However, it may not be necessary or feasible to quantify each factor.

In addition, it may not be possible to represent concisely all conceivable sources of degradation and their interactions. But, once reviewers have specified the scope of their concerns, the framework can serve as a device for organizing the available data, whether quantitative or non-quantitative, and identifying factors for which data are inadequate.

As demonstrated in this study, the data now available on infantry antitank weapons are neither comprehensive nor comparable. DOD measures the performance of infantry antitank weapons under benign conditions but does not routinely and systematically measure their performance under all of the degraded conditions they are likely to encounter. Force-on-force outcomes for several weapons in combination do not indicate the extent to which conditions can degrade the performance of individual weapons. Even when force-on-force analyses estimate loss-exchange ratios per weapon, those ratios can vary widely, depending on the scenario (terrain, tactics, and so on).

Summarizing the available data on each effectiveness factor, we found that many of the elements that can degrade the probability of hit are not routinely covered in DOD's performance estimates, projections, or requirements. These elements include battlefield obscurants, such as rain and haze; enemy countermeasures, such as decoys and camouflage; and the human factor, combat stress.

Coverage of elements that degrade the probability of kill is more complete, but formidable difficulties in estimating penetration into composite armor and modeling behind-armor effects limit the confidence that we can place in simulated probability-of-kill figures. In addition, we did not find comprehensive data on the degrading effect of reactive armor on the performance of light weapons. As noted in chapter 3, developers of future light weapons will need to consider fully the possible trade-offs between penetration and behind-armor effects. These data limitations are, for that reason, critical.

Training exercises and weapon tests provided data on the rates of fire achieved by expert and average gunners, but data were not available on the degree to which combat stress degrades rates of fire.

Finally, to cover sustainability of fire and survivability, some of DOD's force-on-force models estimate attrition rates for each weapon in a force. Attrition is a direct indicator of survivability because it measures the disabling effect of counterfire. It is an indirect—but useful—indicator of sustainability, since gunners who are vulnerable to attrition may be forced to move before refiring or to keep their heads down. Attrition rates can vary widely, however, depending on tactics, force composition, and other model inputs. For this reason, a direct comparison of attrition rates (including point estimates and ranges of variability) is possible only if we run each weapon through the same tests—the same models, the same force combinations, and so on. In our study, we were unable to find the data necessary for such comparisons.

Matter for Congressional Consideration

GAO believes that its analytical framework can be helpful to congressional reviewers as they consider critical performance issues and trade-offs in the acquisition of antitank weapons. We therefore propose that the Congress consider using the framework to guide and help specify its requests for information regarding infantry antitank weapon performance.

Recommendation to the Secretary of Defense

Congressional reviews will be more efficient if DOD generates and organizes its weapon performance data with GAO's framework in mind. We therefore recommend that the secretary of Defense ensure that the data generated by DOD regarding antitank weapon performance are comparable across weapon alternatives and cover the five effectiveness factors and three degradation factors contained in GAO's framework.

This study identified several methodological or performance issues specific to our future weapons. The data that DOD provides for further congressional reviews should cover those issues. For example, SMAW-HEAA reviewers may wish to consider estimates of lethality that indicate SMAW-HEAA's depth of penetration and probability of kill against modern Soviet tanks. More generally, reviewers considering the lethality of any light antitank weapon may wish to evaluate the trade-offs between armor penetration and behind-armor damage. As noted in chapter 3, light weapons designed for maximum behind-armor damage might produce higher probabilities of kill than light weapons designed for maximum penetration. Reviewers who wish to consider this issue will need to know the maximum penetration and behind-armor damage possible within light-weapon constraints such as weight and size. Finally, as also noted in chapter 3, FOG-M deployment doctrine remains undecided. Data supplied for future reviews of FOG-M should cover the effects of deployment doctrine on rate of fire, sustainability of fire, and survivability.

Agency Comments and Our Response

The full text of DOD's comments and our response appears in appendix II. DOD fully or partially concurred with our findings. DOD's reservations center on three issues. First, DOD accepted the relevance of the five effectiveness factors and three degradation factors but argued that system reliability should also have been considered. As noted in the report, weapon assessments may cover several factors not in our framework—cost and logistics requirements, for example, as well as reliability. But such factors do not directly measure the effectiveness of a weapon. They measure the inputs and processes that determine its effectiveness. We believe that the factors covered in this study represent all of those that are directly relevant to weapon effectiveness. Second, DOD noted that quantifying each effectiveness factor and degradation factor would oversimplify the analysis and obscure many possible contingencies. As the report makes clear, we recognize that quantification is not always feasible or necessary. The framework is merely a device for organizing the available information—quantitative or nonquantitative—and highlighting possible problems and trade-offs. Third, a guidance technology has not been selected for the TOW and Dragon replacements. DOD was concerned that our focus on the fiber-optic option implies a DOD preference for that option. The report emphasizes that other guidance options are being considered.

DOD concurred with our recommendation that performance data on infantry antitank weapons be comparable across weapon alternatives and cover all factors in the framework.

Effectiveness Issues for Infantry Antitank Weapons

Probability of Hit

1. What is the weapon's probability of hit under benign conditions—that is, when the mission environment is clear, the enemy is not using countermeasures, and the gunners are expert and fully trained? What features of the weapon contribute to or limit its probability of hit under benign conditions?

2. Does the weapon's probability of hit vary with range? What are its minimum range and maximum range?

3. What is the weapon's probability of hit for night operations? What features of the weapon are relevant to its capability for finding and hitting targets at night?

4. What is the weapon's probability of hit in the presence of battlefield obscurants such as rain, fog, haze, smoke, dust, and aerosols? What features of the weapon are relevant to its capability for finding and hitting targets when the battlefield is obscured?

5. What is the weapon's probability of hit in terrains where it may be employed, including deserts, woods, and hilly or urban areas, and when targets are partially hidden? What features of the weapon are relevant to its capability for overcoming the line-of-sight limitations? Under what terrain conditions is firing unsafe?

6. What is the weapon's probability of hit when decoys and camouflaged targets are present? What features of the weapon are relevant to its capability for overcoming these countermeasures?

7. What is the weapon's probability of hit against targets that are moving evasively? What features of the weapon are relevant to its capability for engaging such targets?

8. What is the weapon's probability of hit when gunners are under counterfire? What features of the weapon are relevant to minimizing the disruptive effect of counterfire on probability of hit?

9. What is the weapon's probability of hit in the presence of electro-optical jamming? What features of the weapon are relevant to its capability against this countermeasure?

10. What probability of hit can average gunners expect to achieve with this weapon? What features of the weapon interact with gunners' attributes (such as visual acuity) and skills (such as aiming speed) to affect the projected probability of hit?

11. What training is provided for this weapon? What training (duration and type) would maximize the weapon's probability of hit?

12. What is the likely effect of combat stress on the probability of hit for this weapon? What features of the weapon are relevant to gunners' susceptibility to combat stress?

Probability of Kill

1. What is the weapon's probability of kill against specific targets when the enemy is not using countermeasures? What features of the weapon contribute to or limit its probability of kill?

2. What is the weapon's probability of kill against targets with applique or integral reactive armor? What features of the weapon can help to overcome this countermeasure?

3. What is the weapon's probability of kill against targets with field-installed armor such as a canopy, mesh, or skirts? What features of the weapon can help to overcome these countermeasures?

4. What is the weapon's probability of kill against targets with insensitive fuels, insensitive munitions, and other capabilities for suppressing behind-armor effects? What features of the weapon can help to overcome these countermeasures?

Rate of Fire

1. What is the weapon's rate of fire under benign conditions—that is, the rate of fire that is technically feasible when gunners are expert and fully trained?

2. What rate of fire can average gunners be expected to achieve with this weapon? What features of the weapon interact with gunners' attributes (such as physical strength) and skills (such as reloading dexterity) to affect rate of fire?

3. What training is provided for this weapon? What training (duration and type) would maximize the weapon's rate of fire?

4. What is the likely effect of combat stress on rate of fire for this weapon? What features of the weapon are relevant to gunners' susceptibility to combat stress?

Sustainability of Fire

1. What is the weapon's sustainability of fire under benign conditions—that is, its carry weight, including round, launcher, day and night sights, battery, coolant, platform, cleaning equipment, storage containers, and other components to be carried in the field? Which components are reusable?

2. At what organizational level is the weapon deployed? How many rounds will a unit be able to carry, given the relevant weight constraints?

3. What is the weapon's sustainability of fire when gunners are under counterfire? What features of the weapon are relevant to its capability for minimizing the suppressive effect of counterfire on sustainability of fire?

Survivability

1. What are the firing signature, range, and degree of gunner exposure for this weapon?

2. What is the weapon's survivability when gunners are under counterfire? What features of the weapon are relevant to its capability for minimizing attrition?

Comments From the Department of Defense

Note: GAO comments supplementing those in the report text appear at the end of this appendix.

OFFICE OF THE UNDER SECRETARY OF DEFENSE

WASHINGTON, DC 20301

ACQUISITION

01 JUL 1987

Mr. Frank C. Conahan
Assistant Comptroller General
National Security and International
Affairs Division
U.S. General Accounting Office
Washington, D.C. 20548

Dear Mr. Conahan:

This is the Department of Defense (DoD) response to the General Accounting Office (GAO) draft report entitled "INFANTRY ANTI-TANK WEAPONS: Current and Future Capabilities", dated March 16, 1987, (GAO Code 973215), OSD Case 7255. The DoD agrees in part with the GAO findings and fully agrees with the recommendations.

The GAO identified five effectiveness factors and three degradation factors for assessing anti-tank weapon performance. The DoD agrees that these factors are essential in assessing performance, but other factors, such as system reliability, should also be included in any overall assessment of weapon effectiveness. In addition, the DoD recognizes the need to assess anti-tank weapons under degraded as well as benign conditions, and is placing increased emphasis in this area in weapon testing.

With regard to future anti-tank weapons, the DoD agrees that the Fiber Optics Guided Missile (FOG-M) is a viable technology for future anti-tank weapons. It should be recognized, however, that other technologies are also being considered and, in fact, are currently being actively investigated by the Army. Each of these technologies offer potential performance improvements over current medium and heavy anti-tank weapons. Selection of the most appropriate technology and weapons mix will not be made until the analyses are complete.

The DoD routinely provides the Congress with information concerning weapon effectiveness in documents such as the Anti-armor Munitions Master Plan. The DoD considers the performance data provided by these documents as appropriate for senior level management, but recognizes that the level of detail must match the specific need. Accordingly, the DoD provides the Congress with additional information when requested, and will continue this policy in the future.

Additional comments on the GAO findings and recommendations are attached. The DoD appreciates the opportunity to comment on the draft report.

Sincerely,

Donald N. Fredericksen
Deputy Under Secretary
(Tactical Warfare Programs)

Attachments
as stated

GAO DRAFT REPORT - DATED MARCH 16, 1987
(GAO CODE 973215) OSD CASE 7255

"INFANTRY ANTITANK WEPAONS: CURRENT
AND FUTURE CAPABILITIES"

DEPARTMENT OF DEFENSE COMMENTS
FINDINGS

FINDING A. Factors Relevant To The Effectiveness of Infantry Antitank Weapons. The GAO identified five factors that it concluded cover the full range of information needed to assess antitank weapon effectiveness: (1) probability of hitting the target, (2) probability of kill, (3) rate of fire, (4) sustainability of fire, and (5) survivability of the weapon and gunner. The GAO also identified three factors that it concluded can degrade antitank weapon effectiveness: (1) mission environment, (2) enemy countermeasures, and (3) human factors. Based on these factors, the GAO established a framework to analyze antitank weapon performance under benign and degraded conditions. The GAO reported that, aside from actual combat, the DOD uses three sources of information to estimate weapon effectiveness: (1) training and field exercises, (2) laboratory tests, and (3) computer-aided simulations. The GAO found, however, that while the DOD measures the effectiveness factors under benign conditions, the DOD does not routinely measure the performance of individual weapons under degraded conditions. The GAO concluded that force-on-force outcomes for several weapons in combination do not indicate the extent to which each weapon is individually degraded. The GAO also concluded that inherent difficulties in measuring probability of kill render the DOD estimates inconclusive. (Pp.2-1 through 2-20/GAO Draft Report.)

Now on pp. 29-34.
See comment 1.

DOD Response. Partially concur. The DOD agrees that the five factors identified by the GAO are essential to assessing the system effectiveness of antitank systems and that system effectiveness can be degraded by the three degradation factors identified. In addition to the five factors noted by the GAO, however, system reliability is another important factor in the overall effectiveness equation. In new system developments, the Army is now using performance data under degraded conditions for individual weapons as input for force-on-force simulations. Thus, the performance of individual weapons can be extracted from the simulation results. The Army has another very important source of system performance information in the vulnerability assessments it generates. This source is field experiments conducted outside the lab under the auspices of independent laboratories early in the development cycle.

See comment 2.

The Army clearly recognizes the need to assess antitank weapons under degraded conditions and in its operational testing attempts to replicate the conditions of the combat battlefield. What is important in the force-on-force engagements is that the contribution of the individual weapons is measured. Such an operational test is currently being conducted at Fort Hood, Texas.

The U.S. Army Operational Test and Evaluation Agency (OTEA), using the U.S. Army TRADOC Combined Arms Test Activity (TACATA) as a testing agent, completed the first phase of testing on April 22, 1987. This testing, using the two-sided operational game as a model, measured the range and angular distribution of engagement between Manportable Antitank Weapons and simulated threat tanks, BMPs and RPG antitank weapons for both Blue Attack and Blue Defense. The Red

Enclosure

and Blue forces were a Mechanized Battalion in attack, versus a reinforced Mechanized Company in defense. Both Red and Blue alternated between attack and defense.

This test is not only updating the Army's World War II data on the range and angular distribution of attacks on tanks by German anti-tank weapons of that time, but is also providing the same type of information for the current longer range anti-tank weapons (Manportable, ITV, Bradley TOW and 25mm Cannon and M-1 tank) in engagements using current U.S. and Soviet doctrine for mechanized warfare. The test is characterized by carefully instrumented free play between well trained and enthusiastic adversaries. While the data are still being reduced, it is safe to say that the capture of essential data, using specially developed instrumentation, has been good.

See comment 3.

Although inherent difficulties in measuring probability of kill (P_k) do exist, it does not follow that performance estimates are necessarily inconclusive. The uncertainty surrounds the input to P_k simulations and the effect of these uncertanties on the output. Since all weapons are evaluated in the same way, the relative ranking, sensitivity to input parameters, and trends are valuable tools for tradeoff studies for design or for evaluation of specific designs. As better information is incorporated in the models (through gathering of data such as that resulting from Joint Live Fire Testing), the P_k simulations will improve in fidelity in an absolute sense. Although there is a lack of certainty, the simulations are useful as a measure of system effectiveness for decision makers.

See comment 4.

The GAO questioned the Ballistic Research Labortory (BRL) lethality procedures and then used the procedures as the basis for estimates such as degradations in countermeasures.
For the GAO proposed methodology to be of value, it needs to be implementable. In order to be so, degradations must be defined; the report fails to define how degradations are quantified.

<u>FINDING B</u>. <u>The GAO Methodology to Assess Weapon Effectiveness</u>. The GAO, working from the established framework of effectiveness and degradation factors (see Finding A), described the actual or projected capabilities of each anti-tank weapon under benign and various battlefield conditions. The GAO reported that it used quantitative data obtained from the DOD, as well as expert judgment, performance projections and requirements, and test results, to develop its effectiveness estimates. The GAO acknowledged that the accuracy of the effectiveness estimates is limited by the quality and availability of data. The GAO concluded, however, that the estimates provide the approximate degree to which performance might be degraded under actual battle conditions. (Pp. 3-1 through 3-4/GAO Draft Report.)

Now on pp. 35-36.

See comment 5.

<u>DOD Response</u>. Partially concur. See the DoD comments to Finding A. A cautionary comment, however, is provided concerning the analytical framework for effectiveness analysis proposed by the report. The method to determine the specific degradation factor for mission environment, countermeasures and human

factors is not discussed and whatever method is established is likely to be controversial. For instance, for countermeasures it is not clear whether the degradation caused by the worst case countermeasure, by the "average" countermeasures only, by field expedient countermeasures only or by some other set of counter-measures should be used. Moreover, it is not clear that the cumulative effect of all three degradation factors is always determined by multiplying the three terms. There are interactions among all three aspects of degradation and the relationships are dependent upon the specific technologies and operating functions involved.

See comment 6.

The GAO only partially assesses capabilities of (future) infantry antitank weapons. The GAO did not consider other candidate technologies being competitively developed for a DRAGON replacement (i.e., Laser Beamrider, Imaging Infrared (TANKBREAKER) or being considered for TOW replacement (e.g., Kinetic Energy Missile). The decision to analyze only a FOG-M technology for the medium and heavy systems avoids analysis of the pros and cons of other relevant technologies. This may inadvertently bias readers of the report in favor of the FOG technology. The Army is currently in a competitive situation on the Advanced Antitank Weapon System-Medium (AAWS-M) program. The reader may incorrectly infer from the report that the FOG-M technology has been preselected.

FINDING C. Effectiveness of Light Antitank Weapons. The GAO assessed the relative effectiveness of the current light antitank weapons (the M72A3 and AT-4 and the M72E4 upgrade) and the future Shoulder-Launched Multipurpose Assault Weapon (SMAW) with its High Energy Anti-Armor (HEAA) round. Based on its assessment, the GAO concluded that the SMAW/HEAA may provide a higher probability of hit than other light weapons, but the rate of fire will be lower if the spotting rifle is used. The GAO concluded that the SMAW/HEAA may also provide a higher probability of kill. The GAO pointed out, however, that the probability of kill is uncertain, because factors such as the warhead's behind-armor effects and penetration against the composite armor of second and third generation Soviet tanks is not yet known. Finally, the GAO concluded that since the effective range for the SMAW/HEAA will surpass that of other light weapons, the SMAW/HEAA may reduce gunners' vulnerability to suppression and attrition, although this may not make much difference at light weapon ranges (Pp. 3-4 through 3-21 and pp.5-1 through 5-2/GAO Draft Report.)

Now on pp. 36-44 and 73.

See comment 7.

DOD Response. Partially concur. Because of its weight (30 lbs), the SMAW requires a dedicated gunner. The Marine Corps has decided the requirement for SMAW exists as both a bunker-buster and a light antiarmor capable system, and that the effectiveness of the SMAW system warrants the use of a dedicated gunner. Marine Corps experience has shown that a dedicated SMAW gunner is better trained than a gunner of a disposable weapon, because he is able to practice rapid and accurate weapon employment on a frequent and inexpensive basis by using the spotting rifle. This higher state of training will reduce misses to the point that rate of fire is not a critical factor. The Marine Infantry Company is structured to employ SMAW from the assault section of the Weapons Platoon, Infantry Company.

The use of the SMAW as the light antiarmor/ bunker-buster weapon has serious implications on the force structure.

The Army force structure does not support both the DRAGON and the SMAW, because both systems require dedicated gunners. The Army is reluctant to strip antitank capability from its forces by substituting the SMAW for the DRAGON. Current Army doctrine for light antiarmor weapons is that they are proliferable and are issued as a round of ammunition and used by combat as well as combat support/service support personnel. The Army has a requirement for a light (15 lbs or less), proliferable, multipurpose individual munition that has the capability to defeat light armor and bunkers/fortifications.

Change in weapon effectiveness (over the minimal requirement) against the additional weight required to obtain the increase has to be considered for light weapons.

FINDING D. Effectiveness of Medium Antitank Weapons. The GAO assessed the relative effectiveness of the current medium antitank weapons (DRAGON and the DRAGON II and III upgrades) and the future Fiber Optics Guided Missile (FOG-M), which is a candidate for both the medium and heavy Advanced Anti-Armor Weapon System. Based on its assessment, the GAO concluded that the FOG-M offers potential improvements over current medium antitank weapons in all five effectiveness factors. According to the GAO, with a vertical launch and flight above the battlefield, the FOG-M may enable gunners to detect and hit targets more often than with the DRAGON, while a steep dive angle may also improve lethality. The GAO also concluded that the FOG-M may offer a higher rate of fire than the current or upgraded DRAGON, although noting that performance under degraded conditions could not be assessed. The GAO further observed that the added range and vertical launch of the FOG-M may leave gunners less susceptible to counterfire and thereby provide a higher sustainability of fire and survivability than any DRAGON. The GAO pointed out that data to estimate the degradation factors were limited, but concluded that even this partial data indicated performance of any medium antitank weapon can be subtantially reduced. (Pp. 3-21 through 3-37 and pp. 5-4/GAO Draft Report.)

Now on pp. 49-51 and 73-74.

See comment 8.

DOD Response. Partially concur. The DOD agrees that new technologies will afford better effectiveness for the medium antitank weapon than currently exists with the DRAGON. The Army is currently pursuing a replacement for the DRAGON. The AAWS-M program entered a "proof of principle" technology demonstration phase in August 1986. During this phase, the Army is investigating three system technologies (Imaging Infrared (TANKBREAKER), Laser Beamrider and Fiber Optic) to determine the best technical approach. The three AAWS-M candidates being considered will each offer significant improvements over the DRAGON in performance, susceptibility to counterfire, sustainability of fire, gunner/system survivability, etc.

See comment 9.

The FOG-M described by the GAO as a medium candidate is incorrect. First, the term "Medium FOG-M" is a misnomer which implies the weapon is a scaled-down FOG-M, as currently being developed in Army labs. While certainly drawing on the FOG-M research program for fiber optic guidance technology, the medium system in the Army competition must develop most of its design independently. The FOG-M employs a fire control system weighing hundreds of pounds while the medium candidate system's fire control system weighs less than ten pounds. The second misconception is that the Mediumcandidate FOG system can be vertically launched, even from a prone position. In reality, the missile would be launched with 5 to 15 degrees elevation followed by a pitch-up/pitch-over maneuver which places the missile in an elevated cruise altitude. This altitude is maintained until the terminal dive phase is initiated. There are significant differences between this and vertical launch.

FINDING E. Effectiveness of Heavy Antitank Weapons. The GAO assessed the relative effectiveness of the current heavy antitank weapons (TOW 2 and the TOW 2A and TOW 2B upgrades) and the future FOG-M design for an Advanced Antitank Weapon System-Heavy. As with the medium weapons, the GAO concluded that the heavy FOG-M promises improved performance over other heavy antitank weapons in all five effectiveness factors. The GAO concluded that the FOG-M may have substantially improved probabilities of hit and kill over current heavy weapons. In addition, the GAO concluded that the FOG-M may provide a higher rate of fire than the TOW, although this capability is not certain without extensive testing. Finally, the GAO concluded that the FOG-M may be less vulnerable to counterfire, since it is expected to have more range than the TOW. The GAO noted that if a heavy FOG-M can reach targets at least 10 kilometers away, its sustainability of fire and survivability should be considerably better than that of the TOW. (pp. 3-7 through 3-51 and pp. 5-2 through 5-4/GAO Draft Report)

Now on pp. 51-59 and 73-79.

See comment 10.

DOD Response: Partially concur. The DOD agrees that new technologies afford better effectiveness for the heavy antitank weapon than currently exists with the TOW. The Army's current concept for replacing the TOW envisions up to a three member Advanced Antitank Weapon System-Heavy family to include a line of sight replacement for the TOW on the infantry and cavalry fighting vehicles, High Mobility Multipurpose Wheeled Vehicle and possibly the COBRA (Advanced Missile System-Heavy (AMS-(H)); a line of sight dedicated Kinetic Energy Missile system (KEM) mounted on a designated chassis to replace the Improved TOW Vehicle; and a Non Line of Sight Antitank (NLOS-AT) missile system (potentially the MICOM FOG-M being developed under the Forward Area Air Defense program). The technologies being pursued in each of these programs offer significant improvement over the current heavy antitank weapon (TOW family). The FOG-M missile described in the report is a candidate for the NLOS-AT system. The fiber optic technology being considered in the AAWS-M program is a candidate technology for the AMS-H. (See also the DOD response to Finding D). The Army has not preselected the FOG-M as the technology for the AAWS-H systems.

See comment 11.

FINDING F: Implications of New Technologies on the Weapons Mix. The GAO reported that the distinction between light, medium and heavy weapons has evolved in the attempt to maximize the capabilities of current technology within the constraints imposed by infantry operations. The GAO found, however, that new technologies offer the opportunity to rethink the current weapons mix. For example, the GAO reported that presently the Army does not count light antitank weapons for any purpose other than self-defense because of lethality limitations. The GAO reported, however, that future weapons could be more lethal than current light weapons and could serve antitank purposes beyond self-defense. In addition, the GAO reported that increased capabilities of a heavy FOG-M may prompt a reconsideration of doctrine. The GAO reported, for example, that some DOD officials have raised the possibility of deploying the FOG-M well inside its maximum range. The GAO observed, however, that moving the FOG-M closer to the front would undermine the reduced vulnerability of gunners at the FOG-M maximum range. Overall, the GAO concluded that the FOG-M has implications for a wide range of doctrinal and procurement decisions. (pp. 3-54 through 3-59 and p. 5-4/GAO Draft Report.)

Now on pp. 60-61 and 74.

DOD Response: Concur. It should be acknowledged, however, that the FOG-M is not the only technology that will have implications for a wide range of doctrinal and procurement decisions. See the DoD responses to Findings B, C and D.

FINDING G. Communication Within the DOD. To assess the adequacy of communication, the GAO reported that it focused on two future weapons: the FOG-M and the SMAW/HEAA warhead. The GAO found that within the DOD, technical staff were aware of all the relevant issues pertaining to their programs. According to the GAO, the staff used a variety of sources, both inside and outside the DOD, to keep abreast of program issues. The GAO found that the staff have maintained frequent contact with other DOD elements and also obtained information informally through sources such as briefings by private industry and professional meetings and conferences. The GAO concluded that within the DOD, program personnel were generally aware of development issues pertinent to the programs and had developed plans to test and resolve them. (Pp. 4-1 through 4-9, pp. 4-11 through 4-12 and p. 5-4/GAO Draft Report.)

Now on pp. 64-69 and 74.

DOD Response: Concur.

FINDING H: Communication from the DOD to the Congress. To determine what information has been communicated to the Congress, the GAO reported that it reviewed two sources: (1) DOD Antiarmor Master Plans for 1984-1986, and (2) DOD appropriation and authorization hearings for FY 1979-1987. The GAO found that the DOD has not provided the Congress with comprehensive estimates of weapon effectiveness under benign and degraded conditions. The GAO reported, for example, that communication regarding the SMAW/HEAA has covered only performance under benign conditions for three factors and degraded performance for one factor. With regard to the FOG-M, the GAO found that communication has covered one factor under benign conditions and degraded performance for three factors. The GAO concluded that the information received by the Congress offers only general projections of weapon roles and performance and very little about their specific capabilities and limitations. The GAO further concluded that additional data on weapon effectiveness would be valuable to the DOD and Congressional reviews, and that the data should be comparable and cover all relevant conditions. (Pp. 4-9 through 4-19, p. 5-4, and p. 5-7/GAO Draft Report.)

Now on pp. 69-72, 74-75, and 79.

See comment 12.

DOD Response: Partially concur. Effectiveness estimates (i.e., P_k) can and in the past have been provided upon request. They are not routinely provided, however, because of the multitude of data and assumptions required to support these figures, and the potential for misunderstanding. For example, a specified weapon system's effectiveness (probability of kill given a shot (P_ks) against a specified tank can vary depending upon range of engagement. The P_ks may increase and/or decrease throughout range in a nonlinear, not necessarily direct relationship. Therefore, someone trying to make a statistical point

See comment 13.

could choose any number within the range and be correct. Similarly, the figure can vary with aspect angle of tank, speed, etc. Because weapon systems have different doctrinal roles and employment schemes, direct comparisons are also difficult. To require the DOD to routinely provide the data implied by the GAO may be overwhelming. The effectiveness charts found in figures II-4 and/or II-5 in the DOD Army Antiarmor Master Plan are prepared for the Congress to provide generic estimates of effectiveness for senior level managers. The level of detail given in the AAMP is appropriate. The DOD will continue a policy of making additional detailed data available upon request.

Now on p. 77.

RECOMMENDATION 1: The GAO recommended that the Secretary of Defense ensure that DOD and Congressional reviewers have access to performance data that cover all effectiveness and degradation factors and are comparable across the weapon alternatives being considered. (p. 5-7/GAO Draft Report)

See comment 14.

DOD RESPONSE: Concur. As discussed in the DoD response to Finding H, the Services provide weapon system data to the OSD to support the Planning, Program & Budget System. The DOD currently provides weapon system performance data to the Congress in documents such as the Anti-armor Munition Master Plan. The degree of detail required by the Congress can vary significantly. Normally the large volume of detailed data available is distilled and only pertinent information is forwarded to the Congress. If the Congress asks for additional information it is provided expeditiously.

Now on p. 77.

RECOMMENDATION 2: The GAO recommended that the Secretary of Defense ensure that future estimates of SMAW/HEAA lethality indicate depth of penetration and kill probabilities against modern Soviet tanks. (p. 5-8/GAO Draft Report)

See comment 15.

DOD RESPONSE: Concur. It should be recognized, however, that as a light anti-armor weapon, the SMAW/HEAA was not designed to defeat the most modern of Soviet tanks. The Marine Corps reviewed the penetration required to defeat the Soviet tank most likely to be engaged in future battle and designed the SMAW/HEAA warhead to achieve the required penetration. Other factors, such as future composite armors and reactive/passive applique armor were considered but were not included in the initial design criteria for the HEAA warhead about to be fielded. Advances in technology such as tandem warheads and heavy metal liners (as opposed to the present copper liners) may be incorporated into future HEAA designs if they prove acceptable to Marine Corps requirements. The OSD will direct the Marine Corps to conduct a study which will give a valid estimate of SMAW/HEAA kill probabilities against modern Soviet tanks.

Now on p. 77-78.

RECOMMENDATION 3: The GAO recommended that the Secretary of Defense ensure that FOG-M field tests determine the effects of deployment doctrine on rate-of-fire, sustainability-of-fire, and survivability. (p. 5-8/GAO Draft Report)

See comment 15.

DOD RESPONSE: Concur. The Secretary of the Defense Decision Memorandum (DSARC I) for the Advanced Anti-tank Weapon System-Medium (AAWS-M) dated May 15, 1986, directed the Army to conduct a Cost and Operational Effectiveness Analysis (COEA) by the end of CY 1988. The COEA will includes the examination "of the preferred mix of AAWS-M and AMS-H weapon systems" on the battlefield and the examination of "a spectrum of likely scenarios and engagement ranges, including offensive and defensive operations" and gunner survivability. The mix of weapons will include the Non-Line of Sight-Anti-tank (NLOS-AT) System, which will probably be a heavy system using fiber optic technology.

RECOMMENDATION 4: The GAO recommended that the Secretary of Defense estimate (1) the maximum penetration and behind-armor damage possible for light-weapon technologies, within operational constraints such as weight and size, and (2) the contribution of penetration and behind-armor damage to light weapons' kill probability against modern Soviet tanks. (p. 5-8/GAO Draft Report)

Now on p. 77.

See comment 15.

DOD RESPONSE: Concur. The Army will perform estimates for future Light Anti-armor development programs (e.g., MPIM). To date, However, light weapons performance against the frontal aspects of modern Soviet tanks is generally conceded as ineffective, i.e., penetration into the interior of the tank does not occur. For each aspect around the sides and rear of a tank, different armor compositions are encountered. Only in the event that penetration into the interior occurs will behind-armor damage have any meaning. The trade-offs between penetration and behind-armor damage is relevant, of course, only when the aspect angle allows penetration. The employment of infantry for "flank shots" is a matter of Service doctrine and organization.

One of the major duties of the Army's Ballistic Resarch Laboratory (BRL), Army Material System Analysis Activity (AMSAA), and the Naval Surface Weapons Center (NSWC) is to conduct penetration and behind armor effect studies. In addition to the continuing efforts in these organizations, there is currently a major armor-anti-armor effort jointly funded by the Defense Advanced Research Projects Agency, the Army and the Marine Corps that will acquire data on penetration and behind armor damage. Some of this data will be applicable to light systems.

RECOMMENDATION 5: The GAO recommended that the Secretary of Defense design future light weapons for maximum behind-armor damage, if such weapons will have higher kill probabilities than weapons designed primarily for penetration.

DOD RESPONSE: Concur. This design consideration, However, over and above the minimal Pk required by the user, must be considered as part of the trade-off analysis for other requirements (e.g.. cost, weight, size).

The following are GAO's comments on the Department of Defense's letter dated July 1, 1987.

GAO Comments

1. For this report, GAO devised an analytical framework that includes five effectiveness factors and three degradation factors. The effectiveness factors are the probabilities of hit and kill, rate of fire, sustainability of fire, and survivability. The three degradation factors are the mission environment, enemy countermeasures, and human factors.

DOD agreed that the five effectiveness factors are essential to an assessment of infantry antitank weapons and that the three degradation factors can reduce effectiveness. DOD's only objection to the framework is the exclusion of system reliability.

As we noted in chapter 1 of the report, a comprehensive assessment of effectiveness might cover factors beyond those in our framework, such as the weapon's contribution to force effectiveness. Additional assessments might cover cost, logistics requirements, system reliability, and other factors. These factors do not directly measure the effectiveness of a weapon; they measure the inputs and processes that determine its effectiveness.

To serve a broader purpose, reviewers may require these additional types of assessment. However, our purpose was more limited given that we were asked to assess the effectiveness of individual antitank weapons, including weapons currently in the field and those now being considered for deployment. The framework that we devised fully covers the factors relevant to that purpose.

2. In its response, DOD also claimed that its force-on-force simulations, field experiments, and operational tests provide sufficient data on the performance of individual weapons under degraded conditions.

We collected extensive performance data from DOD laboratories and other technical-support organizations, as well as from weapon reviewers in the office of the secretary of Defense, the Army, and the Marine Corps. We also visited the program managers and technical staff for current and future antitank weapons, and we asked specifically for any data concerning performance on the five effectiveness factors under benign and degraded conditions. The data that DOD provided indicate that assessments have not covered even all the likely sources of degradation and have not subjected each weapon to similar test conditions.

For these reasons, we have emphasized the need for data that are more comprehensive than those generated by DOD in the past and that provide direct comparisons of weapons' degraded performance (see chapter 5).

3. DOD objected to our finding that its probability-of-kill estimates are inconclusive, claiming they are valid for assessing weapon lethality in trade-off studies, sensitivity analyses, and other research. DOD also noted that our report makes use of these estimates.

As noted in chapter 2, it is very difficult to simulate a weapon's probability of kill. For example, it is not possible to accurately predict a weapon's lethal effects behind the armor, such as fire and spalling patterns. Consequently, the usefulness of simulated probability-of-kill estimates—in trade-off studies or any other sort of analysis—remains uncertain. This is why we relied on descriptive (nonquantitative) information in our assessments of weapon lethality. As noted in the report, we cited DOD's quantitative probability-of-kill estimates only to demonstrate the severe degree of degradation possible if those estimates are accurate.

4. DOD argued that the report does not indicate how to quantify the effects of our degradation factors. Apparently, DOD misunderstood our position. We proposed the framework as a heuristic device. Reviewers can use it, in conjunction with other criteria, to highlight critical performance questions, sort the available data, identify issues for which data are not available, and assess performance trade-offs. We did not insist that all degradation effects be quantified because quantification may not be feasible for some effects. In those cases, reviewers must rely on qualitative data, careful description, and logical analysis. Moreover, even where quantification is feasible, we did not attempt to evaluate particular estimation procedures, nor to propose reliance on a single estimate of any effect. The data should, where appropriate and possible, reflect a range of conditions (such as best, worst, and most likely cases). Accordingly, we argued in chapter 5 that reviewers need both qualitative and quantitative information, covering all likely and predictable sources of degradation and derived from tests conducted under similar conditions.

5. DOD noted that it is difficult to establish definitive estimates of weapon performance, especially performance in the presence of several degradation factors.

As noted in comment 4, we did not attempt to identify a definitive estimation procedure, nor to advocate evaluations of effectiveness that are based on a single estimate of any effect. Indeed, the purpose of the framework is to help reviewers organize and compare data that come to them in diverse forms and cover different conditions. Reviewers may not require an estimate of performance in the presence of several degradation factors. However, to reiterate, we believe that the data available to reviewers should, at a minimum, cover all the likely and predictable sources of degradation, taken one at a time. The revised report stipulates that degradation elements may interact in ways not captured by the multiplication of their individual effects (see chapter 2).

More generally, any framework for reviewing weapon effectiveness is subject to criticism on various methodological grounds. Critics may dispute the accuracy of input, and analytical procedures may be complex and controversial. For these reasons, assessments should raise matters of uncertainty, not obscure them.

6. DOD also noted that our discussion of future medium- and heavy-weapon technologies covers only fiber optics. As explained in chapter 1, we did not attempt to evaluate all future antitank weapons now being considered. To avoid confusion, we clarified this point in later chapters.

7. DOD summarized the Army's and Marine Corps's doctrine concerning light weapons, noting such factors as training requirements and weight. DOD highlighted the implications of SMAW-HEAA for force structure.

Nothing in DOD's comments is at odds with our findings regarding SMAW-HEAA. Our report covers various advantages and disadvantages of the SMAW spotting rifle, such as the possible improvement in accuracy, the dedicated-gunner requirement, the added weight, and the trade-off between accuracy and rate of fire. Our report also explains the Army's concern with the weight of light weapons and the limitations weight places on light-weapon effectiveness (see chapters 1 and 3).

8. DOD stated that a fiber-optic guided missile is one of three candidates for the future medium weapon. As noted in comment 6, the report describes the two other candidates but does not evaluate them.

9. DOD also stated that a medium fiber-optic guided missile would not simply be a smaller version of the non-line-of-sight FOG-M now under development. According to DOD, the fire control system would weigh much less and the launch trajectory would be lofted, not vertical.

We are aware of these distinctions, and we believe that we made this clear in our description of future medium-weapon characteristics such as weight, seeker technology, and range (see chapters 1 and 3). The source of this misunderstanding may be our application of the term FOG-M. While DOD uses it to refer specifically to the non-line-of-sight weapon, we used it in a generic sense, to refer to any fiber-optic weapon in the medium or heavy category. We revised the report to make this clearer.

According to specifications for the future medium weapon, gunners will be able to choose a lofted or flat launch trajectory. We cited both options in the draft report, but we used the term vertical, not lofted; for our purposes, the distinction between those terms was not important. We have revised the report to describe the possible launch trajectories as flat and lofted (not vertical). This revision did not affect our conclusions regarding the capabilities of a medium fiber-optic weapon.

10. The report identifies various heavy-weapon alternatives to FOG-M, alternatives that we were not able to evaluate. According to DOD sources, these alternatives include the additional medium-weapon options (the laser beam rider and the infrared tank breaker), a new version of TOW, and a kinetic energy missile. Chapter 1 of the draft report noted that DOD has not decided which alternative to pursue. The revised report repeats this point in chapters 3 and 5.

11. DOD noted that the non-line-of-sight FOG-M now under development has features not anticipated for a heavy line-of-sight weapon using fiber-optic guidance. DOD also cited other heavy-weapon candidates and emphasized that planners have not decided which candidate to develop.

Again, our generic use of the term FOG-M caused misunderstanding, and we revised the report accordingly. However, characteristics of the future heavy weapon are still uncertain. To cover a wide range of options for the possible heavy fiber-optic weapon, we assumed that it may incorporate characteristics of a medium fiber-optic weapon, the current heavy weapon (TOW), and the non-line-of-sight FOG-M already in development. Specifically, we assumed that a heavy fiber optic weapon may (1) reach targets 5 or 10 kilometers away; (2) follow a flat, lofted, or vertical trajectory; (3) use television or infrared guidance; and (4) fire single rounds or volleys. In the revised report, we clarify our reasons for evaluating these design options (see chapters 1 and 3). The revisions did not affect our conclusions regarding the capabilities of a heavy fiber-optic weapon.

12. DOD reiterated its position that single, quantitative estimates for any effectiveness factor would not be informative because weapon performance is contingent on many variables.

The report emphasizes our belief that estimates of effectiveness need not be quantitative. In addition, we agree that a range of estimates for each effectiveness factor—covering various targets, tactics, operational conditions, and so on—may be more informative than any single estimate. We followed that logic implicitly in our analyses in chapter 3.

13. DOD objected to the prospect that the Congress might routinely require comprehensive data on weapon performance. According to DOD, such a requirement would be unnecessary and burdensome.

Decisions regarding weapon development and procurement should rest, in part, on a detailed assessment of the weapon's capabilities on the battlefield. We do not believe that DOD should routinely provide information that congressional reviewers have not requested. But DOD should ensure the availability of information that (1) covers the full range of likely and predictable battlefield conditions and (2) enables reviewers to compare directly the capabilities of various design options.

14. In the draft report, we recommended that the secretary of Defense ensure that DOD and congressional reviewers have access to data that are comparable across weapon alternatives and cover these five effectiveness factors and three degradation factors. DOD concurred. In the revised report, we retain this recommendation (see below), but we also propose that the Congress consider using our framework to guide and help specify its requests for information regarding antitank weapon performance.

15. In the draft report, we made four additional recommendations. Regarding SMAW-HEAA, we recommended the generation of data on SMAW-HEAA lethality (penetration and probability of kill) against Soviet tanks with composite and reactive armors (draft recommendation 2). We also called for further work in estimating light-weapon lethality, so weapon designers can determine how much penetration and behind-armor damage are possible with a light weapon and how much each contributes to the weapon's probability of kill (draft recommendation 4). Also relevant to SMAW-HEAA was our observation that light weapons designed for maximum behind-armor damage might have higher kill probabilities than light weapons designed for maximum penetration. We recommended

that future light weapons be designed for maximum behind-armor damage if such weapons appear more lethal (draft recommendation 5). DOD concurred with each of these draft recommendations.

Regarding the possible medium or heavy FOG-M, we recommended that DOD conduct field tests to determine the effects of FOG-M deployment doctrine on rate of fire, sustainability of fire, and survivability (draft recommendation 3). DOD concurred.

These draft recommendations called for effectiveness data on particular weapons—the sort of data that will, as a matter of course, be available if DOD acts on our current recommendation. Consequently, chapter 5 now handles the draft recommendations as examples of the data to which reviewers should have access.

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Glossary

Applique Armor	An armor that can be attached to the tank.
Behind-Armor Effects	Interior damage to a tank caused by fire, overpressure, and spall fragments.
Bias	The difference between a gunner's actual and intended aimpoints.
Cardioid Distribution	A distribution of shots in which more shots hit the front of the target than hit the flanks and rear.
Carry Weight	The weight of a weapon's components that a unit carries into battle.
Catastrophic Kill	A combined mobility and firepower kill of a tank with damage too extensive for quick repair.
Chemical-Energy Warhead	A warhead that penetrates by forming a jet of metal.
Close-Combat Distribution	A distribution of shots in which fewer shots hit the front of the target than hit the flanks and rear.
Composite Armor	An armor made of layers of steel and glass-reinforced plastic.
Concealment	A barrier that interferes with the enemy's attempt to locate a gunner.
Conical Warhead	A warhead with a liner shaped like an inverted cone.
Cover	A barrier that prevents enemy hits on a gunner.
Dedicated Gunner	A specialist who carries and handles a weapon in battle.

Degradation Term	The quantitative measure of the degree to which the mission environment, countermeasures, and human factors can reduce weapon performance.
Deployment Level	The level to which a weapon is assigned, such as to an individual soldier or squad.
Dismount	When infantry leave their vehicles to move on foot.
Dispersion	The random scattering of hits around the aimpoint.
Disruptive Counterfire	Enemy fire that disrupts a gunner's aim.
Effective Range	The range at which a weapon's probability of hit, under benign conditions, is 0.50.
Firepower Kill	Disabling a tank by damage to the turret or tank-gun systems or by injury to the gunner.
Force	A combination of weapons in battle.
Frontal Glacis	The sloped plate of armor that provides a tank's thickest protection.
Hull	The body of the tank.
Integral Armor	A combination of reactive and composite armor.
Jitter	A gunner's difficulty in keeping the crosshairs of a guided weapon on target after firing.

Kinetic-Energy Warhead	A warhead that converts high speed into penetrating power.
Light Armor	Vehicles that are less armored than tanks, such as infantry fighting vehicles.
Loss-Exchange Ratio	The ratio of enemy to friendly losses.
Mobility Kill	Disabling a tank by damage to the engine, tracks, or other components or by injury to the driver.
Modern Armor	Composite or reactive armors.
Range Target	The armor plates used in laboratory tests of a warhead's penetration.
Rate of Fire	The number of rounds that a gunner can fire per minute.
Reactive Armor	Steel plates embedded with explosives that detonate when hit.
Remote Launch	The separation of a gunner from a weapon's launch platform.
Rolled Homogeneous Armor	An armor that is made of solid steel.
Rolled Homogeneous Armor Equivalence	The estimated degree of protection (as measured in millimeters) afforded by composite or reactive armor.
Signature Suppression	Camouflage and other attempts to mask the characteristics of a target.
Suppressive Counterfire	Enemy fire that forces gunners to move or keep their heads down.

Survivability	The likelihood of attrition due to gunner injury or weapon damage.
Sustainability of Fire	The number of rounds that a unit can carry and fire.
Tandem Warhead	A warhead designed to send a second charge through the path cut by the first.
Thermal Clutter	Hot objects, such as burning trees, that make infrared guidance more difficult.
Trumpet Warhead	A warhead with a liner shaped like the bell of a trumpet.
Turret	The uppermost part of a tank, housing the main gun.

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