

Attacking the Theater Mobile Ballistic Missile Threat

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Abstract

The United States and its coalition partners achieved a decisive victory over Iraq in the 1991 Persian Gulf War. Despite the spectacular overall success, the coalition had more trouble than expected neutralizing Saddam Hussein's Scud missiles. Many third world nations, besides Iraq, possess menacing theater ballistic missiles. The trend over the past few years points to continued proliferation of these weapons.

This paper reviews the performance of US systems against Iraq's Scuds during Desert Storm, and examines current US efforts to defeat these potentially destabilizing weapons. Which technologies and systems will be most effective against mobile ballistic missiles? How should the United States implement selected technologies to deal with this challenge? This thesis covers the pros and cons of competing concepts to accomplish missile defense. It evaluates the most promising technical solutions to the mobile ballistic missile threat. On the basis of the extensive amount of time and research effort devoted to the problem, it is safe to say there is no quick, easy, or cheap way to locate, identify, and destroy mobile missiles and their launchers. To defeat the mobile missile threat with a high degree of confidence, the US must field an integrated system of both offensive and defensive weapons.

The tasks seem clear: find the target, assign resources, then attack and kill the target. Our operational concepts should flow from these tasks. Obviously the mobile launchers complicate the search problem. Destroying missile factories or known storage facilities is not difficult. The central problem is how to find the missiles once they have deployed to the field.

This paper addresses how best to accomplish **attack operations** against the mobile ballistic missiles *before* they launch. Offensive weapons, including manned and unmanned platforms, may perform this task. However, it is unreasonable to expect that attack operations can knock out all mobile missiles before launch. **Active defense**

provides a second layer of defense. It locates, tracks, and shoots down theater ballistic missiles during their boost, mid-course, and terminal phases. **Passive defense** consists of hardening and dispersal actions to minimize damage from any missiles that manage to penetrate the first two layers of defense. Finally, an effective Command, Control, Communications, Computers, and Intelligence (**C⁴I**) layer connects the other three layers in a unified whole. The United States Air Force, the Department of Defense (DOD), and government contractors are vigorously pursuing programs to enhance existing capabilities in all these areas. This paper evaluates various proposed solutions for existing deficiencies in attack operations and active defense.

Introduction

The problem of ballistic missiles has existed since the Nazis launched their infamous V-2 rockets at England during the Second World War. For more than 40 years, citizens throughout much of the world have lived with the threat posed by nuclear-tipped intercontinental ballistic missiles (ICBMs). The reality of the theater ballistic missile threat came to life during the Persian Gulf War of 1991 when Iraq sent its Scud missiles streaking toward Saudi Arabia and Israel. The Scud caused more problems for the US and its coalition partners than any other weapon in Saddam Hussein's inventory. The danger seems clear enough. What are we going to do about it?

Since President Reagan called for a defense against ballistic missiles in 1983, the Strategic Defense Initiative Organization, or SDIO, has been searching for solutions. In May 1993, Secretary of Defense Les Aspin changed the focus away from the Cold War threat to more limited, regional threats. He also changed the name of the organization to the Ballistic Missile Defense Organization (BMDO). Besides BMDO, the Defense Advanced Research Projects Agency (DARPA) also underwent a recent name change. The Clinton Administration dropped the word "Defense," and the organization's new moniker is the Advanced Research Projects Agency (ARPA). The Army, Navy, Air Force, BMDO, and ARPA are all hunting for solutions to the mobile missile problem.

The new top defense priority is Theater Missile Defense (TMD), with National Missile Defense (NMD) as the second priority. This change reflects the realities of the new world order. The danger of third world countries employing so-called theater ballistic missiles has increased. The probability of a nuclear exchange with the Russians is now lower than at any time since the late 1940s, but the likelihood of US involvement in theater-level conflicts may increase due to regional instabilities. These regional conflicts could involve theater ballistic missiles similar to the Scud. Before he left office in January 1993, Secretary of Defense Dick Cheney stated that the new Regional Defense

Strategy has replaced the former emphasis on containing communist expansion. He added, “Our national strategy has shifted from a focus on a global threat to one on regional challenges and opportunities.”¹ Who are these looming enemies and what weapons will they employ?

The short answer is that no one knows with certainty which nations the US might confront in the future. Four or five years ago, few informed people would have predicted a war between the United States and Iraq. Even though we cannot predict a particular foe, we can foresee a weapon growing in popularity around the globe among potential adversaries: the mobile tactical ballistic missile. Military leaders as well as civilians responsible for defense issues should understand that neither the United States nor any other country has a credible defense against mobile missiles. What about the work done by the SDIO, the new BMDO? Could it furnish a solution to the tactical as well as the strategic missile threat?

BMDO will attempt to apply the technology developed under SDIO to the theater missile problem. The billions of dollars spent since 1983 on strategic defense should not go to waste. Early indications from the current administration suggest that annual budgets for BMDO of \$3 to \$4 billion will continue. Promising technological breakthroughs are coming out of the research labs and into the field for testing. Exotic lasers and hypervelocity kinetic kill weapons are on the horizon. New sensor technologies are emerging to locate missiles both before and after launch.

There are four layers to a defense against mobile ballistic missiles. The first layer is attack operations. These are offensive actions that locate and destroy mobile missiles and their supporting infrastructure. The goal is to find and kill deployed mobile launchers before they can fire their missiles. The second layer is active defense. This involves systems to intercept theater ballistic missiles in their boost, mid-course, and terminal phases of flight. The third layer is passive defense. This includes missile warning, hardening, and dispersal actions taken to minimize damage caused by incoming

ballistic missiles. The fourth layer is Command, Control, Communications, Computers, and Intelligence (C⁴I). It is really the cement that links the other three layers together.

The purpose of this paper is to determine which technologies promise to yield the highest level of effectiveness against mobile ballistic missiles. It will then offer suggestions on how the United States should proceed in adopting and employing the selected technologies. This paper will discuss in some detail attack operations and active defense, with an emphasis on attack operations.

The issue is so complex that no single weapon system will eliminate the threat. Missile mobility creates an elaborate search problem not encountered against fixed targets such as buildings or bridges. The game of hide-and-seek played out between Iraqi Scuds and American air power showed how much of an advantage mobility provides. There are several broad conceptual approaches to the problem.

The US could pursue a strategy of deterrence rather than a more direct approach. Nuclear deterrence apparently worked well between the United States and the former Soviet Union. However, the US's overwhelming military superiority did not deter Saddam Hussein from firing Scuds at Israel and Saudi Arabia. A thorough examination of deterrence theory in relation to the mobile tactical ballistic missile issue is beyond the scope of this study.

The US certainly cannot afford to ignore the mobile missile threat because potential adversaries may use tactical ballistic missiles to coerce our allies or deter the US from taking action to protect its worldwide interests. An impenetrable space-based global defensive barrier, as in the original SDI concept, would have eliminated the advantage offered by mobility. No matter where the enemy put his missiles, our side would simply shoot them down. The US is no longer pursuing a comprehensive space-based defense system, so a genuine defense capability must examine air and ground-based alternatives.

The Air Force and DOD are now examining more modest programs to shoot down tactical ballistic missiles in flight. System concepts to attack ballistic missiles shortly after their launch include airborne platforms orbiting near suspected launch sites. This demands an ability to maintain air vehicles in the right place for long periods of time. This may be possible, but system effectiveness is not yet proven.

An improved Patriot-type interceptor could increase US defensive effectiveness against hostile ballistic missiles, but there are some problems with this approach. A leak-proof, ground-based terminal defense system may not be technically feasible. Analysis conducted after the Gulf War shows the real proficiency of point defense Patriot missiles was less than initially reported. Chapter 1 will cover this issue in more detail. Furthermore, salvo launches of ballistic missiles could overwhelm virtually any terminal defense system. During Desert Storm, Iraq generally launched its Scuds a few at a time rather than in a massive barrage. We cannot assume a future adversary will employ missiles in the same way as Saddam Hussein. In short, a defensive strategy that relies on a single system is risky.

A layered defense strategy offers several advantages. Each layer adds an increment of protection against mobile missiles. Attack operations, the first layer, may significantly reduce the number getting through to the next layer. This offensive search and destroy operation strikes at the mobility problem head-on and increases overall effectiveness in stopping a missile attack. The second layer, active defense, seeks to destroy incoming missiles immediately after launch, during their mid-course phase, and right before impact on friendly territory. This last line of defense, in the terminal phase of flight, was the only defense available during Desert Storm. The Air Force and DOD are considering different proposals for a prelaunch “attack operations” layer.

One approach involves an unmanned search vehicle that flies over mobile missile deployment areas, locates mobile missiles and their transporter erector launchers (TELs), and passes precise targeting information to a manned command and control (C²) node.

This includes platforms such as the Airborne Warning And Control System (AWACS) or the Joint Surveillance and Target Attack Radar System (JSTARS), famous for its debut during Desert Storm. The manned C² node then relays target coordinates to an attack aircraft (fighter or bomber) that kills the target missile and its TEL.

A second approach is to develop a search vehicle with its own lethal submunitions. This unmanned search and kill vehicle would look for deployed mobile missiles, defeat enemy camouflage and deception efforts, and eliminate the mobile missile without the assistance of a manned aircraft. An intermediate step involves an unmanned search and kill vehicle that receives final weapons release authorization through a data link with an airborne or ground control station.

An Autonomous Air Vehicle, or AAV, is an unmanned craft that is able to perform the search and kill roles independent of outside intervention. The AAV performs target search and identification using computer automation. Automatic Target Cueing (ATC) programs point the AAV's search sensors—such as infrared, millimeter wave radar, or laser line scanner—at designated high probability mobile missile hide locations. Automatic Target Recognition (ATR) algorithms resident in the AAV's computer memory interpret the sensor images and compared them with stored data about the target. These ATR programs are quite complex and take years to develop. If the ATR declares that an object is a valid target, the air vehicle can either relay this information to another platform, as described above, or the AAV may use its own submunitions to destroy the missile.

The question of how to conduct attack operations is not a trivial one. There are advantages and disadvantages of using manned aircraft to perform this mission, just as there are pros and cons to employing AAVs. How can we evaluate the different technical proposals to arrive at a preferred approach?

Measurement criteria can help to resolve which approach will best meet the overall requirement for a credible missile defense. Some laboratory test data and field

demonstration results are available concerning the potential utility of the different proposals. The ultimate goal is to propose a system from among competing concepts that will provide the highest possible assurance of destroying hostile theater ballistic missiles. Comparing the dollar costs of competing approaches is beyond the scope of this paper. If the expense of the recommended system is unaffordable, the responsible government agency could scale back or eliminate those segments of the system that provide the least marginal increase in security. This paper's focus is on the feasibility and utility of the solutions based on the following measurement criteria.

The first criterion is effectiveness. The system must prevent theater ballistic missiles from hitting areas the US wishes to protect. The system must work promptly since mobile missiles are time-sensitive targets. Because US interests extend around the globe, any proposed solution must be either mobile or possess inherent worldwide capability. A system that merely detects launches and provides warning is not complete without an effective kill mechanism.

Second, the system must operate successfully in all types of weather. Rain, fog, or snow must not defeat the defensive arrangement. There are certain practical limitations to this criterion. The system does not have to operate in the middle of a hurricane, tornado, or raging blizzard. The proposed solution must function outside these extreme climatic conditions. One should note that Saddam Hussein used bad weather as a shield to conduct Scud launches. Many US systems used in the Gulf War failed to operate well in inclement weather. The US must remedy this deficiency.

A third measurement criterion is day and night operations. The Iraqis launched the bulk of their Scuds at night. The proposed solution must pierce the "veil of darkness" which often provides cover. Infrared sensors work well during the day or at night. Radar is unaffected by the time of day. The fourth criterion is adaptability to different landscapes and environments. Since terrain and vegetation vary significantly from one region of the world to the next, the proposed solution must be adaptable to a variety of

topographic conditions. Predicating system specifications only on a desert landscape, for example, would be a mistake. It is quite likely that the US will have to deal with mobile missiles deployed in heavily forested or even jungle regions. The recommend solution must address these potentially more stressing locations. System performance may be better in certain regions of the world than in others; however, it still must be highly effective in all potentially contentious regions.

A final criterion, although not the least important, is simplicity. This means devising a proposed system that is as simple as possible, yet effective. Simplicity refers to a technical approach that is as self-contained as possible. It makes a virtue of minimizing dependencies on external inputs. Eliminating external inputs is perhaps a near-term impossibility; nevertheless, a system that requires fewer communications interfaces is more independent. One can measure simplicity by determining the number of separate systems that must work together to find and destroy mobile missiles. The smaller the number of components, the simpler the overall system.

Simplicity and effectiveness are not necessarily mutually exclusive properties. They are often fully congruent. A system that relies on numerous subsystems to work in perfect harmony may increase the risk of failure. For example, if many separate platforms have to communicate with one another to accomplish the mission, the overall system may be too complex. In a complex system, a breakdown in any one of the numerous channels and interfaces can prove fatal. Balancing the requirement for technical sophistication necessary to find and destroy mobile missiles with the desire to keep the overall system as simple as possible is a big challenge.

These five criteria serve as a guide to measure the relative performance of specific systems. An individual criterion is not an absolute requirement that is either completely fulfilled or not fulfilled at all. For example, one system may provide better foliage penetration than a competing system, yet neither may be 100 percent effective in all cases. Regarding rank ordering of the five measurement criteria, the first one is

obviously the most important since the system must react within time constraints imposed by the enemy. For example, an effective attack operations system must destroy the mobile ballistic missiles before they launch. The remaining four criteria are roughly equal in importance. Assigning weighted values to these criteria would be difficult and more subjective rather than scientific.

There are different proposed improvements for the first layer of mobile ballistic missile defense, search and destroy attack operations. One viewpoint suggests no existing platforms can do an adequate job countering the mobile ballistic missile problem. Therefore, the adaptation of revolutionary solutions from BMDO, ARPA, and contractors must receive top consideration. Other informed individuals believe that modifying existing platforms could achieve acceptable performance levels. The Air Force is conscientiously examining the potential utility of adding equipment to weapons carriers currently in the active inventory including the F-15, F-16, B-1B, and even the venerable B-52. Because the B-2 program remains highly classified, this paper does not explore its specific capabilities against mobile targets. Using systems already in the inventory has the implied advantage of lowering costs. The question, yet unanswered, is whether these systems can accomplish the mission.

This paper examines specific DOD efforts to enhance the US's capability to defeat mobile missiles. The Air Force, acting through the former Strategic Air Command (SAC), first focused on the mobile ballistic missile issue during the early 1980s in response to the threat of Soviet mobile ICBMs. Over the years, SAC accumulated considerable knowledge about mobile missiles. The newly formed Air Combat Command (ACC) now combines SAC's information with the mobile missile experience of the former Tactical Air Command (TAC). ACC and Headquarters Air Force XO at the Pentagon are fully aware of the mobile missile work ARPA, BMDO, and government contractors are doing. All of these organizations are working together to improve US

capability against mobile missiles. The likelihood that theater ballistic missiles will play an important role in future regional confrontations demands this level of commitment.

Notes

¹Dick Cheney, *Defense Strategy for the 1990s: The Regional Defense Strategy*, (Washington, D.C.: Department of Defense, January 1993), 1.

Chapter 1

Desert Storm

We received a report that a Scud fired at Dhahran had struck a US barracks. The explosion killed 28 of our troops and wounded many more. It was a terrible tragedy—this terror weapon launched into the sky that by sheer fate happened to fall where we had a concentration of troops—and it brought back home once again to our side the profanity of war. I was sick at heart.

—General H. Norman Schwarzkopf
It Doesn't Take a Hero

Surprise in the Desert

Desert Storm's swift, decisive push to victory over Saddam Hussein's military forces was uplifting to an America still haunted by the Vietnam War. The US and its coalition partners achieved spectacular successes in the air and on the ground while sustaining remarkably few casualties. Suddenly, on the night of 25 February 1991, with allied ground forces crushing Iraqi resistance in Kuwait, a Scud missile slammed into a barracks full of US Army reservists.¹ Despite repeated insistence by senior US military officers that Scuds were a militarily insignificant threat, this particular Scud attack produced the single greatest loss of US life in the entire Gulf War.² The US had underestimated the importance of the Scuds and the difficulty in neutralizing them as a threat. Should the US have taken the Scud missiles more seriously before the war? The history of ballistic missiles shows they have been a potential threat for many years. Desert Storm was not the first combat employment of ballistic missiles.

The V Weapons: V-2

During World War II, one of Hitler's goals for the V weapons was to divert Allied bombers away from German cities. In this he succeeded, at least for a time. Saddam Hussein may have had similar motives behind his Scud launches. There is a striking similarity between the level of Allied attention focused on the V weapons during

World War II and the number of coalition resources devoted to stopping the Iraqi Scuds during Desert Storm 46 years later. The V weapons and Scuds, each in its own time, caused a reallocation of Allied and coalition air power out of proportion to the military threat they presented. In this respect, they both succeeded. Ground troops, not air power, finally defeated the V-2 by overrunning the launch areas.³ In Desert Storm, the coalition air campaign reduced the number of Scud launches, but the Scud attacks did not stop until the initiation of Desert Storm's ground phase.⁴ In the Second World War, the Germans used mobility to rapidly change locations when air attacks became threatening.⁵ The Iraqis likewise used the Scud's mobility to their advantage 1991 during Desert Storm.

Ballistic Missiles After World War II

The most notable use of ballistic missiles just prior to Desert Storm was the Iran-Iraq War of the 1980s. Each side fired Scuds at the other, but Iraq was more successful. Saddam Hussein's Scud attacks on Iranian cities helped persuade Iran's leaders to accept a peace treaty. This fresh evidence of Iraq's willingness to launch ballistic missile attacks was a warning of what to expect in 1991.⁶ Appendix 1 contains a more detailed historical review of ballistic missiles from World War II up to Desert Storm.

Scud Development

The Scud is a direct descendant of the German V-2 ballistic missile.⁷ After World War II Soviet scientists, like their American counterparts, copied the German design from captured V-2s. The Soviets' fielded their Scud-A in 1955, and introduced their Scud-B in 1962.⁸ The Iraqis based their missiles on the Scud-B version. The Soviet Union began exporting their R-17, or Scud, to Middle Eastern countries in 1973. By adding fuel sections and reducing payload, the Iraqis more than doubled the original 190 mile range of the Scud-B to create the Al-Husayn, with a range of 400 miles. Further enhancements led to the 560 mile range Al-Abbas.⁹ The Iraqis gained confidence in

their Scud during their war with Iran. Saddam later used the Scuds against Israel in an attempt to draw them into the fray and wreck the carefully crafted US-led coalition.

Planning for the Scuds

US war planners were aware that Scud attacks, particularly on Iranian cities, had a significant impact on the outcome of the Iran-Iraq War.¹⁰ However, General Schwarzkopf viewed the Scud simply as a terror weapon. He did not consider the Scud as militarily effective because it had a small warhead with inaccurate guidance.¹¹ Before Desert Storm, officers at the Air Staff discussed the mobile missile problem with SAC and learned of the difficulty in trying to find individual launchers once they deployed to the field. Air Staff officers therefore formulated a general attack plan to disrupt Saddam Hussein's command and control system rather than attack the separate launchers. The plan also aimed to degrade the Scud missiles' logistics support network.¹² By interrupting Saddam's operational and strategic scheme, US planners hoped to prevent the Iraqis from using their Scuds at all. The strategy for dealing with the Scuds sought to avoid search and destroy missions against dispersed missiles if possible.

After Desert Storm started, officials at the highest levels of the US military soon recognized the importance of the Scuds. On 23 January 1991, the Chairman of the Joint Chiefs of Staff, General Colin Powell acknowledged, "The most significant problem we have right now are the Scuds—there's no doubt about it."¹³ General Merrill McPeak, Air Force chief of staff, admitted the Scud hunt consumed far more air resources than planners anticipated.¹⁴ McPeak stated, "What surprised us was we put three times the effort that we thought we would on this job."¹⁵ Given the difficulty experienced during World War II with the V-2s, and the Air Force's modest capabilities against mobile targets, US leaders could have anticipated problems with the Scuds.

US Concerns

US leaders were well aware of Israel's anxiety about the Scuds, and they made every effort to keep the Israelis out of the conflict. The Israelis have maintained a strict

policy of retaliating for any Arab attacks. Israel developed its own plan for a large-scale assault on the Scud sites in western Iraq.¹⁶ Arab reaction to a retaliatory strike by Israel against Iraqi Scud sites remains speculative. Moderate states, including Saudi Arabia, might have condoned an Israeli strike. Other, more radical nations such as Syria might have immediately pulled out of the coalition. Western officials, including General Schwarzkopf, were concerned that Israeli intervention, even in defense of their own territory, could splinter the fragile coalition against Iraq.¹⁷ Observers deemed it quite unlikely that Arabs would help Israelis kill other Arabs.

During Desert Storm, the Scud launches against Israel came dangerously close to forcing Israel into direct military action against Iraq. Intense US diplomatic pressure, including President Bush's pledge of stepped-up American efforts to destroy the Scuds, apparently kept Israel out of the war and the coalition together.¹⁸ President Bush agreed to rush Patriot defensive missiles to Israel, but he refused a direct Israeli request for our Identification Friend or Foe (IFF) codes. The Israelis needed the IFF codes to avoid hostile fire from the coalition's air defenses. Withholding these codes significantly reduced the risk of a unilateral Israeli strike against Iraq. Furthermore, with all the US and coalition assets devoted to the Scud search, there was really little the Israelis could add.

Besides the missiles themselves, American planners had to consider the possibility of Iraq arming the Scuds with chemical warheads. The US knew that Iraq had a large chemical weapons inventory. However, chemical warheads require more delicate handling than conventional high explosive warheads. American war planners assumed Saddam Hussein would not allow chemical warheads on the Scuds without his personal approval.¹⁹ During the Iran-Iraq War, Saddam maintained control over chemical weapons until he decided to use them. He delegated authority to Iraqi corps commanders who then fired the chemical agents.²⁰ US planners hoped that disrupting Saddam's communications would lessen the likelihood of the Iraqis using weapons of mass

destruction.²¹ The Soviets claimed the Iraqis lacked the capability to put an effective chemical warhead on their Scuds.²² However, by their own admission after the war, the Iraqis claimed an inventory of 30 chemical warheads for their Scud missiles.²³ It is unclear whether Saddam decided not to use chemical weapons or whether he delegated authority for their use but lower ranking personnel decided not to use them.

Intelligence

Unfortunately for the coalition, much of the prewar intelligence on the Iraqi Scuds proved to be erroneous. Since US intelligence analysts knew little about Iraqi procedures, they assumed the Iraqis would follow Soviet doctrine. Sometimes this conjecture proved accurate and sometimes it did not. For example, Scud crews normally rely on pre-surveyed launch sites to increase missile accuracy. The crew normally sends a tethered balloon up to certain altitudes to gather wind information. The crew uses this wind data to adjust the Scud launch angle to improve accuracy.²⁴ During the war though, the Iraqis dispensed with their routine procedures and launched the Scuds more rapidly than US intelligence experts thought possible. The shorter “dwell time” at the launch sites helped thwart coalition efforts to find deployed Scuds. The less time spent deployed out in the open, the harder the job of finding the Scuds.

Along with a shorter time required to actually launch the missile, the time needed after launch to pack up and move to another location was also far shorter than expected. US intelligence estimated it would take 30 minutes after launch before a Scud crew could drive away. Just before the war started, the US learned from the Egyptians that a Scud crew could start moving to another location just six minutes following a launch.²⁵ The US also discovered that the Scuds could remain fueled and ready for launch longer than anticipated. It takes about one hour to transfer the required amount of liquid fuel to the Scud-B. Although the fueled missile is highly volatile, the fuel mixture remains usable for about 24 hours.²⁶ This increased Iraq’s flexibility.

US intelligence also underestimated Iraq's inventory of missiles and mobile launchers.²⁷ The Iraqis had hundreds more missiles than predicted in prewar estimates. This shows the difficulty in trying to assess military capabilities in a relatively closed society. These problems with poor intelligence on the Iraqi Scuds mirrored the trouble Allied intelligence had unraveling all the capabilities of the German V weapons. Although US intelligence knew the Scud could carry a nuclear warhead, the information available indicated the Iraqis had not yet developed nuclear warheads. Fortunately, our intelligence was correct on this point.

Coalition Response

From the first minutes of Desert Storm, while F-117s attacked targets in Baghdad, F-15Es hit suspected fixed Scud launch sites in western Iraq.²⁸ These sites were particularly threatening to Israel. The US successfully destroyed all 36 known fixed launch sites in western Iraq, but it is still unclear if coalition air attacks destroyed any mobile Scud launchers.²⁹ While the air campaign severely disrupted Iraqi communications capabilities, Scud launches continued at a reduced rate. Political pressures forced the US to allocate additional resources to the problem. The US used many of its existing theater air assets, including sophisticated surveillance satellites and TR-1A reconnaissance planes, to probe the Iraqi desert for Scud missile launchers.³⁰ Saddam Hussein's forces were remarkably adept at using mobility and selective hiding spots to frustrate coalition attempts to find the launchers.

US efforts to contain the Scuds continued around the clock. During the day, A-10s shot their Maverick missiles at suspected Scud locations. At night, F-15Es with Low-Altitude Navigation and Targeting Infrared for Night (LANTIRN) pods sought out the Scud's Transporter Erector Launcher (TEL) immediately after a launch.³¹ The Joint Surveillance and Target Attack Radar System (JSTARS) used its sophisticated radar tracking system in an attempt to locate the Scud launchers.

The problem is that the JSTARS cannot distinguish between a Scud TEL and a similar size vehicle like a fuel truck. It is up to another aircraft, such as an F-15E, to get much closer for final target discrimination. JSTARS and other intelligence assets did pick up suspected Scud activity. Operators passed this information to the Airborne Warning And Control System (AWACS) aircraft, which relayed these location cues to the strike fighters.³² The fighters then tried to find the Scuds based on this information, but the results were disappointing. Crews complained that if they did not see the launch themselves, they had little chance of finding the launcher.³³ Adverse weather reduced visibility and greatly favored the Iraqis in this game of hide-and-seek. The Americans even sent their elite Delta Force unit into Iraq to look for the elusive Scuds while the British added their Special Air Service commandos.³⁴ Their objective was to use lasers to designate the Scud TELs. The fighters were to employ laser guided munitions that home in on the beams. Regrettably, as with the fighters, the commandos' results remain unknown. There is no confirmation of any mobile Scud launchers destroyed on the ground. Until the Iraqis open their war records, the US will probably not know what the success rate was against the mobile Scuds.

From a strategic perspective, the anti-Scud campaign achieved its objective of keeping Israel from entering the conflict. Also, average Scud launches per day declined significantly, from five to ten per day early in the war to around one per day three weeks into the war. However, even though the number of aircraft sorties launched against the Scuds remained fairly constant during Desert Storm, the Iraqis actually started increasing Scud firings during the last few days of the war. Western sources still do not know precisely how much of the reduced Scud activity was due to coalition air strikes and how much may be due to other factors such as husbanding of missile stocks.³⁵

Missile attack operations failed in terms of destroying Scuds or launchers.³⁶ The Gulf War did not eliminate Saddam Hussein's Scud arsenal. Inspections carried out in Iraq after the war suggest our air offensive, with 2,493 Scud-tasked sorties, produced less

damage to the permanent Scud facilities than originally estimated.³⁷ Former CIA Director Robert Gates also stated that “several hundred” Scuds survived the coalition’s best efforts to destroy them.³⁸ He estimated that after lifting sanctions, it might take just three to five years for Iraq to restore the conventional military power it had before the war.³⁹ Perhaps not too surprisingly, the Iraqis lied about the extent of their chemical weapons inventory. United Nations’ inspectors found 46,000 chemical weapons instead of the 12,000 claimed by the Iraqis. They also located 3,000 tons rather than the admitted 650 tons of precursor chemicals.⁴⁰ The spectacular precision bombing crusade still left an amazing quantity of dangerous weapons intact.

The Iraqi Army not only used mobility, it employed deception techniques to make target detection more difficult for the coalition. The Iraqis learned from the Soviets how to construct decoy targets and fooled some coalition aircrews during Desert Storm. In another parallel with experience from the Second World War, the Germans used deception to lure Allied bombers into hitting false targets.⁴¹ The Iraqis were also skilled at hiding Scuds in civilian areas, under overpasses, and in prepared shelters.⁴²

While the poor accuracy of the Scud missiles caused some US commanders to dismiss them as a serious threat, the political impact was enormous. Scuds landing in Saudi Arabia and Israel proved Saddam Hussein still had the power to inflict damage despite the coalition’s overwhelming air superiority. One should keep in mind that a nation fights a war for political objectives, and the Scuds threatened the coalition’s political cohesion more than its military strength.⁴³

Desert Storm: Strategy Implications

From a strategic viewpoint, ballistic missiles present unsettling changes in the way some nations contemplate their defense arrangements. For example, Israel cannot rely on preemption to defeat a future ballistic missile attack on its homeland. Iraqi Scud launchers proved much too elusive during the Gulf War. A preemptive Israeli strike could not possibly take out all Iraqi Scuds, and Israel cannot afford to exercise its nuclear

option due to unfavorable world reaction.⁴⁴ Therefore, Israel and many other nations face a new set of security challenges.

In Desert Storm the US enjoyed complete air superiority, devoted nearly 2,500 sorties to the Scud hunt, and still had tremendous difficulty finding them.⁴⁵ We may or may not have an abundance of air power in a future conflict. Air superiority enabled the US to fly expensive, yet vulnerable, AWACS and JSTARS aircraft near the Iraqi border. Communications between all our assets was unimpeded by the enemy; however, we could not eliminate the Scud launches.

Another sobering fact is the fact that the mobile Intercontinental Ballistic Missile (ICBM) problem has not disappeared, it has merely retreated into the shadows. The Russians still deploy their SS-24 and SS-25 mobile ICBMs in large numbers over an area 49 times as large as Iraq.⁴⁶ Although beyond the scope of this paper, the US must not neglect this portion of the mobile missile issue.

Lack of a sufficient capability against mobile missiles is a clear deficiency. Chapters 3 and 4 will focus on how to remedy this inadequacy. Considerable attention is now focusing on regional tactical ballistic missile threats. The next chapter will cover this proliferation issue.

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Chapter 2

Proliferation

Even in this time of downsizing, we must retain capable military forces. For the world remains unpredictable and well armed.

—Dick Cheney
Defense Strategy for the 1990s: The Regional Defense Strategy

The United States and its coalition partners completely outclassed Iraq's tanks, aircraft, and troops. Despite poor quality and primitive technology, only Saddam Hussein's Scud missiles challenged the coalition's military effectiveness. Other third world nations may decide that theater ballistic missiles are the most effective weapons they can add to their arsenals.¹ Today, at least 14 third nations produce their own ballistic missiles or modify missiles they purchase from other nations. An additional five developing nations possess ballistic missiles but have no indigenous production.² A total of 24 countries may have these weapons by the turn of the century.³ While Iraq used only conventional warheads during the Gulf War, future conflicts could include the use of chemical, biological, or nuclear warheads. Regional disputes, such as Iraq's invasion of Kuwait, could again encompass US interests. Ballistic missiles make it easier for a third world nation to strike deep into enemy territory. A belligerent nation with ballistic missiles could threaten other countries far from its own borders.⁴

While the ranges of most third world ballistic missiles are less than 600 miles, some extend to 1,800–2,000 miles, making them potentially threatening to more of the world.⁵ By the end of this decade, six countries will have missiles with ranges over 3,400 miles.⁶ Extending missile range is not technically difficult, as Iraq proved with its long-range Scuds. Other nations are producing long-range missiles. For example, India is testing a missile with a range of 1,500 miles. This would put US facilities at Diego

Garcia within India's reach.⁷ What is the reason India is pursuing a long-range ballistic missile program? It could be due to India's fear of Chinese and Pakistani missile capabilities. In fact, China is selling ballistic missiles to Pakistan, further heightening India's security concerns. By building its own ballistic missiles, India hopes to counter the potential threat posed by its neighbors.⁸ What factors attract third world nations to ballistic missiles rather than a modern air force?

Ballistic missiles are easier to acquire than a credible air force, especially for third world nations lacking a technical tradition.⁹ First, the number and quality of personnel needed to build an air force is much higher than the requirements for a capable missile force. Training missile crews is quicker and cheaper than training pilots and other aircrew members. A relative handful of technicians can operate and maintain imported theater ballistic missiles.¹⁰ Second, the cost of building an effective air force is prohibitive for most underdeveloped nations.¹¹ An expensive air force can disappear quickly against a superior foe. Over Lebanon in 1982, the Syrian Air Force lost 30 percent of its planes trying to battle the Israelis.¹² Third, a third world air force is ineffective against a world power such as the United States. Developing countries cannot hope to compete with the US Air Force in terms of conventional air superiority. The Gulf War showed the Iraqi Air Force's poor performance against the US Air Force. Iraq's ballistic missiles presented a different story.

Currently, ballistic missiles are more effective than aircraft at penetrating air defense networks.¹³ In World War II, German aircraft had difficulty in penetrating British airspace. However, the V-2s, and to a lesser extent the V-1s, got through.¹⁴ Saddam Hussein never attempted to send his aircraft over Israel, but he did succeed in getting ballistic missiles all the way to Tel Aviv.¹⁵ Air superiority normally refers to winning the air battle with enemy aircraft. One might question whether a nation that remains vulnerable to ballistic missile attack can claim to have true air superiority.

A comparison of missile and aircraft capabilities in other categories shows some clear advantages for each. Although ballistic missiles have a predictable trajectory, they are more of a surprise weapon than aircraft due to the missile's short time of flight from launch to target.¹⁶ For example, a 560 mile missile such as the Al-Abbas can reach its target in nine minutes, while a jet aircraft would take close to one hour to fly the same distance.¹⁷ The major advantages aircraft have over ballistic missiles are a larger payload and reusability. A single F-16 fighter can carry the explosive equivalent of 10 Al-Husayn missiles.¹⁸

Although aircraft are more efficient at carrying conventional munitions than missiles, there are several situations where missiles have an advantage. A nation may favor missiles in cases where aircraft attrition is high, or the target is beyond the flying radius of the country's aircraft.¹⁹ Ballistic missiles may have more of a deterrent value than manned aircraft, particularly when tipped with unconventional warheads.²⁰ Analysts believe Israel has nuclear warheads for its Jerico ballistic missiles as a guarantee of national survival.²¹ Speed and the ability to penetrate air defenses are primary advantages of missiles over aircraft.²² Ballistic missiles also provide a certain measure of prestige and autonomy to third world nations.

One important drawback to theater ballistic missiles is their relative inaccuracy compared to manned aircraft. US aircraft consistently dropped precision munitions within a few feet of their intended targets. This is far better than the 1,000 meters or greater circular error probable (CEP) achieved by the Iraqi Scuds.²³ Scud inaccuracy prevented the Iraqis from hitting precise targets and forced them to aim for large targets such as cities. Recall that US military commanders discounted the Scuds as a serious threat before the Gulf War because they were so imprecise. However, third world countries may not need to acquire the precision targeting capability demonstrated by the US Air Force. Simply hitting or terrorizing the population of a large enemy city may accomplish the political objectives. Theater ballistic missiles provide that kind of

accuracy.²⁴ Unlike a moving army, opposing countries know the coordinates of enemy cities before hostilities commence. Former CIA Director William Webster noted that “Iraq’s ability to hit Tehran caused a sizable portion of the population to flee.”²⁵ The terror created by ballistic missiles can, therefore, lead to a significant strategic impact. Citizens dispersed away from their homes and work are less productive, the local economy suffers, and the targeted nation’s government feels pressure to end the conflict. This is what happened to Iran in its war with Iraq.

If third world countries decide they want improved targeting capability, the US is ready to help. The precision accuracy of the Global Positioning System (GPS) constellation of satellites, which US forces used so effectively during Desert Storm, is available to anyone with \$1,000 who wants to buy a GPS receiver. Even technologically unsophisticated countries can increase missile accuracy by installing GPS receivers. The Selective Availability (SA) feature on GPS allows the US to degrade positional accuracy for users who lack certain codes. However, since commercial users lack SA capability and are growing so dependent on GPS, the US government may choose not to turn the SA feature on even during a regional conflict. GPS can bring missile circular error probable (CEP) down to under 100 meters instead of the 1,000 meter CEP achieved by the Scuds. The worldwide GPS network will be completely operational this year. Increased accuracy would make theater ballistic missiles even more of a military threat. For example, reducing ballistic missile CEP from 1,000 meters to 100 meters increases the probability of hitting a 92 acre port facility from only 8 percent to nearly 100 percent certainty.²⁶

With more exact targeting, combined with commercially available improvements to Command, Control, Communications, and Intelligence (C³I) capabilities, third world nations could mount ballistic missile attacks many times more effective than Iraq’s efforts during Desert Storm.²⁷ Fiber optic communication is spreading not only across the US but around the world. Developing countries could tie their military

communications to their civilian system and create a dual-use network. A hostile nation armed with updated C³I capability could threaten other nations with a mass attack of ballistic missiles.²⁸

Another concern is the commercial availability of satellite information. During Desert Storm, the Iraqis were unable to determine the location of coalition forces because Saddam lacked an effective reconnaissance capability. Countries without their own satellites can now buy imagery with two meters' accuracy from the Russians or 10 meters' accuracy from the French.²⁹ Potential adversaries could combine this satellite intelligence with GPS guidance packages to target vulnerable US or allied positions. Less sophisticated, yet highly effective, methods of reconnaissance include using aircraft or Remotely Piloted Vehicles (RPVs) to gather intelligence on force deployments and temporary supply locations. All this means that the US may confront an even more resourceful opponent in its next conflict. Not every nation is an enemy of the US, but it is instructive to examine two representative countries that might cause trouble in the near future.

Libya

Libya's Muammar Qadhafi has enlisted the assistance of North Korea and China to help him build a ballistic missile arsenal and chemical weapon capability.³⁰ North Korea may be exporting a missile with a range of over 600 miles to Libya, while China is helping Qadhafi make chemical weapons. Qadhafi started relying on China for chemical weapons support after western nations barred their corporations from working with the Libyans.³¹ Mindful of the 1986 US air attack on his compound, Qadhafi is also building underground bunkers to thwart future strikes.³² Qadhafi has taken steps to make it more difficult for western nations to use economic levers as retaliatory tools. He has moved cash out of British and Swiss banks and into banks in countries that are friendly with Libya.³³

Iran

Iran is quietly rebuilding its military strength since the end of its disastrous war with Iraq in the 1980s. Some reports indicate Iran has procured nuclear components from friendly sources within Muslim republics of the former Soviet Union.³⁴ Chinese and North Korean technicians have been helping Iran with ballistic missile technology. Since February 1991, Iran has demonstrated its independence by producing its own Scud missiles.³⁵ Iran is building a more serious military presence.

Weapons of Mass Destruction

The Gulf War alerted the world to the reality of theater ballistic missiles. It is not just the potential use of these missiles that should concern the West. The threat of a third world nation combining ballistic missiles with nuclear, biological, or chemical (NBC) weapons should sound alarm bells around the globe. High speed and long range make ballistic missiles attractive platforms for delivering weapons of mass destruction.³⁶ NBC weapons are many times more menacing than conventional weapons. For instance, a Hiroshima-size nuclear warhead is about 10,000 times more powerful than a conventional warhead of the same weight.³⁷ Biological weapons, such as anthrax, could kill on a vast scale. Chemical weapons killed 100,000 people in World War I and left over 1,000,000 total casualties.³⁸ Weapons of mass destruction, combined with ballistic missiles, pose a serious danger to peace and security.

Controlling the spread of NBC technology is a significant challenge.³⁹ A recently released Congressional study concluded as many as 11 nations have biological weapons programs and 31 have chemical weapons.⁴⁰ Despite acknowledging US deficiencies in dealing with biological and chemical agents, the report concluded these weapons will present less of a threat in the future. While this certainly must be our hope, the fact that these weapons are spreading should cause us anxiety. Chemical weapon technology is particularly difficult to detect since even a third world nation can convert an innocent fertilizer plant into a chemical weapons production facility.⁴¹ Israel, Iraq, Iran, Pakistan, India, South Africa, and North Korea either have nuclear weapons or are actively

working to acquire them.⁴² South Africa acknowledged it had a small nuclear arsenal, but claims to have destroyed it.⁴³ North Korea has not been so forthcoming. The International Atomic Energy Commission fears the North Koreans may already have sufficient weapons grade plutonium for several nuclear devices.⁴⁴ Arms control solutions are not likely to solve the problem as long as nations believe they gain prestige and influence by holding nuclear bombs or other weapons of mass destruction. Why should we care about missile and weapon proliferation? We should care because missile proliferation may destabilize international relations.⁴⁵

The spread of ballistic missiles and weapons of mass destruction may deter the US from involvement in future regional strife.⁴⁶ The US might have decided against challenging Saddam Hussein's seizure of Kuwait had he possessed nuclear weapons and a delivery capability.⁴⁷ In the future, some hostile third world countries may flex their newly acquired military power to threaten US interests.⁴⁸ Although the near-term threats are likely to remain localized, the long-term danger to the US from ballistic missiles will probably increase over time.⁴⁹ The combination of ballistic missiles with nuclear, chemical, or biological warheads thus significantly complicates US power projection.

We also cannot automatically assume that nations will become more responsible after they acquire weapons of mass destruction.⁵⁰ If Iraq had nuclear weapons during the Gulf War, would Saddam Hussein have used them? One cannot be certain either way. The long-term stability of the nuclear deterrent between the US and the former Soviet Union may not work with third world nations. The US and Soviets each maintained such an overwhelming destructive capability that neither side could hope to win a full-scale war. Confrontations between developing nations are not analogous to the superpower contest. A third world nation may lack a viable second-strike capability and may feel more threatened by its neighbors. This increases pressure for the first use of NBC weapons to avoid certain defeat. Lacking a tradition of dealing with weapons of mass destruction, third world nations could react in unpredictable ways and upset international

stability.⁵¹ Another complicating factor is the recent collapse of major alliances, such as the Warsaw Pact. This rapid change in military power relationships creates uncertainty and added incentive for weapon proliferation. Also, should a conflict break out in some troubled region, there is a potential for it to spread. This fear underlies Western concern about the war raging in the former Yugoslavia. Widening strife could increase the expansionist ambitions of some nations.⁵²

The US must work now to develop a capability to defeat mobile ballistic missiles since we may not be able to stop continued proliferation. On 24 April 1991, while still Chairman of the House Armed Services Committee, Les Aspin warned of two lessons from the Scuds in Desert Storm. First, superior US retaliatory capabilities may not deter future adversaries; and second, the US must develop theater defenses to protect our own forces as well as our allies.⁵³ Deterrence failed to stop Iran or Iraq from launching 870 ballistic missiles at each other during their eight year war.⁵⁴ The US needs a reliable defensive system against tactical ballistic missiles to lend credibility to our foreign commitments. Without a defense, third world nations could coerce our allies and undermine US power.⁵⁵

The ominous spread of ballistic missiles and NBC weapons is a clear threat. However, the US has little leverage over many of the countries exporting this technology, such as China and North Korea. The good news is that the United States is energized to deal with the tactical ballistic missile issue. The May 1993 reorganization of SDIO into BMDO makes it clear that the nation's top priority has shifted to Theater Missile Defense (TMD), with National Missile Defense (NMD) the second priority. We shall now examine the operational concepts under consideration within DOD for countering the theater mobile ballistic missile threat.

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Chapter 3

Theater Missile Defense Gameplan

There is no powerful and quick strike that a people could deliver, whatever their overall power. The United States depends on the Air Force. The Air Force has never decided a war in the history of wars.

—Saddam Hussein
Interview with Dan Rather, 29 August 1990

In the wake of Desert Storm, Congress directed the Department of Defense (DOD) to initiate a Theater Missile Defense (TMD) program. DOD assigned responsibility for coordinating TMD to the Strategic Defense Initiative Organization (SDIO)—now the Ballistic Missile Defense Organization (BMDO). The idea behind TMD is to throw a protective shield over a theater of operations, intercepting incoming missiles at high altitude if possible.¹ The overall plan is for a multilayered defense. This is a reasonable approach to TMD and divides the problem into rational segments.

The first layer is attack operations. This involves offensive actions to seek out, locate, and destroy theater ballistic missiles before launch. Attack operations include counterforce actions to interdict the missiles during importation, at their factories or storage facilities, or during transportation to a launch site.² Attack operations can also occur against the launch site itself immediately after missile launch but before the crew moves on to another location.³ The second layer is active defense operations to shoot down ballistic missiles in their boost, mid-course, and terminal phases. Terminal defense is the final opportunity to destroy incoming ballistic missiles. It includes Patriot and follow-on missiles as part of the lower-tier in the active defense layer.⁴ The third layer is passive defense measures to reduce the vulnerability of friendly assets to ballistic missile attack. Passive defense measures include air base defense initiatives such as hardening and asset dispersal. Connecting these three layers into a unified whole is the job of the

fourth layer, a robust Command, Control, Communications, Computers, and Intelligence (C⁴I) system for attack warning and battle management.⁵ C⁴I ties together the various segments of TMD and ensures a coordinated response to each missile attack. The TMD framework is logical. The challenge is to develop specific systems within each defensive layer to create a truly effective TMD program.

As pointed out in Chapter 1, political considerations forced the US to focus on the Scuds during Desert Storm. The US's relative inefficiency caused a greater expenditure of resources on this problem than the planners anticipated.⁶ In the next war, the US may not have as many sorties to devote to the antiballistic missile search mission.⁷ Some may argue it is a waste of assets to search for mobile missile launchers. One perspective is that it is more economical to build systems to shoot down the missiles either in the boost or mid-course phases. However, no system is likely to be 100 percent effective in stopping incoming missiles. The US military recognizes this and is acting accordingly. The DOD and the Air Force are devoting a great deal of attention to theater ballistic missiles, both fixed and mobile. They have developed detailed plans to improve US capabilities.

Mission Need Statement

Admiral David Jeremiah, Vice Chairman of the Joint Chiefs of Staff, signed a letter in November 1991 validating the DOD Theater Missile Defense (TMD) Mission Need Statement (MNS).⁸ The MNS specifies the objectives of each of the four layers of the proposed TMD program, outlined at the beginning of this chapter. When attack operations are not successful in destroying hostile ballistic missiles before launch, the US must have the capability of destroying hostile missiles in flight and take passive defense measures to minimize damage.⁹ Clearly, the US needs a theater ballistic missile defense in depth. The TMD MNS approved by Admiral Jeremiah addresses the capabilities needed by each of the services to tackle the mobile missile problem. The Air Force's own TMD MNS lays out what it needs to do to rectify deficiencies against this threat.

The Air Force's TMD Concept of Operations is more specific than the MNS and also mentions the importance of protecting politically sensitive targets from hostile missile threats.¹⁰

In October 1992, Air Force chief of staff General Merrill McPeak directed his organization to take a more aggressive stance relative to the theater missile defense mission.¹¹ He likely reasoned that as the primary player in air defense matters, the Air Force should take the lead in theater missile defense as well. McPeak directed improvements in wide area surveillance, automatic target recognition, and the Airborne Laser program.¹²

The Air Force also views area limitation analysis as a way to improve the probability of target detection.¹³ Area limitation is the systematic examination and categorization of a potential tactical ballistic missile deployment zone. For example, area limitation analysis could evaluate the terrain in western Iraq to assess its suitability for supporting Scud operations. Analysts could eliminate terrain that is too mountainous or swampy for Scud deployment. By eliminating large portions of a given region from deployment consideration, area limitation analysis significantly reduces the amount of terrain that requires searching. Area limitation also helps planners design search routes through suspected mobile missile deployment regions. Now that we have established the background of missile defense, the following will discuss each of the four defensive layers in more detail.

Attack Operations: Rationale

Researchers at the Naval Postgraduate School have compared the mobile missile problem to the challenge of locating an enemy submarine at sea. Both the submarine and the mobile missile leave a base or port, transit to a deployment area or site, and return. A defender is better off in both cases attacking the threat before it launches its offensive weapons. Besides searching for mobile missiles in their deployment areas, the defender should monitor the mobile missile bases and "choke points" that the missiles pass

through on their way to the field.¹⁴ After firing its missile, the launcher must go back to a reload center for another missile or to another location to await further orders. The TEL is more vulnerable to detection during this return leg because the act of launching the missile highlights the area.¹⁵

The TEL is the weak link in the mobile missile threat because a given nation, such as Iraq, may have several hundred theater ballistic missiles but only a few dozen TELs. Consequently, the US could gain significant leverage by hitting an adversary's TELs. For example, assume a TEL's expected probability of returning safely to its reload base after firing its missile is 90 percent. Reducing the launcher's prelaunch survivability (killing it before it shoots) from 1.0 to 0.85 means the number of missiles launched per TEL will drop from ten to less than four before we destroy the TEL.¹⁶ This prevents about two thirds of the expected number of missile launches per TEL from ever taking place. This is consistent with a US Army report that found attack operations can, over time, reduce missile launches by over 50 percent.¹⁷ Therefore, active defense systems designed for the boost and mid-course phases will contend with far fewer missiles.¹⁸ "It is better to destroy the bow than try to shoot down the arrows in flight."¹⁹

Attack Operations: Framework

The first opportunity to do battle with ballistic missiles is through offensive attack operations. The task becomes quite challenging once the missile and TEL have moved to the field. The exposure time for a deployed launcher is normally short, the enemy can easily camouflage the TEL, and decoys are inexpensive.²⁰ The desert environment of the Gulf War is by no means the most stressful for attack operations. Forests or jungles would complicate the problem of finding deployed missiles.

During the Gulf War, Iraq launched 40 Scuds against Israel and 46 against Saudi Arabia.²¹ US attack operations pressured the Iraqis and compelled them to conduct about 81 percent of their Scud launches at night to avoid detection.²² US air operations likely

forced hurried launches, reducing Scud missile accuracy. Salvo launches also tapered off as 40 of the first 42 Scuds were salvo launches but only 12 of the last 39 were salvoed.²³

The Air Force defines attack operations as prelaunch and launch phase destruction of theater ballistic missiles and associated supporting structures.²⁴ Besides destroying deployed missiles, it is also important to eliminate the enemy's ballistic missile infrastructure. This reduces reload and support potential, perhaps shortening the war. Offensive counter air (OCA) and air interdiction (AI) offensive forces will carry out attacks against the missiles and missile infrastructure.²⁵ Offensive forces from all services, including those from land, sea, and air, may carry out theater missile attack operations.²⁶ Secretary of Defense Aspin has curtailed plans for attack operations from space. Although abandoning space-based lethal defense, the SDIO/BMDO budget should remain above \$3 billion.²⁷

One key to TMD attack operations is the ability to monitor the entire theater for hostile missile activity.²⁸ The US is deficient in this regard and is attempting to improve target detection capabilities. Just as the DOD MNS emphasized the need for broad area surveillance, the Air Force TMD MNS calls for continuous monitoring of ballistic missile launch areas.²⁹ The surveillance system's task is to locate the tactical ballistic missile launchers, production facilities, storage areas, and supporting C⁴I.³⁰ The TMD MNS specifies that intelligence sources should feed target information through the Theater Air Control System (TACS) to US attack aircraft. The strike aircraft would receive vectors to the target coordinates and then deliver ordnance against the target.³¹ The manned aircraft would report back mission results to the TACS. A more responsive TACS would improve the effectiveness of attack operations against ballistic missile launchers and associated infrastructure. Ideally, information should flow through the system before an adversary launches his tactical ballistic missiles. This method is similar to the approach attempted during Desert Storm. The goal, obviously, is for a more effective system in the future.

The Air Force's near-term focus is on improving its attack operations' capability by enhancing existing systems.³² Driven in part by budget cuts, this approach first looks at modifying current assets and developing better overall coordination between all the services.³³ The goal is to increase effectiveness against deployed mobile ballistic missiles by improving communications between surveillance vehicles, C² nodes, and attack platforms. However, in the long run, the TMD mission may demand totally new systems to achieved required performance.³⁴

For effective attack operations, intelligence and communications must flow faster than they did in the past from the detection assets to the attack platforms. Rapid retargeting of attack aircraft increases the probability of finding and destroying the target since it cuts down on the time an enemy missile crew has to move. To support this requirement, the Air Force is emphasizing an improved capability to detect missiles before launch, plus better launch detection.³⁵ The AF MNS discusses upgrading missile launch detection capability on airborne assets such as JSTARS and AWACS, as well as developing ground-based radars for missile detection.³⁶ Systems with smart search capabilities and Automatic Target Recognition (ATR) algorithms could help the detection problem. The TMD Concept of Operations states either manned aircraft or Unmanned Air Vehicles (UAVs) could conduct search operations.³⁷

Chapter 4 will describe different approaches to attack operations, including an analysis of how well each approach satisfies the five measurement criteria outlined in the introduction. From the previous discussion, it seems clear that while attack operations form a critical layer in the TMD concept, attack operations will never find and kill all enemy missiles. TMD still needs an effective active defense.

Active Defense

TMD's second layer, active defense, means destroying the missiles in flight during their boost, mid-course, or terminal phases. There are pros and cons to attacking ballistic missiles in each of these three phases of flight. For example, killing enemy

ballistic missiles over the foe's territory or at high altitude reduces collateral damage.³⁸ Among the drawbacks to high-altitude defense are the difficulty in distinguishing between real and decoy targets and the challenge of accurately assessing target kills.³⁹ Sophisticated missile warheads may even have the ability to maneuver during the reentry, making terminal defense very important.⁴⁰ However, terminal defense demands extreme precision because there is little time available during this phase of a ballistic missile's flight.⁴¹ As happened during Desert Storm, the incoming missiles may also break up and create multiple targets, further complicating the intercept problem.

Active defense uses either air-launched or ground-launched weapons. A theater ballistic missile's hot exhaust plume aids detection in the boost phase. Interception during the boost phase is potentially quite cost effective. Active defense weapons would destroy the enemy missile before any multiple warheads or decoys could deploy.⁴² The difficulty with boost-phase defense is that the system must operate over enemy territory or have a very long reach. However, one big advantage of this defensive layer is that it expands the defended area considerably. The Air Force portion of active defense is the interception of missiles in their boost phase of flight.

Active defense requires launch detection and a tracking system that will monitor the incoming missiles throughout their flight and calculate intercept solutions.⁴³ A battle against missiles is many times faster than against fastest aircraft. A Mach 1 fighter might give 20 minutes of warning before it came within range of its target. A Scud missile might provide three minutes of warning, but future high-speed missiles would give less time for detection and destruction.⁴⁴

Timing is certainly a critical factor for boost-phase weapons since this phase only lasts about 30 to 120 seconds. Possible boost-phase weapons include airborne lasers or aircraft armed with high velocity missiles capable of shooting down ballistic missiles.⁴⁵ More time is available for attacking missiles during their mid-course phase since it lasts from 4 to 10 minutes.⁴⁶ For the mid-course phase of active defense, the goal is to achieve

multiple intercept opportunities to reduce leakage.⁴⁷ The C⁴I network will monitor the progress of this battle and direct additional resources, including terminal defense weapons, as needed.

Active Defense: Airborne Laser

The Air Force is examining the utility of an Airborne Laser to knock out ballistic missiles in their boost phase. The requirements include autonomous target acquisition, a range of more than 250 miles, the ability to engage three targets simultaneously, and over 100 seconds of available laser power.⁴⁸ It takes one to five seconds of laser power to kill a ballistic missile. Again, timing tolerances are tight. Only 3 to 10 seconds transpires from initial target acquisition to target kill.⁴⁹ The platform must have a six hour loiter capability and be air refuelable.⁵⁰ Future tests will validate the concept of operations for the Airborne Laser and its integration with other assets to destroy ballistic missiles. The Air Force has scheduled additional tests and demonstrations through the turn of the century.⁵¹

Analysis shows that a single Airborne Laser could have destroyed 87 percent of the Scud missiles fired in Desert Storm.⁵² Three aircraft could provide continuous coverage of a given area. Six aircraft would have protected Israel and Saudi Arabia during Desert Storm.⁵³

Airborne Laser: Analysis

The effective range of the laser is still unresolved. Risk reduction efforts are underway. Technical factors remain under evaluation such as the ability to focus enough laser energy on a target to kill it and the suitability of aircraft to house the laser equipment.⁵⁴ Ground-based laser research provides a foundation for the Airborne Laser program. The concept appears to hold great promise, but potential funding cuts could delay the program.

The Airborne Laser satisfies at least three of the five measurement criteria. It is immune to most weather conditions since it operates at altitude. It should operate during

the day or at night. Terrain is not a factor since the enemy ballistic missile would already be in the air during the engagement. If the Airborne Laser platform can perform target acquisition and kill, it would meet a fourth criterion for simplicity. However, will it fulfill the most important criterion: will it work? Until the completion of additional tests, this question must remain unanswered.

Active Defense: RAPTOR/TALON

BMDO is considering arming a gas-engine AAV with Mach 9 missiles capable of hitting targets up to 60 miles away.⁵⁵ The long-term goal is to reach out as far as 90 to 125 miles.⁵⁶ The AAV would loiter at an altitude of 65,000 feet and fire its high-speed missiles when it detects enemy ballistic missile launch. The AAV's missile would hit an opponent's ballistic missile in the boost phase. This destroys the missile before it deploys any decoys or breaks up, as happened with Scuds during the Gulf War.⁵⁷ This BMDO concept, called RAPTOR/TALON, would provide the upper tier of defense in the larger TMD program.⁵⁸

RAPTOR stands for Responsive Aircraft Program for Theater OpeRations. RAPTOR is a propeller-driven AAV that has its own missile launch detection capability and can track several missile events simultaneously.⁵⁹ RAPTOR uses kinetic energy missiles to destroy ballistic missiles in flight.⁶⁰

These TALON (Theater Application-Launch On Notice) missiles intercept and destroy enemy ballistic missiles in their boost phase.⁶¹ RAPTOR would guide the TALON missile toward the target, but TALON's own sensor and computer would ensure target kill.⁶² TALON would intercept the ballistic missile approximately 20 to 60 miles above the earth.⁶³ One advantage of the boost-phase kill is that chemical, biological, or nuclear warheads would land on enemy, rather than friendly, turf.⁶⁴

RAPTOR can loiter for a long time over the target area. A gasoline engine would power the first generation RAPTOR. The long-term goal is a solar-electric RAPTOR that would fly "virtually forever."⁶⁵ RAPTORs would fly in groups to cover a larger

area. For example, eleven RAPTORS would cover ballistic missile threats from anywhere in North Korea.⁶⁶ Although the RAPTOR flies at 65,000 to 85,000 feet, SA-5 and SA-10 surface-to-air missiles (SAMs) present a potential threat.⁶⁷ However, RAPTOR could employ several methods to avoid enemy air defense threats. RAPTOR could maneuver away from SAMs, tow decoys or electronic countermeasures' devices, or provide its own active defense suppression.⁶⁸ RAPTOR could also alert friendly fighters to intercept hostile aircraft.⁶⁹ RAPTOR deployment options include transporting the AAV into a theater by airlift or it could fly itself to a patrol area.⁷⁰

Technology borrowed from the recently canceled Brilliant Pebbles program helps keep the weight down on the TALON missiles.⁷¹ Miniaturization and lightweight components explain why TALON weights just 18 kilograms compared to the Navy's Phoenix missile that weights 454 kilograms.⁷² The TALON missile flies three times faster yet has a comparable range to the Phoenix.

RAPTOR/TALON: Analysis

The RAPTOR/TALON concept appears to hold great promise. Assuming that it performs as specified, it would provide an important defensive barrier against theater ballistic missiles that elude the attack phase. Since it operates at such high altitude, RAPTOR/TALON is unaffected by weather or local terrain conditions and is equally effective day or night. The idea is relatively simple and straightforward, without relying on complex communications with other platforms. Perhaps the elimination of space-based antiballistic missile defense will keep the interest in RAPTOR/TALON at a high level.

Active Defense: THAAD

The Army is moving ahead with improvements to TMD, focusing on the mid-course and terminal phases of active missile defense. While Patriot is a point defense system, Theater High Altitude Area Defense (THAAD) integrates SDIO/BMDO technologies and will defend an area 20 to 150 times as large as Patriot's defense

perimeter.⁷³ THAAD extends protection to civilian population centers and large military formations.⁷⁴ THAAD complies with the 1972 (Anti-Ballistic Missile) ABM Treaty.

THAAD includes ground-based radars, hit-to-kill missiles, launchers, and the communications equipment needed to make them all work together.⁷⁵ The Army is designing the ground-launched THAAD missiles and TMD ground-based radar to destroy hostile ballistic missiles in flight at ranges of up to 120 miles downrange and at altitudes of nearly 100 miles. TMD radar will pick up hostile ballistic missiles up to 300 miles away.⁷⁶ This ground-based radar will give the THAAD missile its initial vector along with in-flight updates. An infrared seeker on the THAAD missile itself will direct final homing to the target.⁷⁷ The THAAD missile will be lightweight, yet pack enough kinetic energy to destroy ballistic missiles.⁷⁸ THAAD will fly at about Mach 7 from a truck-mounted launcher capable of holding 12 missiles.⁷⁹ Unlike the Patriot, which requires a huge C-5 for air transportation, several C-130s can move THAAD's missiles, launcher, and radar around within a theater of operations.⁸⁰

A candidate for the role of ground-based THAAD missile is the Army's Exoatmospheric Reentry-vehicle Interceptor System, or ERIS, designed to destroy ballistic missiles in space.⁸¹ The ERIS ground-based interceptor successfully caught a dummy ICBM warhead fired from Vandenberg AFB, Calif. on 19 January 1991. The ICBM flew 170 miles above the earth at over Mach 20.⁸² ERIS performance was impressive. It used infrared detectors to home in on the warhead's heat signature and completed the intercept despite the presence of decoys.⁸³ Perhaps this success should not be too surprising since a US Hawk missile intercepted an Honest John rocket back in January 1960.⁸⁴

THAAD Analysis

THAAD meets the five measurement criteria. First of all, it promises to be an effective system. There is reason for this optimism since the successful ERIS launch demonstrated some of the critical technologies. THAAD requires no "miracle" invention

in order to work. Second, THAAD meets the criterion for all-weather operations. The phased array radar provides the capability to detect incoming ballistic missiles during inclement weather. Third, THAAD will work day or night for much the same reason it will work in any type of weather. Fourth, THAAD is unaffected by terrain conditions. Since the system is looking skyward, THAAD will work equally well in the jungle or desert. Finally, the system does not seem excessively complex. An interconnected combination of ground-based radar, mobile battle management center, and launchers is part of THAAD's strength. Outside satellite cues would come in through ground receiving stations and other THAAD units.

Another antiballistic missile system is the Israelis' Mach 9 Arrow. Despite the fact the US provided much of Arrow's funding, the Arrow missile program will not be part of TMD.⁸⁵ Because it is not mobile and has a range of only 24 miles, Arrow does not meet US requirements.⁸⁶

Active Defense: Terminal Phase

While THAAD provides a high altitude missile defense, Patriot and follow-on systems will form a final line of defense.⁸⁷ There are several reasons for a terminal defense. First, the atmosphere helps discriminate real warheads from decoys that might deploy after missile launch.⁸⁸ Terminal defense also provides an additional opportunity to shoot down incoming warheads. Finally, terminal defense already exists in the form of Patriot and provides a base for further improvements.

The Army is not scrapping the Patriot system. Instead, Patriot's active terminal defense system received an upgrade in 1992 to provide better coverage of limited point targets.⁸⁹ Another upgrade called Patriot Advanced Capability-3 (PAC-3) will give existing Patriot PAC-1 and PAC-2 systems increased range, lethality, and firepower.⁹⁰ PAC-3 will also extend the engagement window against targets with reduced radar cross sections. Future upgrades may include an active radar seeker on the Patriot warhead and a new propulsion system.⁹¹

A potential successor to Patriot is the Extended Range Intercept Technology (ERINT) missile. ERINT is a technology demonstration program that uses kinetic energy instead of the fragmentation warhead employed by Patriot. ERINT will have its own wide bandwidth radar for guidance to the target and high impact velocity to achieve a kinetic kill. ERINT promises improved performance over Patriot.⁹² ERINT will use existing Patriot launchers; however, since ERINT is smaller, four ERINT missiles will fit into each launcher instead of just one of the larger Patriot missiles.⁹³ The first two ERINT test flights were successfully completed in June and August 1992. Plans call for eight additional tests in 1993. These ERINT tests will also influence the final PAC-3 package.⁹⁴

Terminal Defense: Analysis

The Patriot system meets some, but not all, of the five measurement criteria. First, it is only partially effective against tactical ballistic missile attack. The spotty Desert Storm experience discussed in Chapter 1 forms the basis for this reserved judgment about Patriot. The Army recognizes the deficiencies and is working on improvements. Patriot does meet the second and third criteria, namely all-weather, day and night operations. It is also unaffected by geography. Patriot is relatively simple, with intelligence tip-offs coming from national assets. ERINT seeks to improve upon the Patriot groundwork. ERINT should be more effective, while retaining all the other positive aspects of Patriot. A final judgment about ERINT must await the result of additional tests.

Active Defense: Concerns

Any ballistic missile getting through the defenses is cause for worry. The threat of chemical warheads was present during the Gulf War, but fortunately Iraq only used conventional munitions.⁹⁵ Intercepting a ballistic missile carrying a chemical warhead could be dangerous. The chemical agent might spread over one's own forces. Locating and destroying hostile ballistic missiles either before or soon after launch minimizes the

risk of chemical agents or missile debris falling on friendly territory. The Patriot record in Israel highlights this concern. Before Patriot deployment to Israel, Iraq fired 13 Scuds that damaged 2,698 apartments and injured 115 Israelis. After the US rushed them to Israel, Patriot missiles intercepted 11 Scuds, but the damage was greater than before. These 11 Scuds damaged 7,778 apartments and injured 168 people.⁹⁶ When the Patriots intercepted the Scuds, the collision spread missile parts over a wider area, resulting in this higher level of damage. While this is regrettable, the presence of the Patriots had a calming effect on the Israelis. They at least felt they were fighting back, so the political impact of the Patriot was quite positive. Still, it is important to remember that even a highly effective terminal defense system creates the risk of collateral damage.

Active Defense: Space Assets

In a speech given on 29 January 1991, President George Bush scaled back the original Strategic Defense Initiative (SDI) program. Rather than trying to build a system to defeat a massive Soviet attack, he directed a shift to the more modest goal of defending against 100 to 200 reentry vehicles.⁹⁷ The earlier SDI plan called for about 4,000 space-based Brilliant Pebbles interceptors. President Bush cut that number to 1,000.⁹⁸ Then, as mentioned previously in this paper, Secretary of Defense Les Aspin terminated space-based weapons in May 1993. Although Brilliant Pebbles appears to be dead for now, a quick review of its design goals is in order.

Brilliant Pebbles are small, 100 pound technical marvels created to detect and kill theater ballistic missiles, ICBMs, and SLBMs in their boost and mid-course phases.⁹⁹ Brilliant Pebbles use a small, inexpensive TV camera to locate a ballistic missile's launch plume and kinetic energy to destroy the enemy missile as it travels in the exoatmosphere.¹⁰⁰ It also has an on-board infrared sensor for terminal guidance to the target.¹⁰¹ Although it was an ambitious program, the Brilliant Pebbles goal is still attractive. It is impossible to predict whether Brilliant Pebbles may one day rise from the ashes or become simply a footnote in the history of ballistic missile defense.

Space Assets: Brilliant Eyes

One element of space-based defense that may survive is Brilliant Eyes. Brilliant Eyes is not a weapon. Brilliant Eyes is a proposed constellation of sensors in low earth orbit that would contribute to TMD by providing a continuous global monitoring system. Brilliant Eyes could cue ground defenses, thereby allowing ground-based missiles to intercept attacking missiles farther from their intended targets.¹⁰² During a ballistic missile's boost phase, the infrared signature is relatively easy to detect with space-based sensors.¹⁰³ In the mid-course phase, after missile burnout, the missile signature is quite dim. However, it is still detectable by infrared staring sensors. The reentry phase lasts only 30 to 100 seconds, hence the value of Brilliant Eyes in expanding the engagement battle space from the launch point to reentry.

Unlike airborne platforms, Brilliant Eyes does not violate enemy airspace. Furthermore, third world countries lack the capability to shoot down or jam it.¹⁰⁴ Compared to geosynchronous sensors orbiting at 22,000 miles above the Earth, Brilliant Eyes orbits at about 1,000 miles over the planet. The lower orbit helps Brilliant Eyes pick up dimmer targets, provides better tracking, and makes it easier to calculating warhead trajectories with precision.¹⁰⁵ Brilliant Eyes' payload has a multiple-band sensor suite including shortwave infrared (SWIR), medium-wave infrared (MWIR), medium/long-wave infrared (M/LWIR), long-wave infrared (LWIR), and visible.¹⁰⁶ The sensor suite can detect ballistic missiles in their boost phase and after burnout. It can also differentiate between real warheads and decoys.¹⁰⁷

The primary value of Brilliant Eyes is its ability to conduct mid-course tracking and cueing for ground-based interceptors. This seems to fit with Secretary Aspin's decision to use ground-based weapons for missile defense. Brilliant Eyes could use its visible and infrared sensors to support target-kill assessments.¹⁰⁸ It complements without competing against the Defense Support Program (DSP) replacement called the Follow-on Early Warning System (FEWS). Brilliant Eyes can observe predesignated geographic

“hot spots,” or another early warning sensor can cue Brilliant Eyes to search for missile launches.¹⁰⁹

Brilliant Eyes extends the battle space and defended area by giving earlier warning of missile attack. It provides early and accurate interceptor commits. This reduces the number of missile batteries needed to defend a given area. For example, with Brilliant Eyes cueing, a single THAAD battery could protect all of Israel and much of the surrounding region from Iraqi missile attack.¹¹⁰ Brilliant Eyes could aid in earlier, higher intercept opportunities and provide the warning time needed for a shoot-look-shoot approach to the ballistic missile defense problem.¹¹¹ THAAD missiles would provide the first shot followed by Patriot or ERINT for the second shot. The combination of Brilliant Eyes and TMD ground-based radar would also enhance target detection and kill assessment through dual phenomenology.¹¹²

Besides its role in active defense, Brilliant Eyes could aid attack operations by pinpointing the missile launch site and cueing offensive assets.¹¹³ This could reduce search times for manned or unmanned vehicles, reduce the number of sorties required to find and kill mobile missiles, and lead to lower attrition rates for attack operations missions.¹¹⁴ BMDO plans Brilliant Eyes subsystem demonstrations for late in FY 93, with flight qualification by FY 95.

Space Assets: Analysis

Cancellation of Brilliant Pebbles is a controversial decision, just as the original decision to embark on the Brilliant Pebbles program was controversial. The theory behind it has considerable appeal, but Brilliant Pebbles fell victim to those who oppose putting weapons in space. Brilliant Eyes is non-threatening, so it should survive. It is not an end in itself. Rather, it adds to the effectiveness of ground-based systems and should be an advantage for active defense and attack operations.

Active Defense: Naval Applications

Putting TMD capabilities on Navy ships offers the important advantage of forward presence without requiring foreign basing.¹¹⁵ The Navy could develop a multitiered TMD capability, including the ability to attack missiles in their boost phase.¹¹⁶ This would help reduce the number of enemy ballistic missiles flying over friendly territory and keep debris on the adversary's side of the line. The Navy could station forces near trouble spots for relatively long periods, while avoiding some of the political liabilities created by stationing ground or air forces on foreign soil. Plans call for all 22 AEGIS cruisers and 26 AEGIS destroyers to receive the AEGIS SPY radar and associated software for ballistic missile operations.¹¹⁷ These upgrades will help provide the Navy with a terminal defense capability against tactical ballistic missiles similar to the enhanced Patriot PAC-3 system on land.¹¹⁸

Passive Defense

Passive defense measures, although less glamorous than attack operations or active defense, are still necessary for a balanced program to defeat ballistic missile attacks. Actions include deception efforts to confuse the enemy, hardening of facilities and protection of vital assets, and dispersal to present a less inviting target. Dispersal depends on adequate tactical warning of missile attack. Although these steps seem relatively straightforward, they are often not easy to implement in practice. For example, there was a serious shortage of available ramp space in Saudi Arabia during the Gulf War. This forced the US to pack aircraft into confined areas. Fortunately, the Scuds did not find these concentrations of coalition aircraft. The US should take positive steps to reduce our vulnerability to theater ballistic missile attack. A future adversary with more accurate missiles could create havoc. Passive defense must be a prime consideration in any prospective deployment.

C⁴I

The Air Force has taken action to improve battle management C⁴I architecture through a TMD baseline simulation. The Air Combat Command's Air Warfare Center at

Eglin AFB, Florida conducted a demonstration at White Sands Missile Range, New Mexico in January 1993. ACC established a simulated air operations center at White Sands while an RC-135 served as the airborne command element instead of an AWACS.¹¹⁹ Additional assets included a Collection Reporting Center (CRC) at Roswell, New Mexico, simulated DSP, a Modular Control Element (MCE) serving as the ground control element, two TPS-75 radar units, a U-2, and a JSTARS emulator. A US Army Lance missile played the role of a hostile Scud ballistic missile while four F-15E fighters from Nellis AFB, Nevada employed simulated weapons.¹²⁰ The test also included ballistic missile decoys for added realism.

The Army launched the Lance from a clandestine location within the White Sands range. The TPS-75, Cobra Ball, and simulated DSP relayed launch data to the CRC for fusion.¹²¹ The CRC calculated launch and impact points and forwarded this information to the U-2, JSTARS emulator, and the simulated defensive batteries. The U-2 detected the launch and vectored the F-15Es close to the launch area. Meanwhile, the JSTARS relayed information about the Lance's (Scud's) movements to the U-2. Next, the U-2 found the Lance TEL and relayed coordinates to the CRC. The CRC told the fighters where to look. Scud decoys complicated the search problem, but the F-15Es found the real TEL using on-board radar and infrared sensors.¹²² The fighters concluded this successful simulation exercise by destroying the TEL. The goal of future demonstrations is to improve the speed of the operation and involving assets from other services. The next demonstration will take place in the fall of 1993. A portion of the exercise will take place at White Sands Missile Range while Nellis AFB will host the second phase.¹²³

C4I: Analysis

The demonstration described above seeks to improve communications between existing assets and increase the US's capability to detect and destroy mobile tactical ballistic missiles. The effort is important since it requires little additional investment. Judging how this approach does or does not satisfy the five measurement criteria is

difficult. First, it is too early to know the degree of improvement to expect from better coordination of assets. If future demonstrations show significant performance gains, perhaps the US can delay costly new antiballistic missile systems. The fifth criterion, simplicity, is the biggest concern with this approach. Getting all of these different platforms to work properly at the same time is a serious challenge. Communications links could prove susceptible to interruption. Those involved with this project will use additional simulations to try to overcome these potential problems.

Closing Thoughts

The TMD gameplan represents an ambitious and comprehensive approach to countering theater ballistic missiles. If Congress believes the threat is serious enough and appropriates sufficient funds, a multilayered defense is possible. If dollars dry up, only the most effective components of TMD will survive. Since attack operations are potentially of great value against theater ballistic missiles, we shall now focus on this first layer of defense in more detail.

Notes

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Chapter 4

Missile Attack Operations

The unmanned vehicle today is a technology akin to the importance of radar and computers in 1935.

—Edward Teller, 1981¹

The previous chapter outlined the TMD gameplan and explained how each of the four layers—attack operation, active defense, passive defense, and C⁴I—contribute to missile defense. The purpose of this chapter is to explore in more depth specific programs to carry out attack operations. Destroying theater ballistic missiles in known storage facilities or in their factories is relatively easy. Finding them once they deploy away from their main operating bases is the difficult job. During Desert Storm, manned aircraft flew “Scud cap” patrols over suspected Iraqi missile deployment areas. US intelligence assets, including JSTARS, monitored Scud launches and vectored US planes to the suspected launch areas. These attempts at finding the Scuds or their TELs failed, thus the push to do a better job of attack operations.

There are three general approaches to the problem. First, Chapter 3 discussed plans to enhance the US’s existing attack aircraft capabilities. The second method uses unmanned search vehicles as scouts to locate tactical ballistic missiles and relay the information back to a ground or airborne C² node. The C² node then would relay missile coordinates to manned aircraft that would reacquire and destroy the missile and its launcher. A third approach, more of a long-term vision, calls for a completely autonomous unmanned vehicle capable of locating a mobile missile and then destroying it with on-board submunitions. This third idea requires advances in technology that are not yet available. However, each of these concepts deserves exploration and serious evaluation. The next section will review the progress of unmanned vehicles.

Unmanned Vehicles

The distinction between cruise missiles, unmanned air vehicles (UAVs) and autonomous air vehicles (AAVs) is not always clear. For purposes of this paper, the following definitions apply. Cruise missiles fly a programmed route to deliver a conventional or nuclear warhead. Cruise missiles have limited on-board decision making capability—restricted to navigation updates and final course corrections to the target. A UAV relies on a human interface to make decisions and has no autonomous flight planning capability. An AAV has independent decision making capability like a manned aircraft. The AAV uses its on-board mission management subsystem to accomplish this function. The AAV can react to new information without outside intervention.² An AAV may or may not have weapons on board.

The history of UAVs extends back to World War I and the first pilotless bomb, but the war ended before it went into mass production.³ Research and development on unmanned vehicles have continued through the years. The US achieved notable success with cruise missiles and UAVs during Desert Storm. The Navy's Tomahawk Land Attack Missile (TLAM) and the Air Force's Conventional Air Launched Cruise Missile (CALCM) proved their value. The first weapons launched during Desert Storm were CALCMs fired from B-52s based at Barksdale AFB, Louisiana. Seven B-52s flew to a designated point well outside Iraqi airspace, launched 35 CALCMs, and returned safely to home base.⁴ The 35-hour mission covered 14,000 miles and was the longest combat mission in history.⁵ Nine Navy ships, including a submarine, fired more than 100 Tomahawks on the first night of the war.⁶ The CALCMs and Tomahawks flew programmed missions at low altitude over Iraq to avoid detection.⁷ These cruise missiles helped to open holes in Iraqi defenses and struck difficult targets without risking American lives.

While cruise missiles destroyed high-value targets inside Iraq, UAVs proved equally useful. The US Navy's Pioneer UAV flew 523 missions in Desert Storm.⁸ The

Navy kept at least one Pioneer UAV in the air continuously throughout the war.⁹ The Navy used it to adjust naval gunfire, perform damage assessment, and conduct reconnaissance.¹⁰ The Pioneer is a versatile system. It can land on a conventional runway, use a capture net, a parachute recovery system, or let a helicopter or airplane pick it up using a snag recovery method. Pioneer can fly either a programmed route or it can fly by way of manual radio commands.¹¹ The Pioneer used real time TV images during the day and FLIR at night to accomplish its mission.¹² A Pioneer UAV launched from the USS Missouri even received credit for “capturing” hundreds of Iraqi soldiers on Faylaka Island, the first such incident in history.¹³ Despite these successes, the US military and Congress still have reservations about the utility of unmanned systems.¹⁴ Manned systems are more flexible and enjoy more appeal, but other nations are pushing ahead with selected UAV/AAV applications.

Foreign Experience

The French Apache program (not to be confused with US Apache helicopters) consists of an advanced cruise missile with 10 Kriss runway cratering submunitions. The submunitions deploy parachutes similar to the famous Durandal bomb that uses a rocket booster to penetrate concrete runways. Manned aircraft carry the Apache to its designated launch point. The Apache can then fly up to 90 miles before dispensing the submunitions.¹⁵ The Apache’s body is faceted much as the F-117 stealth fighter. Radar energy penetrates the Apache’s skin and disperses within the layers of foam.¹⁶ Small size, along with stealth characteristics, makes it difficult to spot visually, with radar, or with infrared detectors.¹⁷ To further aid in defeating enemy defenses, the Apache flies a terrain following profile and uses both an inertial unit and GPS for navigation. Apache is compatible with numerous fighter aircraft including the Mirage 2000, Tornado, F-16, and F-15E. Planned operational capability for the Apache is 1995.¹⁸

The Israelis used UAVs when they invaded Lebanon in 1982 to decoy Syrian air defenses.¹⁹ When the Syrians activated their fire detection radars in response to the UAV

decoys, the Israeli fighters launched radar homing missiles to destroy the Syrian sites, including 17 of 19 SA-6 batteries.²⁰

UAVs/AAVs: Pros and Cons

UAVs and AAVs have several advantages, as well as distinct disadvantages, relative to manned aircraft. Perhaps the biggest advantage as well as the biggest disadvantage for a UAV/AAV is that no human is on board. Therefore, no crew members risk their lives flying over hostile territory. The disadvantage is that no human is present to react to unplanned circumstances. In 1991, Major General Richard E. Hawley expressed this view when he said UAVs could complement manned platforms but “won’t be as responsive as the manned plane.”²¹

In Desert Storm as in Vietnam, the US wanted to get downed airmen back home safely. The search and rescue effort consumes a considerable amount of resources and is not always successful. Perhaps what is more important, the enemy may use captured crew members to gain political leverage over US leaders or for propaganda purposes. While shooting down a UAV or AAV is a loss for the US, the effects are less in terms of human and material cost.²² UAVs proved their versatility during Desert Storm by performing reconnaissance and electronic countermeasures’ missions without risking lives.²³ UAVs and AAVs tend to be smaller than manned aircraft and generally are less susceptible to radar or visual observation.²⁴

UAVs and AAVs can withstand higher G forces than aircraft, which helps increase survivability. Along with the small physical dimensions, new radar absorbing materials contribute stealth characteristics to UAVs and AAVs, reducing their vulnerability to defensive fire.²⁵ Along with improved survivability, advances in electronic miniaturization and computer technology make it possible to put more function into unmanned vehicles than ever before.

Computers process information at a much faster rate than people can. The tremendous volume of information involved with the mobile missiles search mission can

easily overwhelm a human operator. Manned and unmanned systems will rely on computers to automate the task of locating and identifying mobile missiles. Someday, the computer algorithms may do such a fine job of target discrimination, they will make human intervention unnecessary.

Another clear difference between manned and unmanned vehicles is the speeds they fly. Aircraft travel so fast it is almost impossible to locate, identify, and destroy a mobile missile on a single pass. An aircraft on a second pass over a target is at increased risk from hostile air defenses. Unmanned vehicles normally fly at considerably slow speeds than modern jet aircraft. Slower speeds actually aid the mobile missile search but increase the risk to the unmanned vehicle. For example, a UAV or AAV could loiter for over an hour in a search area to get different looks at potential targets.²⁶

To maintain the principle of human decision making, an unmanned vehicle with submunitions could relay sensor images to a manned airborne or ground station for weapons' release authorization. Once given approval, the UAV could execute a 270 degree turn and pass back over the target in about two minutes.²⁷ A 360 degree racetrack would take approximately three minutes at normal cruise missile speeds. This means the mobile missile would likely not have time to relocate before the second pass.

The differences between manned and unmanned systems produce distinct advantages and disadvantages. Planners must evaluate the unique attributes of each and try to match capabilities to particular missions.

Attack Operations: New Technology

Automatic Target Cueing (ATC) systems and Automatic Target Recognition (ATR) algorithms are advancing. What do these terms mean? In the case of the mobile missile search mission, an ATC system has two tasks. First, it points on-board sensors at specific locations that intelligence analysts believe have a high probability of containing a mobile missile. Second, the ATC system reacts to sensor information that indicates the possible presence of a mobile missile. The ATC then directs the sensor, or sensors, to

take additional images of the suspected target. ATR algorithms are computer programs that correlate sensor images with stored data about a particular target. For example, an ATR program has stored in its memory the dimensions of the target vehicle, distance between axles, etc. The ATR compares sensor images with its stored data to determine whether the object is or is not a valid target.

The Navy uses a similar concept with its Tomahawk cruise missiles. Tomahawk has a TV camera and a Digital Scene Matching Area Correlation (DSMAC) to match stored images of a target area to the real time TV pictures.²⁸ With this technique, Tomahawk achieves outstanding weapon delivery accuracy. Buoyed by Tomahawk's success in the Gulf War against fixed targets, the Navy is also considering how unmanned vehicles can search for and destroy mobile targets. An AAV with submunitions could acquire and attack mobile missiles before the hostile missiles could relocate. One approach even envisions manned aircraft providing defensive cover for the AAVs.²⁹ The Army is creating autonomous weapons capability by marrying target recognition algorithms to various sensor technologies including infrared, millimeter wave radar, and acoustic. The Search and Destroy Armor (SADARM) program is one example.³⁰

Since they are smaller and in many ways less complex than manned aircraft, UAVs and AAVs may be more economical.³¹ A large number of relatively cheap unmanned platforms may produce better results than a smaller number of relatively expensive manned platforms. Expensive and scarce manned aircraft such as AWACS and JSTARS are assets the US does not want to lose. Cheaper UAVs can extend the range of these valuable manned platforms and perform certain reconnaissance missions. AAVs can carry lethal weapons without the risks associated with using manned systems.³² If the UAVs or AAVs are incapable of doing a particular mission, then manned platforms should accomplish the job. The Air Force should evaluate each mission area to determine where UAVs and AAVs can supplement manned aircraft and

where they can not.³³ For example, UAVs or AAVs could perform long duration missions or fly in areas where the risks to a manned platform exceed the value added by having crew members present on the scene.³⁴ While most manned aircraft must use low altitude and speed to avoid enemy defenses, a UAV or AAV can afford to take more risk and fly at slower speeds. This makes locating mobile missiles easier.

An integrated platform, with its own sensors and weapons, avoids communications delays that could occur when two or more vehicles perform the search and kill functions. Putting detection and kill capabilities on the same vehicle also eliminates the potential for communications interruptions between a search vehicle and a separate assault platform.³⁵ Using an unmanned platform for target search, then directing in a manned aircraft for the kill, has some risk. The manned vehicle must reacquire the target, which may allow enough time for the mobile missile to relocate. It is important not to overlook the potential utility of unmanned systems.³⁶ The successes of Tomahawk and CALCM in Desert Storm could be just the beginning of more significant accomplishments by unmanned systems. Industry is responding to the challenge of the mobile missile problem with some serious programs.

MUSTRS

One ambitious approach to the mobile missile problem is the Advanced Research Projects Agency's (ARPA's) Thirsty Saber program—now known as Multi-Sensor Target Recognition System (MUSTRS). It started in 1988 as a derivative of ARPA's Smart Weapons Program, which itself began in 1986.³⁷ MUSTRS is a technology demonstration program to locate, identify, and destroy mobile targets. MUSTRS attempts to replicate the human reasoning process so that it can react to unique situations as a person would.³⁸ It combines real time sensor fusion and ATR algorithms, along with accurate submunition delivery capability, all in a self-contained pod.³⁹ ARPA and the Air Force have not decided whether the pod will house the actual submunitions.

MUSTRS makes real time on-board decisions based upon the information received from its sensors.

MUSTRS uses an advanced forward-looking infrared (FLIR) sensor and a multimode millimeter wave radar to conduct its search for mobile targets.⁴⁰ Each sensor can cue the other to potential targets. The on-board mission manager makes route changes based on information from one or both sensors.⁴¹ The system compares FLIR and radar images to stored data about the target system. Examining multiple images of the suspected target builds confidence in the final classification. The on-board computer directs the sensors to check possible mobile missile deployment sites such as along tree lines and roadsides. The sensor manager requests revisits of particular locations and the mission manager selects the routing to optimize look angles.⁴² The potential payoff is low cost per kill with no US lives lost.⁴³

Martin Marietta is developing the MUSTRS Smart Sensor Subsystem. It includes the FLIR, millimeter wave radar, ATR, and fusion processing. Multi-sensor fusion increases the system's confidence in target categorization.⁴⁴ The FLIR normally produces crisp images, but fog and rain degrade its performance. Flying close to the ground and at slower speeds reduces FLIR degradation.⁴⁵ To a certain degree, FLIR systems can penetrate smoke—a helpful feature when flying over a battlefield. The radar is an all-weather system and operates in three modes.⁴⁶ Two of them, real beam radar and Doppler beam sharpening, aid target detection and classification. The third mode, called two-dimensional, identifies target nominations made by the other two modes or by the FLIR.⁴⁷ The radar system has impressive resolution accuracy of one foot in real beam mode and two feet in Doppler beam sharpening.⁴⁸

A goal of MUSTRS is to perfect advanced ATR algorithms that separate false targets from real targets with a high degree of accuracy.⁴⁹ The FLIR and millimeter wave radar each have separate target detection and recognition algorithms based on different ranges.⁵⁰ At closer ranges, the key features algorithm compares details such as the

number of wheels, distance between axles, size of the truck cab, and missile dimensions to stored data.⁵¹ The imaged objects are “compared against range scaled and aspect rotated 3-D target models to determine the likelihood that the object is one of the desired targets.”⁵² The system compares actual radar images to radar models that predict the target’s signature. MUSTRS establishes a track file for each target as the evidence accumulates for individual objects.⁵³ The system keeps a running record of sensor footprints to ensure it checks all high-probability areas.⁵⁴

The system must cross a predetermined confidence threshold on each object before it declares a valid target. These threshold levels are variable. A high threshold is appropriate for situations with a low tolerance for hitting an invalid target. A low threshold is appropriate when a target is a threat that requires immediate destruction.⁵⁵ Thresholds can even vary at different portions of the mission. For example, a commander might request higher confidence levels when the vehicle is operating near friendly troops or in sensitive areas. Near enemy troop deployments or in isolated regions, lower confidence levels are acceptable.⁵⁶ Getting close to the target is important since false alarm rates tend to increase at longer ranges. The millimeter wave radar is the most effective sensor for target detection at distant ranges. For target recognition at mid ranges, MUSTRS uses radar and FLIR images.⁵⁷ Naturally, as range to target decreases, more information is available for evaluation and target identification.

By taking multiple looks at potential targets, and comparing images from the two sensors, MUSTRS increases the confidence level in its final target nominations.⁵⁸ The system continues to process images until the confidence level exceeds the threshold value, or the system decides the object is not a target, or “the target passes out of the field of regard.”⁵⁹ By flying at cruise missile speeds, the system could normally take about four images of a potential target.⁶⁰ This is encouraging since MUSTRS could incorporate a safety constraint to prevent attacking a target unless the sensors captured at least a certain minimum number of images.

Even at cruise missile speeds, there is a large amount of information to process very quickly. Martin Marietta's Geometric Arithmetic Parallel Processor (GAPP) speeds along at over 86 billion operations per second.⁶¹ The GAPP processes the radar and FLIR images in real time so MUSTRS can make nearly instantaneous targeting decisions.⁶²

The MUSTRS technology is adaptable to an AAV or a manned aircraft.⁶³ Putting it into on an AAV combines the search, identification, and target destruction functions on one platform. An AAV could fly along a predetermined flight path and intelligently search a suspected mobile missile deployment area, thereby maximizing the chance for mission success. It could also receive updated intelligence information in flight and change its course to examine new sites. This information could come from the AAV's home base, or directly from a reconnaissance satellite or high altitude search vehicle. A manned aircraft, equipped with the MUSTRS technology, could react similarly to new target information. The manned aircraft has the added advantage of human flexibility and reaction capability.

ARPA has set a requirement for target recognition accuracy of 65 percent, moving to an ultimate goal of 73 percent. False alarms must be less than or equal to .01 false alarm per square kilometer, with a final goal of less than .001 false alarm per square kilometer.⁶⁴ ARPA also wants MUSTRS technology to examine 96 percent of the defined search area. A planned test in the third quarter of 1993 will evaluate how well the FLIR, millimeter wave radar, and ATR help an F-15E crew find and recognize targets.⁶⁵ The aircrew will remain in the loop for final target verification during this test. In the fall of 1994, additional flight demonstrations against realistic targets, to include camouflage and decoys, will take place. These demonstrations will show whether intelligent search, multi-sensor ATRs can succeed.⁶⁶ The test-bed aircraft will fly between 100 and 350 meters off the ground at 150 to 200 mph.⁶⁷ Plans call for airborne

demonstrations on a cruise missile type vehicle in 1996.⁶⁸ MUSTRS demonstrations will evaluate FLIR, millimeter waver radar, and ATR performance.⁶⁹

There is natural reluctance to give the search and kill mission to an AAV without a man in the decision loop. Before decision makers accept a truly autonomous unmanned vehicle, it may have to pass through evolutionary stages. The success of conventional Tomahawks and CALCMs clearly demonstrates their kill capability against fixed targets. As an intermediate step to an autonomous vehicle, an armed UAV could search for mobile missiles and relay information back to a ground, air, or sea-based command center where human operators make the final weapon release decision. Unfortunately, this method would probably require the vehicle to make two passes over the target, the first pass for target identification and the second for weapon release after receiving authorization. Communicating with a C² node are susceptible to jamming. Establishing a data link might also highlight the UAV's location.

MUSTRS: Analysis

Accurate target discrimination is an important requirement. That is why this thesis lists effectiveness as the number one measurement criterion. No one wants to hit the wrong target. An AAV that cannot discriminate between a school bus and a Scud launcher is totally unacceptable. However, even human operators are susceptible to mistakes. With this in mind, the three approaches to applying MUSTRS technology—on a manned aircraft, on a UAV with human control over weapons release, or on an independent AAV—all merit careful evaluation. Additional progress with ATR algorithms is essential, particularly for UAV or AAV applications. The algorithms must prove themselves before the military and Congress will provide needed support.⁷⁰ This should not be an insurmountable challenge. When ATR development has progressed to the point where it meets the ARPA goal of 65–73 percent target recognition, MUSTRS will become a viable option for finding mobile missiles. In terms of the second and third measurement criteria, all weather and day/night capability, the FLIR and millimeter wave

sensors are satisfactory. The FLIR suffers some degradation in adverse weather. The MUSTRS vehicle minimizes this drawback by flying just a few hundred meters off the ground. The fourth criterion, adaptability to different terrain conditions, is more difficult to meet. Jungle canopy will likely defeat the FLIR. The millimeter wave radar has a better chance of penetrating foliage and camouflage nets. Additional demonstrations will determine whether MUSTRS does or does not fulfill this criterion. The specific employment option selected will determine how well MUSTRS satisfies the final criterion—simplicity. Putting MUSTRS on a manned aircraft or an AAV simplifies communications requirements. Putting it on a UAV complicates communications but reduces the risk to crew members. As the ATR algorithms become extremely accurate, the AAV approach becomes more attractive since it combines simplicity with safety. The prudent path to follow is an evolutionary process first putting MUSTRS on a manned aircraft, then on a UAV, and ultimately on an AAV when the ATR technology matures.

Additional growth opportunities for MUSTRS include more advanced infrared sensors plus sensors that detect the electromagnetic emissions and noise generated by the mobile missile launcher.⁷¹ Threat receivers added to the AAV could enable it to take evasive action when under attack.⁷²

AAVs: C-FAST

Counter-Force Automated Surveillance & Targeting (C-FAST) is the application of MUSTRS technology on an unarmed AAV. Researchers at the Air Force's Aeronautical Systems Center and the Electronic Systems Center are active participants in the C-FAST program.⁷³ C-FAST can operate day or night, in fair weather or foul. C-FAST avoids most weather obscuration by flying at between 100 and 500 meters above the ground.⁷⁴ Design specifications also require C-FAST to penetrate foliage cover and camouflage netting.⁷⁵ C-FAST combines airborne surveillance with a network for passing precise target coordinates to a C² platform and separate attack aircraft. The C² aircraft would provide overall battle management and interface with other manned

aircraft capable of conducting broad area search. These search aircraft would cue C-FAST to look at high probability locations. Cueing accuracy within a few hundred meters should be sufficient for C-FAST.⁷⁶ For example, a manned platform like JSTARS could identify a moving target and pass the information to the C² aircraft. The JSTARS' radar is incapable of positively identify the moving target as a mobile missile launcher.⁷⁷ C-FAST would accomplish that task.

For targets deep behind enemy lines and out of JSTARS' range, other reconnaissance assets need to extend the coverage. One potential platform is Boeing's Condor UAV, which flies for three days at an altitude between 55,000 and 65,000 feet.⁷⁸ The Condor, or a similar high-altitude air vehicle, could carry synthetic aperture radar (SAR), signals intelligence (SIGINT) detection equipment, or other sensors to locate mobile ballistic missiles.⁷⁹ A small fleet of these UAVs could provide continuous coverage over a large land area. High-altitude surveillance UAVs could relay target cues to C-FAST or to a manned platform.

A ship, plane, or even a truck could become a C-FAST launch platform. Carrier aircraft, such as B-1Bs or B-52s, could carry C-FAST anywhere in the world in a matter of hours and launch them based on intelligence cues. After flying its search route, C-FAST could relay a strike report back to base through a satellite link.⁸⁰ C-FAST's success or failure in finding mobile missiles would let planners know if they needed to launch additional sorties. C-FAST would have a recovery capability to prevent loss of the expensive sensors and computers. Recovery methods include a parafoil, portable arresting net, and a portable landing field.

Hughes Defense Systems produces the C-FAST Mission Management Subsystem. It contains mission management, navigation, and the guidance function that carries out the planned route of flight and target attack plan.⁸¹ The mission manager also replans the route in flight based upon fuel status, new targets that come up, unplanned threats, and requirements to revisit certain potential target locations.⁸² The C-FAST mission manager

would use logic similar to a human's to calculate a flight path to the potential target locations based on this real time information.⁸³ The mission manager would carry out its work much faster than a human could. It may even do the job better since it evaluates a wide array of decision rules. The mission manager also makes attack assessments and controls on-board munitions.⁸⁴ The Inertial Sensor Assembly and GPS receiver provide accurate navigation.⁸⁵ C-FAST would use its on-board sensors and ATR system to pinpoint target locations to within a few meter's accuracy. C-FAST ATR algorithms should be highly reliable, with low false alarm rates.⁸⁶ Indeed, there is no guarantee false alarm rates would be lower with human intervention.

C-FAST would rapidly pass this targeting information to C² elements and manned aircraft armed with GPS guided weapons.⁸⁷ The C² platform would direct strike aircraft, possibly B-1Bs, F-16s, or F-15s, to acquire and kill the mobile missile target.⁸⁸ The attack aircraft could even receive GPS coordinates directly from C-FAST or through a fusion center.⁸⁹ Researchers forecast targeting errors under five meters.⁹⁰ Aircraft can minimize attrition by launching their precision weapons outside defended territory. C-FAST vehicles could fly back to the target area to furnish real time damage assessment imagery.

Besides searching for mobile missiles on the ground, C-FAST could use its infrared sensor to locate the ballistic missile's plume immediately after launch.⁹¹

Since it is already in the active inventory, the Air Force's Advanced Cruise Missile (ACM) is a potential C-FAST body.⁹² The stealthy characteristics of the ACM would enhance C-FAST's survivability. A stealth platform would have a higher chance of penetrating enemy radar coverage while camouflage paint schemes would decrease the probability of visual detection. Since C-FAST will be considerably smaller than an aircraft and can incorporate stealth technology, it will be more survivable than most aircraft. A mid 1990s demonstration of the C-FAST concept will evaluate its dynamic

route planning and target recognition capability. There is a potential for limited prototype capability by the late 1990s.⁹³

A related Hughes program, called the Advanced Technology LAdar System (ATLAS), consists of a laser radar along with image processing. ATLAS flight tests are underway.⁹⁴ Some researchers believe the laser radar ATR will achieve higher rates of target identification than FLIR or millimeter wave radar. Hughes Defense Systems in San Diego, California is using a common test-bed aircraft for both the MUSTRS and ATLAS programs.

C-FAST: Analysis

C-FAST borrows MUSTRS technology and puts it on an unmanned vehicle. Both systems have good performance expectations relative to the five criteria. Regarding the first criterion, effectiveness, C-FAST performance specifications are encouraging, but the system remains in development. The scheduled demonstrations will provide the answer. C-FAST satisfies the second and third criteria—all weather and day/night operations. C-FAST has an advantage over MUSTRS regarding the fourth criterion. C-FAST's laser radar may furnish superior foliage and camouflage penetration compared to MUSTRS' millimeter wave radar and FLIR alone. In terms of simplicity, C-FAST is somewhat deficient. It is dependent on reliable communications with a C² node or attack aircraft. This complicates the approach. Nevertheless, C-FAST represents an important step on the path to a solution. There is one additional research effort that deserves careful evaluation, Boeing's Sensor Fusion for TMD attack operations.

Multi-Sensor Fusion

The aim of Boeing's Multi-Sensor Fusion Project is to construct a system to locate and destroy mobile missiles using either manned or unmanned platforms. At the core of the Boeing project are a smart sensor and mission manager that employ Expert Systems/ Artificial Intelligence technology. This technology adds decision rules about

how a human operator would react to particular situations. This helps the system evaluate information and prioritization of tasks.

The company used its 757 test-bed aircraft to conduct flight evaluations of three types of sensors, along with Automatic Target Recognition (ATR) algorithms. Boeing evaluated a millimeter wave radar as a wide area search sensor, plus a FLIR and laser line scanner for target identification.⁹⁵ The millimeter wave radar cannot provide positive target identification. It is capable of detecting objects at greater range than the FLIR or laser line scanner. These later two sensors furnish high resolution imagery to the human operator for final target confirmation.⁹⁶

As the mission progresses, the sensor manager uses planned high probability target locations and millimeter wave detections to aim the sensors. When the millimeter wave radar detects an item of interest, the system directs the other two sensors to examine these new points. The mission manager can modify the route plan in flight based on real time information such as external intelligence or surveillance cues.⁹⁷ The FLIR relies on differential temperature to form an image of the target, while the laser line scanner produces three dimensional range and height information to accomplish target recognition.⁹⁸ It uses the range information for distant objects and height information for near objects.

For the in-flight evaluation, Boeing set up a target range at Ft Lewis, Washington. The targets consisted of US Army tanks and refuse trucks serving as surrogate mobile missile launchers.⁹⁹ Boeing developed an area limitation data base that the company used in both the planning and execution phases. This data base assisted in the construction of optimized flight routes through the Ft Lewis range. Boeing conducted six demonstration flights from 22 April–7 May 1992. The flights produced a 62 percent probability of correct target identification.¹⁰⁰ Air Force personnel served as system operators. They reviewed FLIR and laser line scanner images nominated by the system as likely targets. The millimeter wave radar does not generate images for the operators.

The laser line scanner showed whether a target was or was not under a camouflage net.¹⁰¹ This is consistent with a report from the USAF Scientific Advisory Board. This report speculates that fusing laser radar data with infrared sensor information could defeat camouflage.¹⁰²

In September and October 1992, Boeing flew five missions with enhanced millimeter wave radar target detection algorithms, an improved FLIR, and upgraded laser line scanner. Flight results showed an improved ability to locate real targets while reducing false alarms.¹⁰³ The new millimeter wave radar algorithm successfully detected 75 percent of the primary targets that came within unobstructed view.¹⁰⁴ The Texas Instruments Q-17E FLIR produced enhanced image quality. Operators used the FLIR images to achieve a probability of correct target recognition that exceeded 95 percent.¹⁰⁵ The system detected targets hidden under two layers of camouflage netting 57 percent of the time.¹⁰⁶

Boeing believes that sensor fusion is applicable to either a manned aircraft or a UAV. For example, a UAV performing the search mission could transmit mobile missile coordinates to a strike aircraft such as an F-15E or F-117.¹⁰⁷ An alternative approach is to put two or more sensors on a AAV, along with submunitions, and let it perform the whole mission.

Multi-Sensor Fusion: Analysis

The Boeing Multi-Sensor Fusion Project is a serious attempt at a viable approach for attack operations. The in-flight demonstrations show that sensor fusion—combining millimeter wave radar, FLIR, and imaging laser radar—could provide significant capability against deployed mobile ballistic missiles. Therefore, based on the information collected by Boeing, their system appears to meet the effectiveness criterion. Their reported 75 percent detection of exposed targets using millimeter wave and 95 percent recognition accuracy for the FLIR is impressive. The choice of sensors satisfies the second and third requirements that the system operate in all weather and at night or

during the day. Multi-sensor fusion also meets the fourth criterion. The Ft Lewis, Washington area is heavily forested, representing a challenging terrain category. In addition, the imaging laser radar and FLIR combination produced a 57 percent target detection rate against double layers of camouflage netting. At the very least, these results should encourage further support and study. For simplicity, the verdict is much the same as with C-FAST. Separate search and kill platforms are a necessary intermediate step, but should not limit attempts at a fully autonomous solution.

Smart Weapons

Up to this point, the discussion has centered on how sensors and automatic target recognition apply to attack operations. Locating a mobile missile is only part of the objective. The remaining job is to destroy the missile and its TEL. A wide variety of weapons or submunitions could carry out this task. For example, either a manned aircraft or AAV could house numerous small, inexpensive rockets or shells. With precision delivery, even modest explosive charges would destroy the target since a mobile missile is quite “soft.” Shells piercing the skin of a missile canister would likely disable or even destroy it. Shooting several low cost “bullets” at the target is an economical way to increase the probability of kill. There are alternatives to this low-technology approach.

Remember that ARPA’s smart weapons program was the genesis for MUSTRS. Smart weapons have the potential to kill the mobile missile target and help find it. Smart weapons already exist for other targets, most notably armor. Textron has in production a Sensor Fuzed Weapon (SFW) Tactical Munitions Dispenser (TMD) that contains 10 submunitions. Each submunition has four Skeet warheads.¹⁰⁸ The SFW locates and kills stationary or moving armored vehicles. The targets must show a detectable temperature contrast with their immediate environment.

The Air Force is also looking into a submunition program directed at the armor threat. One version of the smart submunition program, called LOCAAS (Low-Cost Anti-Armor Submunition), uses radar to locate targets on the battlefield and then kills them

with shaped charges.¹⁰⁹ A bomber would launch the LOCAAS dispenser at high altitude, and the dispenser would release the submunitions over the battlefield.¹¹⁰ A competing design uses laser radar to create a three-dimensional image of the target. The submunition would compare stored target reference images to the sensor images to determine if an object was or was not a target.

While work continues with armored targets, Textron is likewise working with ARPA on DAMOCLES. It is an autonomous smart submunition designed to destroy tactical mobile ballistic missiles before they launch.¹¹¹ It has all weather capability and uses high resolution long-wave infrared and millimeter wave sensors to find hidden targets, even in foliage. DAMOCLES submunitions are totally independent and operate in smoke or electronic countermeasures (ECM) environments. A UAV or AAV dispenses each submunition from an altitude of 500 meters above the ground. The submunition's own parachute guides it in a shallow, circling glide path. The submunition searches a relatively wide area for mobile missiles as it slowly falls to earth.¹¹² DAMOCLES has sophisticated target recognition algorithms to reduce false alarms and high speed parallel processing. Multiple sensor platforms can scan for potential targets from several different look angles to increase the probability of target detection and kill. Each sensor would confirm real targets through multiple looks before it shoots.

Smart Weapons: Analysis

DAMOCLES sounds almost too good to be true. However, the system is receiving serious attention from the Air Force. Actual flight demonstrations will prove whether it is as effective as promised. If DAMOCLES performs as advertised—all weather, day/night, penetrating forests and camouflage, resistant to jamming, all on a self-contained unit—then it would represent a truly revolutionary advance in the search for an attack operations platform. It would meet all five criteria, including simplicity since it would not require communications with another platform for weapon release authorization.

Attack Operations: Manned Aircraft

Chapter 3 discussed the January 1993 demonstration at White Sands involving F-15Es and surveillance aircraft in a live search for a Scud surrogate. This effort aims to improve C⁴I capabilities so existing manned aircraft can do a better job finding mobile missiles. Along with that important ongoing program, this chapter has described how new technology, such as MUSTRS and multi-sensor fusion, is compatible with either manned or unmanned vehicles. Upgrading existing aircraft sensors and computer processing is a valid near-term approach. It may take many years before the more autonomous technical proposals are ready for deployment. Enhancing the US's current aircraft inventory may provide a rapid improvement in attack operations.

The Air Force's proposal to use the B-1B bomber to search for mobile missiles is one specific example of how modifications to present systems may help. The Air Force is considering plans to adapt the Low-Altitude Navigation and Targeting Infrared system for Night (LANTIRN) system for the B-1B. LANTIRN is now on the F-15E and F-16C.¹¹³ If Congress provides funding, the B-1B could receive a sensor management system combined with LANTIRN to aid in target identification.

Manned Aircraft: Analysis

Manned aircraft could become much more effective at finding deployed mobile missiles. There is practically no where to go but up. Despite all the intelligence support available during Desert Storm, aircraft failed to locate Scud launchers. Eyeballs in the cockpit will not solve the problem. Changing tactics will not solve the problem. The Air Force recognizes this and is trying to add new capabilities to its aircraft. Potential effectiveness depends on new technology.

The technology will determine whether an aircraft can function in all weather, day or night, and in all terrain environments. The first and fifth criteria are the toughest to gauge. The higher speed and wider turn radius of jet aircraft are impediments to an effective system. The risk of human life is also a consideration. This may not be a factor

in undefended areas, but high-threat situations could cause unacceptable losses. Concerning the fifth criterion, simplicity, an aircraft with its own sensors and weapons is a big plus.

If instead of a complete package, the manned aircraft is just a weapons platform, then it would be susceptible to communications upsets and consequent delays in getting to the target. Manned aircraft should and are receiving serious consideration for the attack operations phase of the antimissile mission. However, the Air Force should not concentrate solely on upgrading existing planes. A parallel program must look beyond near-term enhancements.

Attack Operations: Final Thoughts

Attack operations form the first line of defense against mobile ballistic missiles. Destroying the TELs before launch significantly reduces the number of incoming missiles that the active defense systems will have to intercept. Emerging technologies will make it easier to find hidden missiles, even under camouflage nets or jungle canopy. This chapter showed that several proposed systems may meet the five measurement criteria established at the beginning of this thesis. Decision makers and researchers should examine near-term, intermediate, and long-term goals for the tactical mobile ballistic missile mission.

Near-term systems enhancements to aircraft such as F-15Es or B-1Bs could provide incremental improvements. A combination of unmanned search platforms and manned strike aircraft would serve as a logical second step for a more effective system in the intermediate time frame—perhaps 1998 to 2003. For the long-term, an autonomous system looks attractive. Manned or unmanned vehicles, capable of fairly independent operations, avoid the plethora of communications links and interfaces present in some schemes. An autonomous attack operations system, whether manned or unmanned, greatly simplifies communications by reducing or eliminating dependence on other

systems. Although it may take a decade or more to achieve, this approach deserves further exploration.

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Chapter 5

Conclusions

This paper set out to find which technologies promise the highest level of effectiveness against mobile tactical ballistic missiles. What solutions does the evidence point to? The previous chapters showed that the mobile missile problem is too big for a single system to furnish perfect protection. A multilayered approach, consisting of attack operations, active defense, passive defense, and a robust C⁴I network forms the framework for a mobile missile defense. Not surprisingly, the layered approach helps to assure a high level of confidence in defeating the threat. Perhaps least appreciated is the tremendous leverage gained by effective attack operations. Destroying the mobile missile TELs significantly reduces the quantity of incoming missiles that the other layers have to defeat. As the lead agency for attack operations, what specific programs should the Air Force pursue?

The five criteria mentioned throughout this paper can help. The first criterion is effectiveness. A proposed solution must work to protect US assets and allies from missile attack. The second and third criteria are all-weather capability along with day and night operability. Fourth, any antitactical ballistic missile system must maintain its effectiveness in potential theaters around the globe. Finally, although the problem is quite complex, we should seek a straightforward solution. This means the fewer requirements for outside inputs the better. The more independent a given system is, the less vulnerable it is to communications interruptions and delays. The fast pace of actual combat puts a premium on rapid, decisive action to eliminate time-critical threats such as mobile missiles.

Attack Operations: The First Step

Attack operations are a key element of an effective total solution. Historically, attack operations from the air, followed by ground occupation of the launch areas, is the

only sure way to stop ballistic missile launches.¹ Allied World War II experience with the V-2s illustrates this point. To defeat mobile missiles before they launch, the defense needs to search wide areas on a continuous basis.² Brilliant Eyes could fulfill that requirement. For attack operations to succeed, the US must also complete an area limitation analysis for potential flash points around the world. This will make intelligent route planning possible and greatly reduce the search area.

A fully autonomous air vehicle, equipped with lethal submunitions, would provide a highly attractive attack operations platform. If engineers and programmers perfect the ATR algorithms, AAVs could measurably enhance the US's ability to locate and destroy mobile missiles. This approach best satisfies all five measurement criteria and best answers the question posed at the beginning of this paper. Based on the evidence gathered, it appears that an AAV—with a highly effective target discrimination system, all weather and day/night sensors capable of penetrating foliage and camouflage netting—is feasible. The AAV approach is cleaner and simpler than using separate search and kill platforms. This system is not available today. The best avenue for the DOD and Air Force to follow is a phased implementation strategy that will add capability incrementally.

Attack Operations: Phase One

With this in mind, the Air Force should continue with near-term enhancements to help current assets perform attack operations more effectively. This is a relatively low-cost endeavor. The US may face a theater ballistic missile threat before more advanced technology is available. This strategy could pay big dividends if quick, inexpensive upgrades produce a higher probability of target detection. For example, installing MUSTRS technology or Multi-Sensor Fusion technology on a manned platform is a viable alternative to putting this equipment on an unmanned vehicle; however, this puts lives and expensive aircraft at risk. Because UAVs or AAVs are less expensive, the Air Force could procure more of them. *Ceteris paribus* (other things being equal), more

search and kill platforms should mean a better chance of finding and destroy the mobile missiles. Analysts should compare the cost of putting a search capability on an unmanned vehicle to the cost of adding it to a manned aircraft. The UAV or AAV solution may be less costly than using manned aircraft. If this is the case, the manned aircraft approach must demonstrate additional performance to justify the additional expense. Despite these problems with the manned aircraft approach, there are some very important reasons for going ahead with it.

First, the manned aircraft already exists in the form of F-15Es, B-1Bs, etc. The taxpayers have already made the investment in the airframes. Only the incremental costs of adding search and kill capability is relevant. Second, scientists may have difficulty replicating human reasoning powers in a computer. The flexibility of the human decision maker is an unquantifiable factor—nevertheless this added advantage for manned vehicles is an important consideration. Third, national leaders may have more confidence in a military operation knowing that people, not just machines, are making the final decisions.

However, based on the Desert Storm results, improving the interfaces between various airborne platforms and intelligence fusion centers may yield only incremental benefit. Even the F-15E's radar is inadequate for identifying a mobile missile launcher.³ Also, communications links are susceptible to interruption and jamming. This does not mean these near-term efforts should stop. It does mean that the Air Force and DOD should aggressively investigate other programs, aimed at more substantial performance results. An open mind and willingness to explore new territory are essential ingredients for an objective evaluation of alternatives.

Attack Operations: Phase Two

The MUSTRS technology installed on an unarmed C-FAST AAV is a logical second step. Boeing's Multi-Sensor Fusion Project also merits further consideration. Boeing has shown great progress with sensor technology to defeat foliage and

camouflage. The ideas behind MUSTRS/C-FAST and Multi-Sensor Fusion are quite similar. They both appear to satisfy the five measurement criteria to a fairly high degree. Future demonstrations would prove precisely how capable they really are. C-FAST could locate the mobile missiles and a manned aircraft could fly in to destroy them. However, instead of requiring the aircraft to fly directly over the target, C-FAST could relay images to a “shooter” aircraft with standoff weapons. This preserves the principle of man-in-the-loop without risking lives.⁴

It is somewhat surprising that ARPA, after putting MUSTRS technology on an AAV and calling it C-FAST, is not going the extra mile and putting submunitions in the vehicle. The potential problems with the existing C-FAST approach are complex communications requirements between the various airborne platforms and resultant delays in getting a “shooter” to the mobile missile launcher. Minutes-old information may or may not be good enough. Since the TEL can relocate in a matter of a few minutes, any delay may allow the launcher to escape. This happened during Desert Storm.

Attack Operations: Phase III

When and if the ATR algorithms mature to the point where human involvement is unnecessary, the Air Force should support a truly autonomous system. For example, C-FAST with smart submunitions like DAMOCLES could form the basis of an exceptionally effective system. Assuming the technology works as advertised, the combination of a smart search vehicle with smart or even brilliant weapons would furnish tremendous capability against theater mobile ballistic missiles.

Active Defense: Technology Review

Active defense remains a firm requirement since current and projected attack operations technology will not locate all mobile missiles before launch. The Air Force is concentrating on the boost phase of a ballistic missile’s flight profile and has high hopes for its Airborne Laser program. An Airborne Laser platform is attractive since it could

operate above or away from clouds. Terrain conditions are not a factor. The current approach uses a manned platform with a six-hour loiter capability. This relatively short on-station time is a limitation, but having more platforms would compensate for the short loiter time. Effectiveness is still a question mark. The system's ability to destroy missile in flight is still undetermined.

RAPTOR/TALON is a tempting alternative boost-phase weapon. This BMDO project overcomes the long loiter problem by using a vehicle capable of remaining on station near world trouble spots for weeks—perhaps months—ready for short-notice contingencies. Like the Airborne Laser, RAPTOR/TALON is yet unproven, but it is potentially a major part of a theater ballistic missile defense. RAPTOR/TALON meets the five criteria and merits continued development. If it proves its capabilities, RAPTOR/ TALON could serve as a cost effective boost-phase weapon.

Another element of active defense is THAAD missiles for high-altitude intercepts. The THAAD program is very much alive and well. The technical risk factors associated with ground-based interceptors are less than with other programs such as the Airborne Laser. A THAAD missile based on the ERIS prototype could intercept inbound ballistic missiles outside the atmosphere. Support for THAAD appears strong. The design objectives for THAAD defensive missiles meet the five criteria. Further tests will determine exactly how well it achieves these objectives.

Patriot or the more advanced ERINT missiles will perform close-range terminal engagements with incoming ballistic missiles. Patriot's PAC-3 upgrade is in development. This will extend Patriot's capability against targets that have lower radar cross sections. The smaller ERINT missile would further enhance US terminal defenses. These programs will continue. ERINT should satisfy the five criteria better than Patriot.

Attack Operations and Active Defense: Recommended Path

The DOD and Air Force should follow the three-phased approach outlined above for attack operations. This evolutionary scheme allows for the implementation of

technology as it matures. The most promising approach combines the DAMOCLES submunition with a C-FAST/MUSTRS AAV or Boeing's somewhat similar Multi-Sensor Fusion technology. Budget pressures may delay these ambitious programs, but the DOD and Air Force should continue to look for long-range solutions, in addition to short-range enhancements. For active defense, BMDO should keep pressing ahead with RAPTOR/TALON, THAAD, and Patriot/ERINT. The potential effectiveness of the Airborne Laser is less certain. Additional research should determine how well the Airborne Laser satisfies the first and fifth criteria.

Final Thoughts

The proliferation of tactical ballistic missiles is a growing challenge. The parallel spread of nuclear, biological, and chemical weapons could turn certain third world nations into menacing opponents. The United States has become more concerned about mobile missiles because of what happened during Desert Storm. As the memory of that war fades, the level of interest in solving the defense problem may also decline. That would be a mistake. The US must field a system to find the target, kill the target, and assess damage.

The path outlined above shows how technology may provide a solution. The challenge is complex. It requires determination and a willingness to commit financial resources over many years. Competing societal needs as well as other legitimate defense requirements must receive proper consideration. However, this nation should not ignore or minimize the potential danger posed by mobile tactical ballistic missiles. A steady effort, as outlined above, should take the US toward a solution.

Notes

¹Michael W. Ellis and Jeffrey Record, "Theater Ballistic Missile Defense and US Contingency Operations," *Parameters*, Spring 1992, 19.

²George W. Conner, Mark A. Ehlers, and Kneale T. Marshall, "Countering Short Range Ballistic Missiles" (Department of Operations Research, Naval Postgraduate School, January 1993), 5.

³Report for Tactical Air Command, "Requirements Survey for Theater Missile Defense (Pre-Launch)," (Hampton, Va.: Betac Corporation, 31 March 1992), 44.

Notes

⁴Gilbert G. Kuperman, Air Force Materiel Command, Armstrong Laboratory, interview with author, 18 December 1992.

Appendix 1: Emergence of the Threat

The V Weapons: V-2

Of the two German V weapons, the V-2 most closely parallels the modern theater ballistic missile. The development of a long-range rocket dates back at least to 1923 when the German scientist Herman Oberth conceived of a liquid fuel rocket for carrying poison gas to Germany's enemies.¹ He was a visionary who viewed interplanetary missions as a worthwhile human pursuit. It was an American though, Dr Robert Goddard, who had the honor of launching the world's first liquid fuel rocket in 1926.² By 1936 German Major General Walter Dornberger devised plans for the A-4 rocket that, although it weighed 13 tons, was transported and fired from a mobile truck launcher.³ Dornberger's team originally scheduled the A-4 for mass production beginning in September 1941. However, Hitler made a crucial decision and cut the program's steel allocation by 50 percent on the assumption he would not need rockets to gain victory over Germany's enemies.⁴ After Hitler failed to win the Battle of Britain, he again ordered work to proceed on the project. Testing of the A-4 began in early in 1942, but the first three launches were failures. The first successful A-4 launch did not take place until 3 October 1942. Finally, a militarily useful ballistic missile was born as the vehicle flew 118 miles to a target in the Baltic Sea.⁵ The A-4 evolved into the V-2, or *Vergeltunswaffe 2*, meaning Vengeance or Reprisal Weapon.⁶ The other V weapon, the V-1, was the cheaper "buzz bomb," an early cruise missile.

Because he lacked a suitable air force, Hitler could not retaliate in kind for the bombing of German cities. He remained skeptical about the new missiles and once dreamed the V-2 would never make it to England.⁷ Hitler's armaments minister, Albert Speer, helped convince him the V-2 was a viable weapon. In July 1943, Speer showed Hitler a color movie of a successful V-2 launch. The movie impressed the German leader so much that he elevated the program to the highest priority, along with tank

development.⁸ He saw the V weapons as a formula for exacting retribution from the British and boosting domestic morale.⁹ There remained a disagreement over the V-2's launch mode. General Dornberger argued for small, mobile launchers. Hitler wanted large rockets, fired from fixed sites, capable of carrying ten tons of explosives.¹⁰ Hitler initially won the argument, but Dornberger later built mobile V-2 launchers. This was a significant step because mobile launchers were extremely difficult to locate.

The Germans shot approximately 2,600 to 3,000 V-2s toward Allied territory between 8 September 1944 and 27 March 1945.¹¹ The V-2 had a payload of 2,150 pounds and a range of 180 to 220 miles.¹² Unlike the relatively slow V-1, the V-2 was literally impossible to stop. The V-2 shot through the sky at supersonic speeds of about 2,500 mph, making it completely invulnerable to all defensive measures of the time.¹³ This invulnerability helped the Germans rationalize the heavy investment required for the V-2 program. A single V-2 cost about 20 times more to produce than a V-1; however, the damage produced by the V-2 was not in proportion with its higher cost.¹⁴ Fortunately for the United States and its allies, the war ended before the Germans could realize their dreams of intercontinental missiles. At war's end, the Germans were working on a long-range missile with the capability of hitting New York City.¹⁵ One should not dismiss this as fantasy since the brilliant young scientist, Wernher von Braun, led the V-2 team. It was von Braun who, just 24 years later, directed America's successful Apollo mission to the moon.

A multitude of technical problems delayed operational use of the V-2 by many months.¹⁶ In March 1944, *Reichsfuehrer* SS Heinrich Himmler further delayed the V-2 by arresting and threatening von Braun in a failed attempt to take control of the rocket program away from the German Army.¹⁷ Despite all the obstacles, the Germans fired the first V-2 in anger toward Paris on 6 September 1944.¹⁸ Just two days later the first V-2 rocket to land in England struck Chiswick and killed three people.¹⁹ The V-2 initially caused few casualties and seemed less threatening than the V-1. That perception changed

on 25 November 1944 when a single V-2 produced 268 casualties in London.²⁰ Unlike the V-1, the V-2 struck without warning, and people were unable to take shelter. The unpredictability of the V-2 made it a more sinister, and deadly, weapon than the V-1. A single V-2 killed 160 shoppers in a London Woolworth's store.²¹ On 16 December 1944, a V-2 aimed at the port of Antwerp missed its intended destination and instead killed 271 people in a packed theater.²² By February 1945, the Germans were launching about 10 V-2s per day at England.²³

The V Weapons: V-1

The V-1 was completely different from the V-2. The V-1 was the forerunner of today's cruise missiles. It was relatively inexpensive and slow, but was produced in large quantity. From 13 June 1944 until 29 March 1945, the Germans launched between 10,500 and 13,000 V-1s, including about 1,600 from Luftwaffe aircraft. The V-1 had a payload of 1,988 pounds and flew at 350 to 420 mph, remarkably close to the speed of modern cruise missiles.²⁴ The V-1 was capable of carrying poison gas warheads but the Germans stayed with a conventional explosive.²⁵ Although primitive by modern standards, the V-1 was a technical marvel for its time. The V-1 relied on three gyroscopes for guidance. At a predetermined point in the mission the fuel shut off, and the V-1 dove toward its intended target.²⁶ It was not an accurate weapon. At its average range of 130 miles it had a circular error probable (CEP) of about 8 miles. The V-1 was 27 feet long, had a wingspan of 17 feet, and was an inviting target.²⁷ The British quickly learned they could deal with the V-1. RAF fighters and anti-aircraft batteries trained their sights on the V-1s over England.

The V Weapons: Allied Countermeasures

First, even before the outside world knew much about the V-1 and V-2, the Allies tried to deal with these weapons programs by attacking them at their source in Peenemunde, Germany. The British Special Operations Executive (SOE) first learned of the German experiments in 1942 through contacts with the local underground.²⁸ British

intelligence experts also carefully examined aerial reconnaissance photographs taken of the area. In June 1943, after the British obtained pictures of an A-4 (V-2) rocket on its launch pad, they decided to launch an air raid. Sir Arthur “Bomber” Harris planned the attack and hoped to kill many of the German scientists working on the rocket projects.²⁹ Harris launched Operation Hydra on 17 August 1943 as 590 British bombers struck the German rocket facilities at Peenemunde.³⁰ The British lost 40 aircraft and 240 men, but the bombers managed to destroy many of the research buildings. The British felt satisfied with the strike and thought they had destroyed Peenemunde.³¹ Unfortunately, the bombs also killed hundreds of foreigners forced to work at the plant and many German civilians, some of them young women.³² General Dornberger claimed at least 735 people died as a result of the raid. However, among the key scientists, the raid only claimed the life of propulsion expert Dr Walter Thiel.³³ Dr von Braun even risked his own life during and immediately after the attack. He rushed into burning buildings to save vital documents from the fires that engulfed several of the important offices.³⁴

The raid was the last straw for Luftwaffe chief of staff *Generaloberst* Hans Jeschonnek. He took the blame for the Luftwaffe’s failure to defend Germany’s skies against Allied bombers. Jeschonnek could no longer tolerate the verbal abuse he received from *Reichsmarschall* Hermann Goering and Field Marshal Erhard Milch. Jeschonnek committed suicide on 18 August, the day after the Peenemunde raid.³⁵

Dornberger and von Braun were quick to react to the raid without causing a significant disruption to the missile programs. They dispersed the work formally concentrated at Peenemunde to different locations in Germany and Nazi controlled Europe. The Germans continued some work at Peenemunde while they relocated production facilities to Mittelwerke near Nordhausen, south of the Hartz Mountains. This underground location was impervious to Allied bombing since the rock walls were 25 to 30 feet thick.³⁶ Nordhausen contained the largest underground factory in the world, at one time employing 10,000 slave laborers. The Germans produced almost

6,000 V-2s here by April 1945 when American troops captured the facility intact.³⁷ The Germans also moved their missile test operations to secret installations in occupied Poland.

After the Peenemunde raid, while the Germans busied themselves with research activities, the British continued their aerial reconnaissance to analyze German progress in rocket development. Flight Officer Constance Babington-Smith, while looking at a picture taken on 28 November 1943, discovered what turned out to be a V-1 missile and launch ramp.³⁸ Soon, photo interpreters detected other similar locations. The British decided to strike these mysterious weapons before the Germans had a chance to use them. In early December 1943, bombers pounded 95 identified V-1 ramps. This was the beginning of the Allied air campaign, code named Operation Crossbow, against the V weapons. Crossbow continued until just before German surrender in 1945.³⁹

On Christmas Eve 1943, 672 B-17s went after an additional 24 launch ramps.⁴⁰ This intense bombing had an unintended consequence that worked to the detriment of the Allies. The bombing caused the Germans to develop prefabricated ramps that they could move and quickly reassembled. The Germans also camouflaged some of their launch sites to look like farm buildings from the air.⁴¹ This made detection and targeting exceptionally difficult. The Germans learned the value of mobility and deception. This brings up an interesting parallel between the German tactics of World War II and the Iraqi tactics during Desert Storm. Nearly 50 years after the German experience moving missile launch sites, the Iraqi army used mobility and deception techniques, taught to them by the Soviets, to foil US efforts to destroy Scud missiles on the ground.

It was the Americans, rather than the British, who tried to apply science to the task of eliminating the threatening launch sites. In January 1944, Army Air Corps General Hap Arnold ordered simulated V-1 launch ramps built at Eglin Field, Florida. Engineers constructed the ramps, which resembled ski jumps, to test the effectiveness of various munitions and bombing tactics. Brigadier General Laurence Kuter wrote to

Arnold in late February 1944 about the Eglin tests. Kuter informed the Army Air Forces chief that fighter glide bombs, dropped from minimum altitude, worked best against the mock V-1 ramps when target identification was difficult.⁴² The Eglin test showed how hard it was to find a concealed target when flying below 1,500 feet. This is the same grazing angle problem that makes it tough even today to locate concealed mobile ballistic missile launchers. Kuter reported that when the target was easy to spot, minimum altitude level bombing was very accurate. Despite the Eglin tests, the British remain fixated on high altitude bombing due to their fear of Germany anti-aircraft fire.⁴³ In the end, the British view prevailed and the Allies did not attempt minimum altitude bombing against the German V-1 ramps. High altitude heavy bombers continued to drop most of the tonnage on the V-1 sites.⁴⁴

The Germans also discovered the value of decoys. The Germans employed old fixed launch ramps as bait for Allied bombers. During the first half of 1944, the new modified launch ramps went untouched while the Allies wasted considerable bomb tonnage on the old, unused ramps.⁴⁵ From August 1943 to April 1944 the Allies launched about 65,000 sorties against the German V-1 and V-2 sites. The British and Americans devoted an astonishing 90 percent of their sorties in January 1944 and 30 percent in April 1944 to Operation Crossbow, but V-1 and V-2 production continued.⁴⁶ With D day approaching, the emphasis shifted away from the V weapons as Allied bombing concentrated on preparation for the June 1944 Normandy landing.

Many Allied leaders felt all their efforts against the V weapons had been a waste of valuable resources. They believed the V weapon threat was merely a German hoax cleverly designed to divert Allied attention from more valuable targets. The Germans launched the first V-1 a week after D day, and suddenly everyone realized it was no hoax. They carried out a massive launch of 244 V-1s on 15 June 1944 from their new sites in northern France.⁴⁷ The concern was so great that by 16 June 1944, a scant 10 days after the Normandy landings, General Dwight Eisenhower ordered Crossbow targets

to take priority over everything else except critical battlefield support missions.⁴⁸ General Eisenhower decided to divert over 30 percent of Allied bombers away from industrial targets inside Germany to attack the V-1 launch sites in France. He did this despite the battle still raging in Normandy.

American air commander General Carl Spaatz argued in vain with Eisenhower that instead of directly attacking the launch sites, the bomber force should hit factories in Germany that made key components of the flying bomb.⁴⁹ General Spaatz also came up with an innovative, though somewhat impractical, idea for dealing with the V-1s. He proposed using remotely controlled bombers loaded with explosives as missiles to attack the launch sites.⁵⁰

Despite the renewed air campaign against the launch sites, a solitary V-1 chanced to find a London church on 18 June, killing 119 people and wounding 141.⁵¹ Results of the strikes against the V-1 ramps were disappointing, partly due to the difficulty in locating the ramps. The inability of the bombers to slow V-1 launches frustrated the British so much that they considered, but rejected, a proposal to use gas attacks against the launch facilities.⁵²

One of Hitler's goals for the V weapons was to divert Allied bombers away from German cities. In this he succeeded, at least for a time. Saddam Hussein may have had similar motives behind his Scud launches. There is a striking similarity between the level of Allied attention focused on the V weapons during World War II and the number of coalition resources devoted to stopping the Iraqi Scuds during Desert Storm 46 years later. The V weapons and Scuds, each in their own time, caused a reallocation of Allied and coalition air power out of proportion to the military threat they presented. In this respect they were both triumphant.

Over 7,000 of the more than 10,000 V-1s launched by the Germans reached England. Although bombing had relatively little impact on the V-1s, British fighters, anti-aircraft artillery, and balloons claimed nearly 3,500 V-1s shot down. Another 2,000

crashed, leaving about 2,300 missiles that hit the London area.⁵³ Unlike the V-2, the British could track the V-1 on their radar to warn the air defenses. The fighters either shot the V-1s down or used a more daring method. Although not a common practice, some adventurous pilots would fly along side a slow moving V-1 and use the fighter's wingtip to flip the V-1's wing, sending the missile crashing to earth.⁵⁴

The V-1s gradually became easy prey for the British, but the missiles were nevertheless a blow to civilian morale in London. The citizens had grown reasonably secure after the aerial terror bombing of the Battle of Britain. The V weapons changed that sense of security beginning in June 1944. Civilians sometimes vented their anger over the V weapon attacks at Churchill rather than Hitler. These people expected their government to do something about the dreadful rockets.⁵⁵ This result is not unique. Allied bombing of German cities sometimes created hostility toward Hitler.

Allied efforts to curb the V-1 launches during the summer of 1944 remained ineffective. On 3 August 1944 101 V-1s landed in London, the highest daily total of the war. V-1 launches from northern France did not stop until the Allies captured the sites later in August. The Germans pulled back and built new V-1 ramps in western Holland, and in March 1945 they were again hitting London.⁵⁶ They launched a total of 275 V-1s, lighter weight and with greater range, from these three ramps.⁵⁷ The last V-1 hit north of London on 29 March 1945.⁵⁸ The Allied ground march across Europe finally terminated V-1 employment.

The Allied air campaign against the V-2 was just as disappointing as the air action against the V-1. Some V-2 launch sites, located close to populated areas in Holland, were unattractive targets for aerial bombing. One of the German's main rocket launch sites was in a forested park in the middle of The Hague. The camouflage offered by the trees prevented the Allies from pinpointing the precise launch sites.⁵⁹ Allied bombers failed to destroy the V-2s and had the unhappy consequence of killing many Dutch civilians. Another difficulty was the fact the V-2 launch sites were mobile. Launch areas

were easy to set up since reasonably small sheets of metal or concrete slabs provided a sufficient surface for firing the rockets.⁶⁰ To confuse the allies, the Germans would use a launch site, then abandon it and return again after a few days break. Although air attacks were beneficial to the overall effort against the V-2, it was the relentless Allied ground advance that put the greatest pressure on V-2 operations.

Field Marshal Bernard Montgomery started his ill-fated Operation Market-Garden on 17 September 1944. One of Montgomery's goals was to capture the V-2s along the Dutch coast. Unfortunately, as soon as the British attacked, the Germans immediately pulled their V-2s back to Germany and northern Holland.⁶¹ The Allies did not fully realize at the time that the Germans could easily relocate their V-2s by way of the mobile launchers. On 3 October the V-2 attacks against London resumed.⁶² In a similar vein during Desert Storm, the Iraqis were able to fire their Scuds and move away much faster than prewar intelligence indicated.

As the Americans and British advanced from the west, by late February 1945 the Soviets pushed into Germany, forcing the final evacuation of all 4,000 remaining rocket personnel from the Peenemunde complex to the Hartz Mountains.⁶³ Despite pressure from both east and west, the German rocket program continued. Allied fighters strafed transportation routes cutting some, but not all, German supplies. Enough provisions got through to keep the V-2 units in operation. Remarkably, over 200 V-2s hit England during February 1945 despite all the difficulties the Germans were under.⁶⁴ V-2 attacks against Britain ceased after a 27 March 1945 strike that killed 134 people and wounded 49.⁶⁵ Ground troops, not air power, finally defeated the V-2 by overrunning the launch areas.⁶⁶ It is important to note that Scud attacks, although significantly reduced during the air campaign, did not stop until the initiation of the Desert Storm's ground phase.⁶⁷

The V Weapons: Final Results

The Germans launched about 1,400 V-2s at London from 8 September 1944 to 27 March 1945. The attacks shook British morale at times, killing over 2,700 Londoners.⁶⁸

V-1s claimed the lives of over 5,800 British citizens and wounded approximately 40,000.⁶⁹ This represents about ten percent of all British civilian deaths and injuries suffered during the war.⁷⁰

The Allies used more than 68,000 sorties to drop 122,000 tons of bombs on the V-1 and V-2 facilities.⁷¹ This was a significant diversion of air assets, but the results disappointed Allied air leaders. British air defense turned in the most productive results against the V-1s. Fighters claimed 1,847 shot down, antiaircraft artillery destroyed 1,878, and barrage balloons bagged 232 V-1s.⁷² After the war, the United States Strategic Bombing Survey (USSBS) estimated that the V-1s by themselves inflicted almost four times as much damage to the Allies as it cost to build the missiles.⁷³ The Germans also introduced the V-2 too late to be truly effective. The elaborate V-2 was less economical than the V-1.⁷⁴

The cost of air attacks against the V weapons was severe: 450 planes and 2,900 crewmen lost.⁷⁵ Intelligence shortcomings were a major reason for the high cost and poor results of the bombing campaign against the V weapons. The Germans used mobility to rapidly change locations when air attacks became threatening.⁷⁶ The Iraqis likewise used the Scud's mobility to their advantage 1991 during Desert Storm.

Ballistic Missiles After World War II

Several nations used ballistic missiles in battle to a limited extent in the 1970s and 1980s. Although not decisive to the conflict, Egypt and Syria launched a few Scuds at Israel during their October 1973 war.⁷⁷ Libya retaliated for the April 1986 US air strike by firing two Scuds at a US Coast Guard station on the island of Lampedusa, off the coast of Italy.⁷⁸ The rounds fell short. Tactical ballistic missiles did not have a major impact until the 1980–1988 Iran-Iraq War. Iraq was particularly successful using Scuds to terrorize Iranian civilians, producing an average of 75 casualties per missile.⁷⁹ Iraq launched an impressive number of ballistic missiles toward Iran. Saddam Hussein sent 135 Scuds in March 1988 and another 66 in April against Iranian cities.⁸⁰ Along with the

human suffering caused by the missiles, there was economic damage as well. Businesses incurred serious losses when the Scuds forced the Iranians to evacuate urban areas, including Tehran. Many people panicked, helping push Iran to sign a peace treaty with Iraq.

In addition to employed conventionally armed ballistic missiles against cities, Saddam used artillery shells with chemical weapons against mass Iranian human-wave attacks. Iraqi mustard gas and nerve agents killed or injured over 13,000 Iranians during their war.⁸¹ Saddam Hussein also shocked the world by using poison gas on his own rebellious Kurdish population in 1988.⁸²

Closing Thoughts

The Allied experience in World War II showed how difficult it was to destroy mobile ballistic missiles. This mobility, combined with camouflage and other deception efforts, served as a model for Iraq during the Gulf War. The V-2, and to a lesser extent the V-1, showed the military impact of a terror weapon. It caused the Allies to divert a disproportionate share of resources to try to solve the problem. The poor track record of countering missiles in World War II set the stage for our deficiencies in Desert Storm.

The Iran-Iraq War also furnished some valuable lessons about theater ballistic missiles. This fresh evidence of Iraq's willingness to launch ballistic missile attacks was a warning of what to expect in 1991.⁸³ However, the US made some attempts after the Second World War to deal with the ballistic missile threat. Appendix 2 covers this topic.

Notes

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Appendix 2: The Long Search for a Solution

Between World War II and Desert Storm

Although one may consider the Allied bombing effort against the V weapons a fiasco, the failure did stimulate research to deal with fast-moving missiles. Prompted in 1946 by the recommendation of the War Department Equipment Board, known as the Stilwell Board, the United States began to study ballistic missile defense. After the Soviets acquired nuclear weapons and intercontinental delivery capability, the focus was on strategic threats. In the mid 1950s, Bell Laboratory scientists concluded they could develop a defensive missile capable of intercepting an Intercontinental Ballistic Missile (ICBM) speeding along at 24,000 feet per second.¹

Work continued during the 1950s. The Army and Air Force combined separate missile defense research programs in 1958. In 1961, Secretary of Defense Robert McNamara supported continued research and development, but not actual deployment of an antiballistic missile (ABM) system called ZEUS.² He decided not to field ZEUS due to its limitations and concern about the destabilizing effects of ballistic missile defense.

McNamara subsequently dropped development of the ZEUS in favor of the NIKE-X ABM system with its advanced phased array radar. Later in McNamara's tenure, he moved away from missile defense entirely, favoring more cost-effective offensive weapons over defensive weapons. His adherence to the concept of Mutual Assured Destruction (MAD) influenced important decisions about missile defense. In 1966 he rejected advice from the Joint Chiefs of Staff to deploy an ABM system. In 1967 he did agree to a limited Sentinel system, a follow-on to the Nike-X program, as a hedge against a possible Chinese ICBM threat to US cities.³ President Richard Nixon changed that decision after he took office and built the Safeguard system, with its own nuclear-tipped missiles, to protect our ICBM fields at Grand Forks AFB, North Dakota.⁴

In 1972, while the tug-of-war over missile defense continued, the United States and Soviet Union signed the Anti-Ballistic Missile (ABM) treaty banning weapons in space. Soon even the land-based Safeguard program fell into disfavor. Congress cut funding for Safeguard in 1976, and the system was deactivated immediately after achieving operational status. No comprehensive ABM system has yet taken its place in the US.

President Reagan resurrected the idea of missile defense in 1983 with his now famous “Star Wars” speech calling for a defense against ballistic missiles. The Strategic Defense Initiative, or SDI, was born. Over the last decade the United States spent many billions of dollars exploring the feasibility of missile defense. Some SDI technology, now under BMDO, may play an important role in future theater missile defense.

Patriot

In addition to the strategic missile research accomplished by the SDIO, the Army has a long record of tactical antimissile work. The Patriot defense system is the fruit of that labor. It all began in 1951 when the Army launched a missile defense effort called Project Plato.⁵ Plato was the first project expressly tailored to counter tactical ballistic missiles. The Army terminated the program in 1958. Next, the US initiated the Field Army Ballistic Missile Defense System (FABMDS) in 1961. The DOD’s director of defense research and engineering, Harold Brown, canceled FABMDS in 1963.⁶ The Army persisted in its need for an antimissile capability. By 1964 it came up with Surface-to-Air Missile Development (SAM-D), a mobile anti-aircraft and short-range antiballistic missile defense system.⁷ In 1973 SAM-D became strictly an anti-aircraft effort. Over the years, SAM-D survived several budget cut attempts. Not accidentally, SAM-D became Patriot in during the Bicentennial year of 1976.

During the 1980s Patriot adapted to changing requirements. In 1982, Raytheon began work on an anti-tactical ballistic missile capability for Patriot.⁸ This antimissile function was not available when the Army first deployed Patriot in 1985. In November 1987, an upgraded Patriot intercepted another Patriot missile and demonstrated its

antimissile capability.⁹ Although designed to protect relatively small, point targets instead of large area targets, Patriot was the only terminal defense weapon the US had in the Gulf War.¹⁰ It is somewhat of a miracle that Patriot existed at all in 1991 given its troubled history. Thanks to the Army's commitment to missile defense, the United States had at least something to throw against Iraq's ballistic missiles.

Patriot helped thwart Saddam Hussein's plan to break up the Allied coalition against Iraq by using his "invulnerable" Scuds against Saudi Arabia and especially Israel.¹¹ The Iran-Iraq War convinced Saddam that nothing could defeat his Scuds. Iran had suffered approximately 5,000 civilian casualties due to Scud attacks and the Iraqi leader may have reasoned the makeshift US-led coalition would crack under the strain of a relentless missile barrage.¹² Iraqi foreign minister Tariq Aziz also may have been relying on the Scud's combat-proven capability. On 9 January 1991 he told US Secretary of State James Baker that Iraq "had not miscalculated" and would retain Kuwait.

When the war got under way, the seemingly spectacular success of Patriots against the Scuds was a tremendous boost to coalition morale. Early reports indicated nearly 100 percent effectiveness for the Patriot. However, after the war, the Army lowered its official estimate of Patriot's proficiency. In December 1991, the Army claimed Patriot had successfully intercepted over 80 percent of the Scuds launched against Saudi Arabia and over half of the Scuds targeted on Israel.¹³ What is confusing about these assertions is that a "successful" Patriot intercept did not necessarily equate to destruction of the Scud. The Army credited Patriot with a successful intercept if the Scud warhead had a reduced detonation when it impacted its target. By April of 1992, the Army lowered its estimate again by rating Patriot success at over 70 percent in Saudi Arabia and 40 percent in Israel.¹⁴ The disparity in results between Saudi Arabia and Israel is likely due to differences in the way the operators used Patriot in the two countries. In Saudi Arabia, the operators employed the faster automatic mode, while Patriot operated in the slower manual mode in Israel.¹⁵ Also, newly trained Israelis

operated some of the Patriot batteries in their country while Americans were in total control in Saudi Arabia.

It is important to recognize that Patriot is not a perfect system. The Iraqis played a role in the Patriot's problems by modifying their Scuds. They extended the Scud's range by adding midsection pieces from other missiles. Poor workmanship often caused the missiles to break up in flight. This created several targets, instead of one, for Patriot to intercept. Although this was an unintended countermeasure by the Iraqis, it nevertheless proved effective. With experience, US crews in Saudi Arabia learned to distinguish the Scud warhead from the other missile parts.

Patriot's builder, Raytheon, made several software changes and rushed them to the theater to help overcome this breakup problem and other difficulties.¹⁶ For example, the longer range of the Iraqi Scuds versus the Soviet-made Scuds caused a 50 percent increase in reentry velocity.¹⁷ This forced the US to make corrections in the guidance calculations. Fortunately the Iraqis chose to fire Scuds singly or in twos or threes. It is critical to realize that barrage firing could have swamped the Patriot batteries.¹⁸ It is also fortunate that the Iraqis chose not to put chemical warheads on their missiles. Since some of the Patriot intercepts broke up the Scuds but did not destroy the warheads, the result could have been wider dispersion of the chemical agent.¹⁹

The debate continues over Patriot effectiveness in Desert Storm. MIT professor Theodore A. Postol contends Patriot failed almost completely to intercept Scuds.²⁰ He claims at least 25 Patriot missiles in Saudi Arabia missed their intended Scud targets by hundreds of meters.²¹ He also believes third world nations can develop inexpensive countermeasures to defeat Patriot, reducing the cost effectiveness of terminal missile defense.

Why is terminal defense such a challenging task? The high speeds create incredibly close tolerances that spell the difference between a hit or a miss. The Scud slows from a top speed of about 5,400 mph to approximately 3,600 mph at impact. The

Patriot closes on its target missile at around 3,700 mph. Patriot warhead detonation must be accurate to “within 1/1000th of a second to miss by 3.5 meters.”²² With such tight constraints, it is not surprising that many intercepts failed during Desert Storm. Postol alleges no one will ever know Patriot’s true level of success since operators failed to record data on most of the launches.²³

The Army compensated for the vagaries of the missile intercept problem by launching Patriots in salvos to increase the probability of hitting a target. The US and Israel launched 158 Patriots against 47 of the 86 Scuds fired by Iraq.²⁴ Operators did not launch Patriots against Scuds heading toward non-populated areas. Tragically, the Army failed to shoot any Patriot missiles against the Scud that killed 28 US personnel in Dhahran. According to a 26 February 1991 briefing from Marine Corps Brigadier General Richard Neal, the Patriot operators fired no missiles because the Scud started tumbling, putting it outside the Patriot’s engagement envelope.²⁵ The story changed in April of 1991 when the Army said a radar malfunction had prevented a Patriot launch.²⁶

No matter what the cause, the Army realizes that it must improve the Patriot’s capability against ballistic missiles. To overcome some of Patriot’s deficiencies, the Army plans to improve the system’s guidance, warhead, and range.²⁷ An active radar seeker will improve Patriot’s lethality against smaller targets, while range enhancements will give it broader area coverage.²⁸

The history of antimissile development runs all the way from the immediate postwar period to the present. A series of starts, stops, and “near death” experiences characterize the search for a counter to the tactical ballistic threat created by the Nazis. The US made meaningful progress with Patriot.

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Appendix 3: Additional Missile Defense Research

MUSTRS: Related Research

ATR is obviously a key element of MUSTRS. Statistical pattern recognition is one ATR processing technique. It involves using some sensor data that a human operator never sees or uses.¹ This additional information, not usable by a person, aids the ATR algorithm in assessing whether an object is or is not a target. Researchers at Wright-Patterson AFB are working on several programs to bring sensors together with advanced ATR algorithms to improve target recognition performance. The Automatic Radar Air-to-Ground Target Acquisition Program (ARAGTAP) focuses on using synthetic aperture radar (SAR) and a technique called model-based vision to improve ATR algorithms so they can recognize mobile missiles in real time (covering four square miles of ground in only seven seconds).²

The Concealed Target Detection (CTD) program involves the development of an airborne foliage penetration radar combined with automatic cueing of concealed or camouflaged targets.³ Foliage interferes with current sensors and the CTD program uses microwave radar frequencies to detect hidden targets such as mobile missiles.⁴ The first phase of an experimental program is scheduled for completion by the end of FY93.⁵

The Strategic Avionics Battlemanagement Evaluation and Research (SABER) program is part of the Armstrong Laboratory at Wright-Patterson AFB. SABER's task is to determine how well humans evaluate synthetic aperture radar (SAR) images of real and false targets, including mobile missiles, and make targeting decisions. SABER integrates automatic target cueing and automatic target recognition (ATC/ATR) programs developed by the Wright Laboratories.⁶

Wright Laboratories is also working with ARPA on a program to locate mobile missiles along tree lines. The Three Dimensional Interferometric Synthetic Aperture

Radar (3D IFSAR) program runs through FY94.⁷ The goal of the Multispectral Sensor program is to develop day and night multispectral capability along with automatic target recognition of hidden targets.⁸ It supports the WarBreaker program.

WarBreaker

ARPA's WarBreaker project combines reconnaissance and intelligence with mission planning and targeting.⁹ Rapid mission planning and pinpoint targeting for time critical targets, such as mobile missiles, are important program objectives.¹⁰ Specific goals include the ability to monitor an area of a million square kilometers, conduct mission planning in 10 minutes, and find one square meter targets in a 10,000 square kilometer search box.¹¹

A key element of finding mobile time critical targets is reducing the required search area. It is not feasible to examine large areas with a high resolution sensor. Reducing the search area to manageable proportions makes it possible to conduct an intelligent search for targets such as mobile missile launchers. WarBreaker's Tracker technology uses a massively parallel processor to eliminate up to 96 percent of the terrain in a given region. This machine evaluated and categorized one million square miles of territory in just 18 minutes, a process that would take months to do manually.¹² WarBreaker Tracker prioritizes the remaining area in terms of suitability for mobile target deployment. The system then creates a mission plan that maximizes the probability of passing by these high likelihood sites. Automating intelligence and battle management functions in a local command and control mode is another objective. Processing these large amounts of data requires super computing speed and capacity.

Researchers hope to put WarBreaker capability on airborne platforms perhaps as early as 1996.¹³ An airborne platform orbiting close to the battle area could receive near real time updates and redirect search missions based on this intelligence information. Focusing surveillance assets on high probability areas will increase the chances for locating the mobile targets. Another aspect of WarBreaker is garrison monitoring of time

critical targets. For example, monitoring mobile missile garrisons would provide a tip-off of missile dispersal.¹⁴

USAF SAB

At the request of the Air Force chief of staff, the USAF Scientific Advisory Board's (SAB) Ad Hoc Committee on Offboard Sensors to Support Air Combat Operations studied the mobile missile problem. They concluded off-board sensors are absolutely necessary for the theater ballistic missile mission.¹⁵ They determined it was impractical from a cost perspective to put the necessary sensors and correlation capability on a single attack platform. This finding conflicts with a Boeing evaluation that concluded a UAV could house the required equipment. The Committee's own Fusion Panel stated that correlating sensor data close to the sensors would minimize communications requirements.¹⁶ The Fusion Panel seems to support a more autonomous approach rather than insisting that target cueing information should pass from off-board platforms to manned aircraft. Placing this correlation processing on the same platform would simplify and speed the task of killing mobile missiles.

The SAB Committee thinks that it is too expensive to host the required computing power directly on the shooting platform. The Committee favors the controller-to-shooter approach.¹⁷ For economy reason, the SAB believes the computer processing belongs on large aircraft. If the SAB's position is correct, a manned attack aircraft or UAV could still receive cueing information from other sources. The SAB lists DSP, FEWS, weather satellites, and multispectral imaging systems as candidates for this task.¹⁸ However, multispectral imaging systems like Landsat have problems with responsiveness. Landsat's two day turnaround for processing and dissemination plus its 16 days between revisits is often insufficient.¹⁹ The 30 meter accuracy of Landsat is also a limitation. The SAB recommends 3 meter accuracy and 12 hour revisit capability.

Airborne platforms like JSTARS and AWACS might also provide cueing. The SAB found JSTARS currently lacks sufficient radar resolution for target identification

and AWACS needs the capability to automatically correlate on-board and off-board target information.²⁰ Another difficulty with using aircraft to perform the fusion function is having these planes airborne when and where needed. Manned vehicles can support relatively short duration conflicts. This becomes increasingly difficult over time due to the potential for competing demands on the assets and the expense of flying.

No single sensor can do everything. National assets may not be looking in the right place at the right time and airborne systems may have to avoid high threat areas to survive. As mentioned earlier, processing time for off-board sensors presents a problem. This seems to be a good reason for combining functions on a single platform where possible.

Mobile missiles are likely to hide along tree lines, limiting the potential viewing angles. Camouflage and deception techniques make it difficult for coarse resolution sensors to detect real targets.²¹ Automatic target identification facilitates the search because the time available to view the target will be quite short.²² This seems fully in consonance with other studies. However, the SAB report states the Air Force only needs nonlethal UAVs for tasks such as reconnaissance and target acquisition to support manned aircraft.²³ The SAB report mentions reliability, recovery, and cost concerns as reasons why UAVs were canceled in the past.

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Glossary

AAV	Autonomous Air Vehicle.
ABM	Anti-Ballistic Missile.
ACC	Air Combat Command.
ACM	Advanced Cruise Missile.
AF	Air Force.
AI	Air Interdiction.
ARAGTAP	Automatic Radar Air-to-Ground Target Acquisition Program.
ARPA	Advanced Research Projects Agency (Formerly DARPA).
ATC	Automatic Target Cueing.
ATLAS	Advanced Technology LAdar System.
ATR	Automatic Target Recognition.
AWACS	Airborne Warning And Control System.
BMDO	Ballistic Missile Defense Organization (Formerly SDIO).
C ²	Command and Control.
C ³ I	Command, Control, Communications, and Intelligence.
C ⁴ I Intelligence.	Command, Control, Communications, Computers, and Intelligence.
CALCM	Conventional Air Launched Cruise Missile.
CEP	Circular Error Probable.
C-FAST	Counter-Force Automated Surveillance & Targeting.
CIA	Central Intelligence Agency.
CRC	Collection Reporting Center.
CTD	Concealed Target Detection.
DARPA	Defense Advanced Research Projects Agency (Now ARPA).

DOD	Department of Defense.
DSMAC	Digital Scene Matching Area Correlation.
DSP	Defense Support Program.
ECM	Electronic CounterMeasures.
ERINT	Extended Range INtercept Technology.
ERIS	Extroatmospheric Reentry-vehicle Interceptor System.
FABMDS	Field Army Ballistic Missile Defense System.
FEWS	Follow-on Early Warning System.
FLIR	Forward Looking InfRared.
GAPP	Geometric Arithmetic Parallel Processor.
GPS	Global Positioning System.
ICBM	Intercontinental Ballistic Missile.
IFF	Identification Friend or Foe.
JSTARS	Joint Surveillance and Target Attack Radar System.
LANTIRN	Low-Altitude Navigation and Targeting InfRared for Night.
LOCAAS	LOw-Cost Anti-Armor Submunition.
LWIR	Long-Wave InfRared.
MAD	Mutual Assured Destruction.
MCE	Modular Control Element.
MIT	Massachusetts Institute of Technology.
M/LWIR	Medium/Long-Wave InfRared.
MNS	Mission Need Statement.
MUSTRS	MUlti-Sensor Target Recognition System.
MWIR	Medium-Wave InfRared.
NBC	Nuclear, Biological, Chemical.

NMD	National Missile Defense.
OCA	Offensive Counter Air.
PAC	Patriot Advanced Capability.
RAPTOR/TALON	Responsive Aircraft Program for Theater Operations/ Theater Application–Launch On Notice.
RPV	Remotely Piloted Vehicle.
SA	Selective Availability (for GPS).
SAB	(USAF) Scientific Advisory Board.
SABER	Strategic Avionics Battlemanagement Evaluation and Research.
SAC	Strategic Air Command.
SADARM	Search and Destroy ARMor.
SAM	Surface-to-Air Missile.
SAR	Synthetic Aperture Radar.
SAS	Special Air Service.
SDI	Strategic Defense Initiative.
SDIO	Strategic Defense Initiative Organization (Now BMDO).
SFW	Sensor Fuzed Weapon.
SIGINT	SIGnals INTelligence.
SLBM	Sea Launched Ballistic Missile.
SOE	Special Operations Executive (British).
SWIR	ShortWave InFRared.
TAC	Tactical Air Command.
TACCSF	Theater Air Command and Control Simulation Facility.
TACS	Theater Air Control System.
3D IFSAR	Three Dimensional InterFerometric Synthetic Aperture Radar.

TEL	Transporter Erector Launcher.
THAAD	Theater High Altitude Area Defense.
TLAM	Tomahawk Land Attack Missile.
TMD	Theater Missile Defense.
TMD	Tactical Munitions Dispenser.
TMDI	Theater Missile Defense Initiative.
UAV	Unmanned Air Vehicle.

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