BRILLIANT ATTACK:

THE NEED FOR AUTONOMOUS STANDOFF WEAPONS IN AIRFIELD ATTACK MISSIONS

A Monograph
by

Major James Riggins
United States Air Force

School of Advanced Military Studies
United States Army Command and General Staff College
Fort Leavenworth, Kansas

First Term AY 94-95

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
12/12/94

3. REPORT TYPE AND DATES COVERED
MONOGRAPH

4. TITLE AND SUBTITLE
BRILLIANT ATTACK: THE NEED FOR AUTONOMOUS STANDOFF WEAPONS IN AIRFIELD ATTACK MISSIONS(U)

5. FUNDING NUMBERS

6. AUTHOR(S)
MAJ JAMES RIGGINS, USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
SCHOOL OF ADVANCED MILITARY STUDIES
ATTN: ATZL-SWV
FORT LEAVENWORTH, KANSAS 66027-6900
COM (913) 758-3300 DSN 720-3300

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

14. SUBJECT TERMS
AIRFIELD ATTACK
STANDOFF
AUTONOMOUS WEAPON
OPERATION DESERT STORM
ARAB-ISRAELI WAR

15. NUMBER OF PAGES
67

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT
UNCLASSIFIED

18. SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

19. SECURITY CLASSIFICATION OF ABSTRACT
UNCLASSIFIED

20. LIMITATION OF ABSTRACT
UNLIMITED

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std Z39-18
298-102

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to ***stay within the lines*** to meet ***optical scanning requirements***.

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C - Contract
G - Grant
PE - Program Element
PR - Project
TA - Task
WU - Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If known)*

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

DOD - See DoDD 5230.24, "Distribution Statements on Technical Documents."
DOE - See authorities.
NASA - See Handbook NHB 2200.2.
NTIS - Leave blank.

Block 12b. Distribution Code.

DOD - Leave blank.
DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
NASA - Leave blank.
NTIS - Leave blank.

Block 13. Abstract. Include a brief *(Maximum 200 words)* factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code *(NTIS only)*.

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.

SCHOOL OF ADVANCED MILITARY STUDIES

MONOGRAPH APPROVAL

Major James Riggins

Title of Monograph: Brilliant Attack: The Need for Autonomous Standoff Weapons in Airfield Attack Missions

Approved by:

Myron J. Griswold

LTC Myron J. Griswold, MS, MMAS — Monograph Director

Gregory Fontenot

COL Gregory Fontenot, MA, MMAS — Director, School of Advanced Military Studies

Philip J. Brookes

Philip J. Brookes, Ph.D. — Director, Graduate Degree Program

Accepted this 17th day of December 1994

ABSTRACT

BRILLIANT ATTACK: THE NEED FOR AUTONOMOUS STANDOFF WEAPONS IN AIRFIELD ATTACK MISSIONS by Maj James Riggins, USAF, 67 pages.

Since the 1967 Arab-Israeli war, the airfield attack subset of the counter-air role became increasingly hazardous to attacking aircrews due to improvements and proliferation of anti-air weapons. The United States and coalition air forces in Operation Desert Storm relied primarily on direct overflight and short standoff (man-in-the-loop) missions to perform airfield attacks, requiring numerous support aircraft, and resulting in aircraft losses. With only a single funded stealthy aircraft procurement program (F-22) in the near future, the need for weapons which allow non-stealth aircraft to more efficiently attack heavily defended airfield targets will exist well into the future. This monograph describes how the development of moderate cost, all weather, intermediate range, standoff autonomous weapons (SAWs), combined with the appropriate doctrine, would improve the effectiveness and efficiency of the airfield attack mission at the tactical level of war.

As background, this monograph presents data from the 1967 and 1973 Arab-Israeli wars to describe the evolution of airfield attack tactics, and the resulting trends in aircraft attrition from these missions. It also uses the United States Air Force commissioned <u>Gulf War Air Power Survey</u> to analyze the nature and deficiencies of all coalition airfield attacks during Operation Desert Storm.

TABLE OF CONTENTS

FIGURES AND TABLES

SECTION 1: INTRODUCTION

> *The progress of scientific discovery and invention is so fast, even though it does not keep pace with the imagination of those who exploit it in the popular press, that it would seem to be changing all traditional conceptions of warfare.*
>
> B. H. Liddell Hart, 1930[1]

While Liddell Hart's proclamation is as valid today as in 1930, the current phenomenal pace of technology development creates a corollary problem: "traditional conceptions of warfare" not changing quickly enough to exploit fully the advantages of new technologies. Indeed, such may be the case with the United States Air Force's critical mission of counterair, and its key offensive component, the attack of enemy airfields. The "new technologies," in this case, are autonomous stand-off weapons, and the question of interest is whether such weapons can improve upon the "traditional conceptions" of airfield attack.

Problem Background and Significance: The stunning success of the air campaign during Operation Desert Storm, seems, on the surface, to validate the tactics and technology the Air Force developed over the previous two decades. It is certainly an impressive record that the Coalition launched so many attacks with so few casualties, and achieved command of the air in less than half the time predicted. While some key deficiencies, such as fratricide, and the inability to kill mobile SCUD launchers grab the bulk of post war attention for the Air Force, the results of the war point to still others.

One such deficiency appears in the area of Offensive Counterair (OCA). While the number of friendly losses during attack of enemy airfields was small, it is appropriate to question whether such losses are avoidable in the future. In one fundamental sense, the airfield attack tactics used during Desert Storm still resemble those of the 1970s. While the level of support aircraft (suppression of enemy air defense (SEAD), fighter escort, electronic warfare (EW), etc.) for such missions was the greatest of any conflict in history, the *attack* aircraft relied strictly on direct overflight or short stand-off to put weapons on heavily defended targets.

The danger of such tactics on the modern battlefield has been evident since the 1973 Arab-Israeli war when the Egyptians and Syrians inflicted serious aircraft attrition on the Israeli Air Force (IAF) through an integrated air defense network using modern surface-to-air missiles (SAMs) and anti-aircraft artillery (AAA). The United States (U.S.) and the North Atlantic Treaty Organization (NATO), absorbing the lessons from this war, embarked on technology and tactical programs to penetrate such defenses. Advances in electronic warfare, anti-radiation weapons, night and low altitude flying capability, and stealth reflect the fruits of these technological efforts. All these efforts aimed at making the attacker less detectable, or destroying defenses, to enable the attacker to reach his target. The U.S. largely ignored technologies emerging since the early 1980s which would have allowed an attacker to launch weapons from *outside* the range of point defenses, making target overflight irrelevant. This paper will refer to the amalgam of such technologies as Stand-off Autonomous Weapons (SAWs). As early as 1982, the U.S. and NATO recognized "the requirement for some type of stand-off capability for air base attacks..."[2] However, attempts to develop such weapons ended in a series of canceled programs.[3]

The implications of such an oversight are more significant today than ever. With the large scale draw down of aircrews and aircraft, the capability for the U.S. to successfully handle the potential two "nearly simultaneous major regional conflicts" rests with the ability to quickly and efficiently gain air superiority. The smaller force structure does not allow the U.S. to fight a battle of air attrition, but will require the Air Force to inflict maximum attrition on the enemy, while losing few aircraft. While stealth aircraft go a long way toward realizing that goal, stealth today only represents 3 percent of the fighter and bomber fleets,[4] a figure not expected to rise significantly in the near future. Additionally, even stealth has the limitations of high cost, being restricted to night, and requiring clear weather over the target.

As the technology of SAWs continues to advance in government laboratories, the question which arises is, can the U.S. Air Force better execute the airfield attack subset of the OCA mission by using such weapons. Specifically, this monograph explores the hypothesis that **the development of moderate cost, intermediate range, SAWs will improve the effectiveness and efficiency of the airfield attack mission over that achieved in Operation Desert Storm.** Before analyzing this hypothesis, one must first understand the definitions involved.

While many measures and interpretations of "effectiveness" and "efficiency" exist with respect to air power, this monograph employs the following definitions. Improved "*effectiveness*" implies increased tactical flexibility, greater surprise, and increased ability to mass weapons effects on target. Improved "*efficiency*" implies increased survivability (reduced attrition), fewer aircraft per attack mission, fewer attacks per objective, and reduced combat aircraft turn around times.

The concept of "moderate cost" is crucial to the hypothesis of this monograph, for the weapons discussed must be employed in large numbers to be tactically and operationally beneficial. "Moderate cost" is also one key feature which distinguishes these weapons from the cruise missile whose price tag today, for all variants, is greater than one million dollars per copy. For the purpose of this paper, "moderate cost" implies approximately $150,000 per weapon. Also crucial to the employment of these weapons is the ability to deliver them day or night, and in "all weather." "All weather" does not imply 100 percent of all possible weather phenomena, but does include smoke, fog, haze, heavy rain, and moderate snowfall. Finally, the term "stand-off autonomous weapon" defines a proposed class of weapon which can be launched from bomber or fighter type aircraft, at ranges outside the low altitude point defense range (approximately fifteen to twenty miles), and which will guide to the target and impact the appropriate point without human input after launch. Some in the defense industry refer to such devices as "brilliant weapons" to differentiate them from "smart" laser or electro-optically guided weapons which require a human-in-the-loop to identify and steer to their target.

Assumptions: The analysis rests on three assumptions. First, the Air Force's ten year fighter and bomber roadmaps of today are accurate. This assumption implies that the U.S. will procure only one new stealthy fighter (F-22) which will not completely replace non-stealth OCA platforms such as the F-15E, F-111 and F-16[5]; and the B-2 stealth bomber purchase, currently planned at twenty aircraft, will remain a small fraction of the overall bomber fleet. Consequently, any major conflict will involve a number of non-stealth bomb delivery platforms. The second assumption is that the current military draw down is not a short lived phenomenon. This assumption holds that the current number of SEAD and EW aircraft will remain fairly constant or decrease slightly over the next ten to fifteen years. The third and most critical assumption is that SAWs are technically and financially feasible. While this assumption is necessary in proving the hypothesis, its validity sparks debate from government labs to Capitol Hill. So as to not accept such a critical assumption blindly, the Appendix provides evidence supporting the feasibility of these weapons.

Methodology: With today's widespread acceptance of the societal impact of technology comes the potential for the soldier or scientist to view technology as the central, if not overwhelming, element in war. As military historian and analyst Christopher Bellamy states,

> "Excessive preoccupation with technology, and even in its wider utility (technics), to the exclusion of tactics and practical soldiering, is not a modern problem: it was widespread in the more technical arms (artillery and engineers) before World War One....However, weapons development is only one corner of a triangle, of which the other two are a tactical 'doctrine' for using the weapon, and the training of the combatants, individually and collectively to use it."[6]

For the problem at hand, then, to simply state that SAWs will improve the way the U.S. performs airfield attacks based on a technology assessment alone, would violate Bellamy's tactical level "triangle." Therefore, this monograph will explore the previously mentioned measurements of effectiveness and efficiency in the context of Bellamy's three-point model with the emphasis at the tactical level of war. Within such an analysis, this monograph will also answer the following additional questions; how will SAWs affect counterair tactics?, do SAWs compete against, or complement stealth platforms?, and how will the introduction of SAWs impact aircrew and support personnel training?

Scope: Any discussion of a technological impact at only a single level of war leads to an incomplete, and often invalid, analysis. The emphasis of this monograph is at the tactical level; however, some discussion at the operational and strategic levels is necessary. A thorough evaluation at all three levels is beyond the scope of this work.

Additionally, in order to remain unclassified, this monograph will not present detailed technical aspects of SAWs, or specific weapons effects and limitations. While the emphasis is on airfield attack due to its primacy in the role of aerospace control, the discussion of SAWs applies equally well to any fixed, heavily defended target (and certain mobile targets).

Format: This monograph analyzes the need for SAWs through a three part approach. Section 2 provides a historical background of the airfield attack mission in major conflicts through an analysis of the OCA aspects of the 1967 and 1973 Arab-Israeli wars. Section 3 discusses current OCA tactics as applied in Operation Desert Storm, and uses data from the Air Force commissioned Gulf War Air Power Survey to analyze the strengths and weaknesses of this doctrine given current weapon systems. Section 4 looks into the future (ten to fifteen years) of airfield attack and the potential impact of SAWs on the effectiveness and efficiency of such missions within the context of the Bellamy three point model. Finally, Section 5 provides conclusions and recommendations on the future of SAWs.

SECTION 2: HISTORICAL BACKGROUND

> *Since the German attack on Poland in 1939, no country has won a war in the face of enemy air superiority, no major offensive has succeeded against an opponent who controlled the air, and no defense has sustained itself against an enemy who had air superiority.*
>
> Col John A. Warden III[7]

The German Luftwaffe introduced the concept of attacking airfields in order to gain air superiority during their rapid drives across Poland and France in World War Two (WW II). While WW II exposed many valuable lessons in the concept of airfield attack, this was a period of maturation, the solidification of air power doctrine in twentieth century combat. Although WW II is a relatively recent conflict, the ever increasing rate of technological change has rendered many of its airfield attack lessons at the *tactical level* obsolete. The more recent 1967 and 1973 Arab-Israeli wars generated a greater impact on the evolution of airfield attack tactics and represent the transition to the missile age of airfield defense, the era of electronic combat, and the first major demonstrations of western aviation technology encountering a sophisticated integrated air defense. Both examples, taken together, illustrate the shift to the modern OCA mission seen in Desert Storm, and highlight the inherent risks when conducting such missions without stand-off weapons. This section examines the airfield attack aspects of these conflicts, and presents each case in terms of the nature of the air forces and base defenses, the tactics employed, the subsequent results, and the emerging OCA lessons concerning the difficulties of such attacks.

The 1967 Arab-Israeli War: Aerospace historian Richard Hallion states, "the 1967 Arab-Israeli war had been the last great pre-missile era air war, for even though

Egypt and Israel had substantial numbers of missile batteries, they played virtually no role in the war."[8] Thus, an analysis of this war serves as a valuable starting point to understanding the rapid increase in problems associated with modern airfield attack which would occur between 1967 and 1973.

At the start of the war on 5 June 1967, the Israelis faced a formidable counterair problem. The Israeli Air Force (IAF) operated 196 operational combat aircraft. Of these, none were bombers, and approximately twenty were Super Mystère fighters,[9] the only aircraft the Israelis considered technologically equivalent to the Arab MiG-21s. Protecting this force against Arab attacks also posed serious problems for the Israelis, as the small size of the country placed all airfields close to the borders of at least one of their hostile neighbors. "Tel Aviv was only about four and a half minutes' flying time from El Arish [Egyptian airfield in the Sinai], while from Tel Aviv to Cairo the flight took only about 25 minutes."[10] Additionally, although the Israelis possessed approximately fifty SAMs, the U.S. made HAWK, Israel used them to protect the Dimona nuclear plant and Tel Aviv, not airfields.[11] Given these defensive disadvantages, the only viable strategy to protect the nation was an emphasis on OCA and first strike.

The Egyptian Air Force (EAF) presented the strongest of the Arab air forces facing Israel. It contained 450 to 500 combat aircraft, of which 120 to 140 were the Soviet built MiG-21, considered the most advanced fighter in the Middle East at the time. Also included in that total were approximately seventy-five TU-16 medium and IL-28 light bombers.[12] The Egyptians maintained twenty-three jet capable airfields, each containing a single runway and parallel taxiway, with aircraft parked either in the open or in high walled revetments.[13] They also placed approximately 150 SA-2s in eighteen sites to defend against medium and high altitude penetrations of their airspace, and protected key assets, such as airfields, with AAA.[14] Maintaining a large advantage in total aircraft, payload, and range, the EAF was confident they could survive any Israeli first strike, then cripple Israel with bomber counter-strikes against population, industrial, and government targets.

Israel also faced air threats on her other borders. The Syrian Air Force contained approximately 80 to 120 combat aircraft stationed at ten airfields, protected by AAA but no SAMs. While not as large as the EAF, the Syrian Air Force did possess thirty to forty MiG-21s, and four to six IL-28 bombers.[15] The Iraqi Air Force consisted of approximately 175 combat aircraft including sixty MiG-21s, six TU-16 bombers, ten IL-28s, and fifty British Hawker Hunter ground attack fighters,[16] while the Jordanian Air Force entered the war with the smallest force of thirty-four aircraft at two jet capable airfields. The most sophisticated of the Jordanian aircraft were twenty-two Hawker Hunters.

Israel initiated hostilities with a preemptive strike on the morning of 5 June 1967. This marked the culmination of years of meticulous planning and training, and the collection of precise intelligence on the location of EAF aircraft and air defense sites. The IAF placed the greatest OCA targeting priority to the TU-16 and IL-28 bombers, MiG-21s, and other fighter bombers; while the SA-2 and early warning radar sites were only secondary targets.[17] IAF tactics included an extremely low altitude ingress to remain below the early warning radar and SA-2 coverage, and persistent attacks in groups of four aircraft against the key Egyptian airfields.[18] By using a surge capability in which landing aircraft could be rearmed and refueled in ten minutes, and re-launched in thirty (compared to two hours for the EAF), the IAF rolled a continuous stream of five waves (approximately forty aircraft per wave), at ten minute intervals, onto the key airfields. As the first wave departed the target, the second wave was approaching, the third wave was en route, the fourth wave was just getting airborne, and the fifth wave was waiting for takeoff.[19] This punishing cycle, continued over two eighty-minute periods with fifteen minutes in-between, generated chaos in the EAF and prevented them from mounting any serious response. Approaching the target airfields, the Israeli pilots conducted two or three cannon strafing passes at the numerous aircraft parked in the open or taxiing for takeoff, then popped up to deliver 500 and 1000 pound bombs against the runways.[20] Additionally, some Vatours and Mirages in the initial waves introduced a previously secret runway cratering bomb known as the "concrete dibbler," released from a low altitude, level delivery.[21] By sunset on the first day, the IAF had successfully attacked seventeen Egyptian airfields, ten of them repeatedly.[22] The IAF plan to neutralize the EAF prior to concentrating on the other hostile nations, had been successful.

Jordan, and Syria, believing Egyptian propaganda of great success against the Israelis,[23] commenced air attacks late in the morning of 5 June. The Israelis countered with OCA missions that afternoon, and succeeded in virtually destroying the entire Jordanian , and half the Syrian Air Forces. Although the Iraqis would not launch their first raid until 6 June, the IAF struck at Iraqi airfield, H-3, on the afternoon of the 5th, destroying nine aircraft.[24] In all these raids, the IAF tactics reflected those used against the Egyptians, tactics that provided the IAF with stunning success on the first day of the war, but not without losses.

The Israelis achieved air supremacy, through airfield attack, on the first day of the war when they destroyed 367 enemy aircraft on the ground.[25] By the end of the war, the IAF had destroyed approximately 450 enemy aircraft, with no more than fifty of those from air-to-air action. Israel, on the other hand, lost forty aircraft: "eight to twelve of the forty were lost in aerial engagements and the rest to AAA and ground fire."[26] However, the remaining IAF aircraft did not come through unscathed. Major Edgar O'Ballance claims that on the first day alone, "apart from the 19 aircraft shot down either by Egyptian MiGs or ground fire, practically every Mystère - the bulk of the attacking planes - was hit by shrapnel or anti-aircraft fire...."[27] The lead aircraft of the first wave generally received minimal damage by surprising the air defense units, but subsequent waves faced fully alerted AAA defenses at the airfields. This predominately OCA air campaign resulted in relatively few casualties for the Israelis, but was heavy in damaged IAF aircraft.

The conflict imparted some key airfield attack lessons to its participants. The Israelis learned the value of a well executed OCA plan, especially when operating from a numerically inferior position, as well as the importance of training. Their incredible success seemed to validate their tactics of low level, daytime ingress followed by multiple passes over the airfields. While Israel did apply some electronic countermeasures (ECM) against ground radars and communications during the initial attacks, its overall impact was negligible. The IAF defeated the relatively unsophisticated Arab air defense networks through low altitude flight and exploiting gaps in coverage, and did not require ECM to enhance survivability. The Arab states learned through disaster, the dangers of concentrating aircraft unsheltered on the ground within range of Israeli fighters, and how easily the IAF could penetrate their relatively unsophisticated air defense network. These lessons, interpreted and acted upon, would have significant impact seven years later when these nations again went to war.

The 1973 Arab-Israeli War: The rapid annihilation of their air forces in 1967 formed the impetus for major change in the quality and complexity of air base defenses in the Arab nations. Almost immediately after the 1967 war, the Soviet Union contributed to major airfield upgrades in Egypt, Syria, and Iraq to make those airfields less susceptible to closure from runway attacks, provide greater protection for parked aircraft, and most importantly, provide a stronger air defense. Additionally, the Arabs built new dispersal airfields to increase aircraft survivability and decrease the impact of a primary airfield closure, and thus increased the number of targets the IAF would have to strike. All these factors contributed to a much more difficult OCA problem in 1973 than that encountered in 1967.

Between the wars, the IAF continued to place their emphasis on the offense. They converted the heart of their fighter fleet to the American built F-4E and A-4E/H, and simultaneously increased the size of the force to approximately 440 combat aircraft.[28] The Israelis more than doubled their number of airfields by constructing two new ones and using four they captured in the Sinai Peninsula during the previous war. At the same time, the IAF had established only eight batteries of HAWK SAMs,[29] reflecting a belief that they could once again thwart any large scale air threat to Israel.

In terms of Arab improvements, the Soviet Union provided large numbers of additional aircraft, increasing Egypt's fleet of combat aircraft to over 550, Syria's to over 300, and Iraq's to over 190.[30] However, the most sophisticated aircraft remained the MiG-21 and TU-16, because the Soviet Union attempted to restrict their Arab military aid to defensive capabilities only. The Soviets did maintain advanced MiG-23s under their control in Egypt; however, they removed all these aircraft following their July 1972 expulsion from Egypt. While they owned numerous aircraft, the Arab air forces were plagued by pilot shortages and deficient training as compared to the Israelis. These deficiencies, combined with the IAF's modernization, compelled the Egyptians to develop a strong anti-aircraft defensive system.

The Arab nations reduced the impact of runway attacks by widening and lengthening airfield surfaces, increasing the number of runways and taxiways, and improving rapid runway repair capabilities. In Egypt alone, seven jet capable airfields had new runways added.[31] The Arabs also increased protection to parked aircraft by constructing a vast number of hardened aircraft shelters (HASs). Whereas individual Israeli fighters, in a single mission, were able to destroy multiple aircraft parked in the open in 1967, the new shelters could not be penetrated by rockets and could withstand multiple direct hits from 500 and 1000 pound bombs. While the airfield improvements were important, the single change resulting from the 1967 war which would bring the airfield attack mission into the modern age was the development of sophisticated air defense networks, integrating AAA, SAMs, early warning and air defense radars, and command and control elements. The Egyptians more than doubled the number of SA-2 SAM sites, and added the low altitude SA-3, the very low altitude SA-6 , the infrared (IR) guided SA-7 shoulder-fired SAM, and the mobile ZSU-23-4 AAA piece to their arsenal.[32] The Syrians also purchased SA-3s and SA-6s, but in smaller numbers than the Egyptians. Finally, the principal Arab nations built nineteen new dispersal airfields, fourteen in Egypt and five in Syria, during the interval between the wars.[33] The combination of these improvements created a much more complicated and risky airfield attack problem for the IAF then that of 1967.

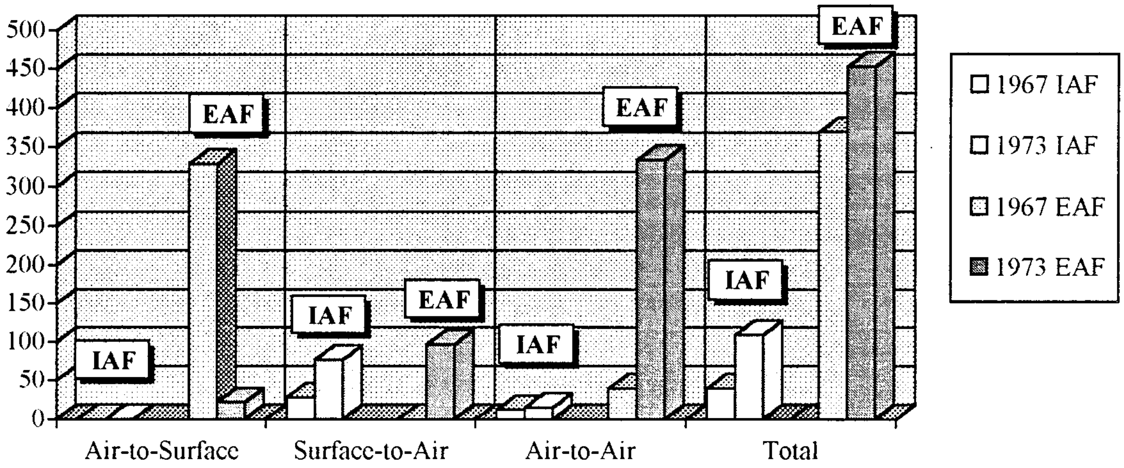
The Egyptians initiated the war at 1400 on 6 October 1973 with a strike against six Israeli airfields, HAWK and radar sites, command posts, and ground unit locations.[34] While the Egyptians lost seven aircraft in air-to-air engagements during these missions, this single strike did achieve one desired effect of luring the IAF into the Arab air defense networks. The Israeli counterattacks, launched immediately after the first Egyptian raid, experienced attrition from the very start. In Egypt, air defenses shot down eleven IAF aircraft the first day, while in Syria defenses shot down ten aircraft in thirty minutes, and thirty aircraft in approximately two hours.[35] As a further complication, the IAF found their ECM only partially effective against the SA-2 and SA-3, and ineffective against the SA-6.

These early and significant losses forced the IAF's airfield attack tactics to evolve into a phased approach. Instead of directly attacking airfields as in 1967, they first diverted a number of missions to a SEAD effort which attacked the integrated air defense networks of Egypt and Syria. The attacks against radars, air defense command posts, and SAM and AAA sites slowly created gaps in the air defense barriers. Finally, the diversion of air assets to bolster the increasingly desperate Israeli Army situation also impaired the overall OCA effort. In spite of these early setbacks, as the IAF began to plan sorties through the newly created air defense gaps, and use improved evasive maneuvers and ECM assets against the airfield threats, IAF attrition dropped quickly. Over Egypt, IAF losses in the first four days totaled thirty-four aircraft, but in the last twelve days of the war they lost only fourteen.[36]

The Arabs' passive air defense measures also impacted the IAF's airfield attack tactics as the HASs sufficiently protected parked aircraft and forced the IAF to target runways and taxiways. The Israelis attacked these using low level ingress, followed by daytime dive bomb tactics to achieve sufficient runway penetration, and flew repeated missions to hamper runway repair efforts. Unlike the 1967 war where low altitude ingress kept aircraft below SA-2 coverage, this tactic now placed the aircraft in SA-6 and SA-7 coverage, greatly increasing risk. To counter the effects of the radar guided SAMs, attacks on the airfield defenses with anti-radiation missiles and cluster bombs typically preceded the runway attacks to give the fighters a greater chance of survival.[37] The combination of these tactical modifications undertaken by the IAF averted a disaster which seemed all too possible in the opening days of the war.

The results of the 1973 Arab-Israeli war reflected the significant impact of the Arabs' improved air base defense measures on the IAF's airfield attack efforts. As an indication of the changing nature of airfield attacks between 1967 and 1973, consider the following aircraft loss summary[38]:

FIGURE 1: AIRCRAFT LOSSES SUSTAINED



Note that the Arab dispersal and sheltering efforts contributed to reducing the number of EAF and Syrian aircraft destroyed on the ground from 329 to twenty-two. As the IAF targeting between 1967 and 1973 shifted from aircraft to runways, the measure of success in the airfield attacks correspondingly shifted from the number of aircraft destroyed to the level of sortie generation disrupted. According to Blustone and Peak of the BDM Corporation, "There is good evidence that the IAF was successful at suppressing Syrian Air Force operations at critical times in the conflict. The evidence is less clear that they were able to accomplish this against the EAF."[39] The EAF's larger and more numerous airfields, as well as their successful rapid runway repair efforts, diminished the degree of effectiveness of IAF OCA missions. The bulk of IAF counterair kills resulted instead from air-to-air combat, an indication of the superior skill and training of the IAF aircrews. Israeli ground based defenses also took their toll on Arab aircraft. While Israel did not maintain as sophisticated or dense an air defense network as the Arabs, they still succeeded in bringing down twenty-five aircraft with the HAWK, and seventy-two with AAA.[40] For the IAF, the primary source of loss was ground based air defenses. Unlike the 1967 war where no IAF aircraft were lost to SAMs, in this conflict forty were lost to radar SAMs, six to IR SAMs, and thirty-one to AAA. Over one hundred others were damaged.[41]

The air power lessons of this war were as powerful in their impact on the world's air forces, as the armor lessons of 1973 were to the world's armies. The first lesson was that HASs reduced the efficiency of airfield attack by shifting the focus from aircraft targets to runways and taxiways, and forced a greater number of attack sorties to disrupt airfield operations. Secondly, the improvement of SAMs and their inclusion in an integrated air defense network further reduced efficiency by increasing the attacker's attrition rate. The final lesson, also concerning an adverse impact on efficiency, was that successful attack against a heavily defended airfield required additional support aircraft to perform SEAD and ECM. These lessons would drive America's airfield attack doctrinal thinking and technology efforts through Operation Desert Storm (ODS). The U.S. Air Force would seek to improve its ECM, SEAD, and night low level capabilities; and most importantly, to pursue the radical new approach of stealth aircraft development. Still, ODS would show that such improvements do not make all aircraft immune to ground based air defenses.

SECTION 3: AIRFIELD ATTACK IN DESERT STORM

> *"...we then attacked at about 520 kts and 180 ft radar altitude, through what seemed to be a solid red and white wall of tracer.... It was obvious that the US formations that had attacked before us had stimulated the defenses into action.... None of it seemed aimed at us since it was all pointed more or less vertically upwards but it was nevertheless a fearsome sight."*
>
> British Tornado Pilot, Feb 1991[42]

Airfield attacks in ODS followed two distinct technological paths, but neither eliminated the fundamental tactical factor of human-in-the-loop weapons delivery. The primary path was the technologically improved version of the 1973 Israeli technique: suppressing ground based air defenses to deliver ordnance in close proximity to the target airfield. The new path replaced the defense suppression aspect with stealth technology, and appeared in the form of the F-117 fighter. Overflight of the target still occurred, but without the massive support from fighter escort, ECM, and SEAD aircraft. Both paths experienced limitations during the war which impacted the effectiveness and efficiency of airfield attacks. To analyze these limitations, this section will assess data from the Gulf War Air Power Survey (GWAPS) to describe the nature of the opposing air forces; Iraqi airfields, and ground based air defenses; Coalition airfield attack tactics; results of the airfield attacks; and the lessons from these missions.

Although the Coalition air forces contained twenty-four different fighter/attack/bomber type aircraft, not all contributed to airfield attacks. Five aircraft types performed 77 percent of the airfield strikes. These included, in order of contribution, the F-16, Tornado GR-1, F-111F, F-117, and F-15E.[43] Notably, the B-52 and Tomahawk Land-Attack Missile (TLAM) also conducted airfield attacks, but contributed less than 1 percent of the total airfield strikes. Of the aircraft listed, only the F-111F, the F-117, and some F-15Es[44] possessed the capability to employ, and self designate, laser guided bombs (LGBs) from the start of the war.[45] All the above aircraft were capable of night flight and weapons delivery, but only the GR-1, F-111F, and F-15E could perform low altitude, adverse weather deliveries. A key feature of the GR-1 contributing to the airfield attack mission, was its ability to employ the JP-233 weapon system, a fixed canister which releases concrete penetrating and area denial mine submunitions. The submunitions could crater runways and taxiways, and then disrupt the repair effort through mine detonation. Unfortunately, the JP-233 required aircraft flight directly over the desired point of impact and at very low altitude. Additionally, any significant movement of the aircraft during submunition release, such as that necessary to avoid surface-to-air fires, severely degraded the accuracy of the weapon.

Direct support to these aircraft during airfield attacks came in the form of SEAD (including ECM), and fighter escort. The primary SEAD aircraft, in terms of percentage of OCA support sorties flown, were the F-4G, F-16, F/A-18, EA-6B, and EF-111. Of these, the F-4G, F/A-18, and EA-6B employed the High Speed Anti-Radiation (HARM) missile to suppress radar emitters. The F-15C, F-14, F-16, and F/A-18 flew the bulk of the OCA escort missions. Taken altogether, these attack and support assets afforded the Coalition an around-the-clock capability to strike Iraqi airfields, but with adverse weather attacks limited to non-precision weapons.

Prior to the war, the Iraqi air threat appeared formidable in numbers, less so in technology. Of the more than 700 combat aircraft, only a small number were the modern MiG-29 interceptor and SU-25 ground attack aircraft.[46] Only a fraction of their aircraft were night/all-weather capable, and even those were inferior in technological sophistication as compared to the Coalition aircraft. However, the sheer number of aircraft, their demonstrated willingness to employ chemical weapons, and the possession of some modern aircraft and air deliverable weapons[47], posed a threat that the Coalition could not take lightly.

The Iraqis learned the value of expanded, dispersed, and hardened airfields from the 1973 Arab-Israeli war, and their war with Iran. The nearly seventy airfields in Iraq presented a severe targeting challenge to OCA planners:

> Iraq itself contained twenty-six main operating bases (sixteen air force, five army, two navy, and three training). The seizure of Kuwait in August 1990 had given the Iraqis two additional fighter bases in that country...plus the international airport in Kuwait City and one Kuwait Air Force highway strip.... When the war started, Iraq also had another twenty-one deployment bases, some still under construction, that provided an "outer ring" of reasonably capable bases around the main operating bases.[48]

On each main operating base the Iraqis constructed up to thirty-nine state-of-the-art HASs, totaling 600 overall.[49] The Iraqis also complicated the runway attack problem by constructing two or more widely separated runways, connected by multiple taxiways, and by building redundant taxiways from each HAS to the main runway.[50] Such redundancy reduced the probability of shutting down an airfield by cratering a few key choke points.

The Iraqis complemented these passive defense measures with a dense ground based air defense system at each key military airfield. The system consisted of approximately five hundred radars, 120 SAM batteries, and 7500 AAA pieces[51]. While not all these systems protected airfields, a significant number served this purpose. For example, Table 1 shows the distribution of major defenses, excluding IR SAMs, at just five key airfield areas.[52]

TABLE 1

IRAQI AIR DEFENSE DISTRIBUTION

	Tallil	H2/H3	Mosul/Kirkuk	Al-Basrah	Baghdad*
Missile Launchers	10	90	122	118	552
AAA Sites	73	138	39	167	380
AAA Guns	180	281	110	442	1267

* Includes entire Baghdad area, not strictly the Rasheed and Saddam airfields.

An elaborate computerized command and control system, known as KARI[53], integrated these air defense weapons with early warning radars, ground control intercept radars, and interceptor aircraft. The system employed hardened, redundant transmission links and rapid communications to combine the individual components synergistically .[54] The powerful KARI network, together with Iraq's airfield improvements, presented the Coalition with a complex OCA challenge.

While the sophistication of airfields and their defenses had improved dramatically since 1973, so had the tactics and technology to penetrate those defenses. During the first three days of the war, Coalition tactics relied on night, low level, penetration of airfield terminal defenses for either direct overflight or short stand-off weapon release. The mission of operating surface (runways, taxiways, aprons) attack generally went to the British and Saudi Tornados using the JP-233. To attack the airfield structures at night without direct overflight, Coalition planners tasked the F-111Fs, F-117s, and F-15Es using LGBs and their self-designating capability. The tactics involved in such releases, however, did not keep the aircraft outside the lethal range of the air defenses except for the shortest range AAA. Other strike fighters, such as the F-16, flew primarily daytime sorties, using low level tactics, and employing general purpose unguided bombs against airfield structures[55]. Even the B-52 flew low level missions against airfields, thirteen on the first night, dropping general purpose bombs, cluster munitions, and mines.[56] After the third day, Coalition tactics began to change. The use of anti-radiation missiles suppressed the majority of the radar guided SAM threat, while a significant air-to-air threat never materialized. With the massive volume of AAA and IR guided SAMs still effective at lower altitudes, Coalition planners restricted attacks to above 15,000 feet.

The move to medium altitude required a modification of existing tactics for most aircraft. Because NATO planners never envisioned such a degree of air supremacy during a NATO-Soviet conflict, aircrews had not trained in medium altitude tactics. These medium altitude deliveries generally fell into two categories: LGB capable aircraft employed such weapons, usually at night, from level deliveries using altitude and time separation to avoid interference; non-LGB capable aircraft mostly employed diving deliveries with medium altitude releases during the day, and level radar deliveries at night. While the move to medium altitude provided aircrews protection from AAA and IR SAM threats, it also resulted in decreased bombing accuracies for non-precision weapon drops.

The results of the OCA effort must be measured both in terms of the level of Iraqi flight activity and aircraft destroyed. In the opening days of the war, the air planners emphasized runway and taxiway attacks, "not so much as a means of completely closing Iraqi air bases [but] as a way of limiting the interceptors that the Iraqis could put into the air...."[57] This limitation on the objective was due to the robust nature of the airfields and the inordinate number of sorties required to shut down a base completely . When the few Iraqi attempts at air-to-air engagements ended in disaster, they declined to fly and retreated to the protection of the HASs. The existence of an "air force in being" forced the Coalition to shift the focus of attacks from operating surfaces to aircraft and HASs in the second week.[58] As for aircraft destroyed, "by the war's end, 324 of the original 750-plus Iraqi fixed-wing combat aircraft, were reported destroyed, captured, or relocated outside Iraq."[59] More specifically, the coalition destroyed 151 on the ground, shot down thirty-three, and captured or destroyed thirty-one with ground forces. An additional 109 aircraft escaped to Iran. In the process, the Coalition destroyed or damaged 375 of 594 aircraft shelters.[60] Further destruction of aircraft was prevented by limited numbers of precision munition capable aircraft, and Iraq's moving of aircraft near residential areas and cultural monuments, areas which the Coalition would not bomb because of collateral damage concerns.

. Lessons related to the Coalition's short stand-off range tactics appeared in four categories: first, in the number of aircraft shot down by ground based air defenses over or near airfields; second, in the large number of support aircraft required to suppress Iraqi airfield terminal defenses; third, in the reduced accuracy of attacks after the change to medium altitude; and fourth, in the problems of adverse weather on both stealth and non-stealth aircraft ordnance delivery. Each of these categories requires further explanation.

The difficulty in declaring aircraft loss and damage rates during airfield attacks by Coalition air forces a "problem" is that they occurred in remarkably low numbers. But, the purpose of the current analysis is to determine if the few losses which *did* occur were *preventable* through increases in stand-off range. Using the GWAPS to perform this analysis requires some interpretation, as the document does not indicate which downed aircraft were specifically attacking airfields, but it does indicate which aircraft were on OCA missions. While the bulk of the OCA category was indeed airfield attacks, this category also included non communication electronic installations, air depots, and air ammo depots.[61] The GWAPS does, however, indicate the location of the "lost" aircraft. One can assume that those lost at or very near airfields were attacking those airfields since an aircrew would not normally plan a route through such heavily defended airspace. With this in mind, the GWAPS data, summarized in Table 2,[62] indicates that OCA losses account for six of the thirty-eight total Coalition combat losses, with four of these occurring at or near the Tallil, H-2, and H-3 airfield complexes.[63]

TABLE 2

COMBAT AIRCRAFT LOSSES FOR OCA MISSIONS

DATE	ACFT TYPE	DAY OR NIGHT	SOURCE OF LOSS	LOCATION
17 Jan	Tornado	Night	AAA	8 nm NW Tallil
17 Jan	Tornado	Day	Radar SAM	1 nm W Basra
19 Jan	Tornado	Day	Infrared SAM	51 nm SE Tallil
19 Jan	Tornado	Night	Radar SAM	H-3 Airfield
21 Jan	F-14	Day	Radar SAM	H-2, H-3 Airfields
14 Feb	Tornado	Day	Radar SAM	40 nm NW Baghdad

Also, of forty-eight Coalition aircraft listed as combat "damaged", none occurred during OCA missions,[64] indicating that all aircraft hit by enemy air defenses during these missions were lost. One also notes that the low altitude, direct overflight mission was particularly dangerous, as witnessed by the high percentage of Tornado GR-1 losses.

The large number of support aircraft required to assist a strike package in penetrating the terminal airfield defenses illustrates the second shortfall. For example, the Coalition would form packages similar to the one flown on 17 January 1991 against the Al Jarrah Airfield facilities and runways, and the Al Fulejah Radio Relay Station. This typical package consisted of eight F-111Fs and four Tornado GR-1s as the strikers, four F-4Gs and two EF-111s performing SEAD, and four F-15Cs serving as fighter escort.[65] Such consolidated packages were difficult to plan with the aircraft based at different locations, and complicated in their execution and synchronization, especially at night.

While not an airfield attack mission, a situation on 19 January 1991 highlights the results which can occur if the support is not available. This mission, known as Package Q, was the largest of the war, consisting of seventy-two F-16s, eight F-4G Wild Weasels, eight F-15Cs, and two EF-111s, and was to strike targets in the Baghdad area. With the F-4Gs in place at the target area, the Iraqis fired their SAMs ballistically, and were largely ineffective. But, before all the strikers could release their bombs, the F-4Gs exhausted their load of HARM missiles or ran low on fuel and departed the area. As a result, the Iraqis returned to guiding their SAMs, shooting down two F-16s, and causing others to jettison their weapons during evasive maneuvers.[66] Commanders would cancel other missions or send aircraft to alternate, less heavily defended targets during the war when SEAD support became unavailable on short notice. This reliance on numerous support aircraft added cost and complexity to the missions. It also reduced the efficiency of air effort due to the limited numbers of these specialized aircraft, which in turn limited where and how often the air planners could schedule attacks.

The third problem with Coalition tactics occurred when the commanders shifted attacks to the medium and high altitude regions. According to the GWAPS, the shift degraded attack operations in two ways. First, "tactical surprise was lost due to detection by early warning and ground control intercept (GCI) radars, and the aircraft were more vulnerable to some enemy defenses, notably surface-to-air missiles." Second, "accuracy was reduced for all weapons except precision-guided munitions."[67]

The fourth problem with Coalition tactics concerned the increased probability of weather obscuring targets for visual, laser guided, and electro-optically guided deliveries. Even stealth aircraft were not immune to this problem. With each F-117 carrying only a pair of laser guided bombs during the war, the weather impact on them was particularly harsh. Some GWAPS statistics serve to illustrate the severity of this problem in what should have been a region of the world most conducive to clear air bombing:

> Bad weather had already affected F-117 operations on the night of 18/19 January when roughly two of every three planned strikes either missed or could not be dropped due to weather. While the F-117 "no drops" and misses attributed to weather improved to one out of two on the night of 19/20 January, half the planned effort from the F-117s against strategic targets was still frustrated by weather in the target areas....[S]ignificant losses of F-117 strikes to weather would recur in early February on ATO Days 17 and 18, and ATO Days 40 and 41, during the ground campaign, would see the F-117s nearly grounded by weather.[68]

In the first ten days alone, the Coalition canceled 15 percent of all attack sorties because of poor weather .[69] Forty-three percent of the 6583 canceled sorties for the entire war were canceled because of weather.[70] The conclusion derived from these statistics is that while precision weapons afforded the Coalition a tremendous capability to destroy pinpoint targets with limited collateral damage, the weapons were weather dependent. Also, in the case of the F-117, weather dependency negated the advantages of stealth. The lack of all weather weapons impaired the air planners' abilities to strike at the time and target of their choosing, and degraded the effectiveness and efficiency of airfield attack missions. Weather related mission delays lowered overall effectiveness by providing Iraq additional time to recover from previous attacks. The lower efficiency resulted from the need to schedule additional sorties against targets from aborted missions.

In summary, although the Coalition enjoyed overwhelming air campaign success, certain limitations degraded the effectiveness and efficiency of airfield attacks . The Coalition lost four aircraft performing these missions, but required a number of defense suppression support aircraft to prevent the loss of more. Even when the Coalition moved to medium altitude to avoid the most lethal of the remaining defenses, their weapons possessed limitations of reduced accuracy or incompatibility with adverse weather delivery. Finally, even the stealth fighter was constrained in its tactical flexibility due to weather limitations. All these limitations were based on technology; and thus, technology serves as a source for a potential solution.

SECTION 4: THE NEED FOR STAND-OFF AUTONOMOUS WEAPONS

> *Medieval Jewish legend told of an automaton called the "Golem" that mysteriously came to life to protect its owner. Today a new breed of "Golem" is on the horizon - robot warriors - and no serious look at Third Wave war and anti-war can afford to ignore them.*
>
> Alvin and Heidi Toffler[71]

To overcome the limitations of airfield attack tactics exposed in ODS requires a significant advancement in the technology of air-to-surface weapons. The next fundamental form of improvement is informational, integrating the artificial intelligence required for weapon navigation and steering into the weapon , in order to remove human combatants further from danger. This "third wave" notion of air-to-surface weapons development has been technologically feasible since the mid-1980s, and current trends in microelectronics, inertial measurement units, and target recognition algorithms continue to improve potential performance and lower cost. But, with technical advancements in the science of war comes the danger that the allure of technology may blind one to its true impact. Such is the basis of Bellamy's caution that technology advancement at the tactical level of war must be considered in terms of a three point framework consisting of technological development, the tactical doctrine to employ that development, and the combatant training required to exploit the development's potential fully. This section analyzes the impact of SAWs, in terms of the effectiveness and efficiency of the airfield attack mission, within each of Bellamy's three "points of the triangle," and concludes with potential drawbacks of SAW implementation.

Technology Development: The individual capabilities of the theoretical SAW are not unique. What makes this weapon unique, however, is the combination of precision guidance, medium stand-off range, autonomous capability, hard or area target capability, all weather delivery, and moderate cost in a single unit. Current cruise missiles, the Conventional Air Launched Cruise Missile (CALCM) and the TLAM, provide long stand-off range and autonomy, but do not provide precision within the Air Force's three meter circular error probable (CEP)[72] criterion. Cruise missiles also suffer from a lack of hard target kill capability and cost over one million dollars per copy.[73] Laser and electro-optically guided bombs proved their precision and hard target capabilities during ODS, and at moderate cost, but do not provide sufficient stand-off or all weather capability. Their lack of autonomy also forces the laser designating or data link operating aircrew to maintain line-of-sight with the bomb until impact. Finally, general purpose weapons, while inexpensive,[74] are relatively inaccurate (especially from higher altitudes), and require aircrews to release ordnance in close proximity to their targets. Thus, all current air-to-surface weapons in today's inventory only offer a compromise of the desired characteristics of a SAW.

The U.S. does have three SAW-like weapons currently under development. But, while these next generation weapons offer much improvement over current weapons, they do not fill all the desired criteria of a SAW. The first of these is Northrop Corporation 's Tri-Service Stand-off Attack Missile (TSSAM). Northrop will produce two air launched versions of the fully autonomous TSSAM: a submunition dispensing weapon, and a unitary warhead version employing a precision terminal guidance seeker for point or hard targets.[75] This engine powered, long range weapon suffers from cruise missile-like costs, estimated at $13.9 billion (total program cost) for just 7,450 missiles, or roughly $1.8 million per unit.[76] Technologically, the TSSAM fits all the criteria of a SAW (with the possible exception of all weather: the seeker details remain classified), but its high cost limits its employment in large quantities.

The second weapon under development is the Joint Direct Attack Munition (JDAM). Phase I of this program will produce a GPS (Global Positioning System)/INS (Inertial Navigation System) guidance kit to strap onto an existing 2000 pound class bomb body. Phase III of this program, scheduled for demonstration in fiscal year 1995, would add a terminal guidance seeker to achieve CEPs of three meters or less, in all weather.[77] This program emphasizes low cost and reduced risk, with Phase I setting $40,000 as the guidance kit cost goal, and Phase III aiming for $120,000 per kit . The trade-off to achieve such low cost is the reduction in stand-off range. This is an unpowered weapon which will offer little or no improvement in stand-off range over current LGBs, especially at low altitudes.[78]

Finally, the Navy's Joint Stand-Off Weapon (JSOW) program is developing an unpowered, submunition dispensing weapon, which uses a folding wing and aerodynamic body to provide greater range than the JDAM. The looser precision requirements for a submunition dispensing versus unitary warhead weapon allows JSOW to use only INS/GPS guidance, without a terminal seeker.[79] All three weapons represent advances in air-to-surface weapons technology, but none answer the need for an affordable, autonomous weapon able to strike targets at medium stand-off range from *low or high* altitude.

The necessary characteristics for a SAW include precision, powered flight and aerodynamic shape for low altitude delivery and stand-off, and autonomy for guiding to a target. Each of these technical characteristics contributes to improving the efficiency of the airfield attack missions in four ways. First, by providing nominal accuracy of fifteen meters with INS/GPS only, or three meters when including a terminal seeker, target destruction requires fewer weapons and sorties than missions using non-precision weapons. The results of precision attacks in ODS prove this point: LGB missions successfully attacked approximately thirteen times as many targets as non-precision missions for the same number of sorties.[80] Additionally, because mission success would require fewer aircraft and follow-on strikes, more aircraft would be available to strike other targets, and hence accelerate operational level success.

Second, SAW missions do not require specialized laser target designating or data link equipment, found on relatively few aircraft in the inventory. The greatest advantage in efficiency would come from mating these weapons with the large payload capacity of the B-1, B-2, and B-52 bombers, which currently can not employ LGBs (with self designation), as well as to all air-to-ground capable fighters. Such payloads would permit air planners to use fewer aircraft against an airfield, or a single aircraft against multiple airfields.

Third, stand-off provides the obvious increase in efficiency resulting from lower aircraft attrition, and fewer missed targets caused by last second pilot maneuvers for avoiding terminal air defenses.

The fourth advantage of SAWs improves the efficiency of the airfield attack mission indirectly. The aerodynamic shape of the weapon, especially when combined with a conformal (mounting flush to the fuselage or wing) versus pylon type mounting on fighter aircraft, greatly reduces aircraft drag and fuel consumption. Calculations performed at the Wright Laboratories, Armament Directorate indicate a 30 to 40 percent increase in unrefueled range for an aircraft carrying two, 2000 pound, low drag conformal weapons versus two conventional 2000 pound, pylon mounted bombs. Such numbers translate to either a greater number of targets that a fighter could reach as a result of increased range, or for the same range, less fuel usage and reliance on air refueling.

Tactical Doctrine: In this, the second point of Bellamy's triangle, one finds the greatest improvements in the effectiveness of SAW based airfield attacks. The modifications to tactical doctrine allowed by SAWs increase effectiveness through improvements in tactical flexibility, surprise, and massing weapons effects. To appreciate the potential of SAWs fully, each of these categories requires further explanation.

The current short stand-off range tactics used in ODS, impose constraints on the mission planners' **tactical flexibility** in a number of ways. First, the requirement to strike a number of airfield aimpoints in a short period of time forces the planner to compress multiple attacking aircraft in limited airspace over the target. Particularly at low altitude, the planner's requirement to separate aircraft from both the bomb fragmentation of other weapon releases, and other aircraft in the strike package, hampers the package's ability to strike multiple targets simultaneously at a single airfield. Even in the case of LGB deliveries, where the aircraft remains outside the bomb fragmentation zone, the release distance is still short enough to limit the number of simultaneously attacking aircraft in order to prevent aircraft interfering with each other. A second constraint of current tactics occurs during airfield attacks when aircrews employ either non-precision or precision weapons. Specifically, attacks against runways with a string of general purpose bombs requires an attack heading approximately twenty to forty degrees off the axis of the runway to maximize the probability of cutting a swath across the surface. Likewise, for

LGB deliveries against a structure, the aircrew must plan their attack profile such that they can maintain the laser spot on the same point of the structure throughout the time of flight of the bomb, and not have it move off the aimpoint or be blocked by another structure.

Current weapons impose a final constraint on tactical flexibility by the limited numbers of aircraft capable of employing precision weapons. For example, in the U.S. Air Force, only 16 percent of the active duty fighter/attack/bomber fleet maintains a LGB capability with self-designation. This low percentage caused concern in ODS :

> The lack of PGM [Precision Guided Munition] capability on many US aircraft required planners to select less-than-optimum attack options, such as delaying attacks or assigning multiple sorties with non-precision munitions. Operation Desert Storm results argue that a higher percentage of US attack aircraft should have PGM capability to increase the amount of target damage that can be inflicted by a finite number of aircraft.[81]

SAWs would overcome these constraints on tactical flexibility. The stand-off range of the weapon gives planners the ability to prepare simultaneous attacks on a single airfield without the concern of aircraft interfering with each other. Furthermore, the fifteen meter or less accuracy of the SAW allows it to approach the airfield from any angle and still strike the appropriate aim point, loosening the restrictions on attack heading and increasing the release envelope. Finally, SAWs remove the specialization required by the aircraft for precision attack and place it in the weapon, thereby opening up the employment of such weapons to other aircraft in the inventory. This improves tactical flexibility, and thus mission effectiveness, by increasing the number of aircraft available to mission planners which can deliver precision weapons in all weather conditions.

The increased ability to **mass weapons effects** on an airfield through the use of SAWs provides the next improvement in effectiveness. By eliminating the need for a sequential flow of aircraft over the airfield, through increased launch range, the attackers are able to employ a large number of weapons simultaneously , each targeting separate aimpoints. Additionally, by keeping the launching aircraft a safe distance from the airfield, the air planner can better coordinate SAW attacks with surface-to-surface weapon systems such as the Army's Tactical Missile System (ATACMS), thus enhancing the volume of fires which can strike an airfield.

The same SAW characteristics which allow concentrated weapons effects also improve mission effectiveness by allowing greater **surprise.** Time sequenced airfield attacks forfeit whatever surprise they may have had after the lead aircraft release their weapons and alert the air defenses. Also, jamming and long range SEAD missions which precede attacks have the unavoidable drawback of alerting defenses to an impending attack. The use of SAWs lessens both problems and can create a surprise factor which amplifies the overall impact of the mission. Surprise and massing effects can combine synergistically at an individual airfield to impart a greater disruptive effect than if the attackers drop the same volume of weapons in a time phased manner.

Training Combatants: The third element of Bellamy's model is the training of combatants to use the available technology in combat effectively. Developing a new system and determining the doctrine for its use are insufficient to extract its most potent value. The individual combatant who will control the technology must be proficient in its use. A different aspect of this element of Bellamy's model, however, analyzes how the new technology modifies the roles and functions of individual combatants, and what overall tactical effect results. In the case of the SAW, overall mission efficiency improves due to reduced workloads for the aircrew both in flight and prior to launch.

The in-flight reduction in workload occurs during weapons delivery, considered by aircrews as one of the most demanding in-flight phases of any current air-to-surface mission. During this phase the aircrew performs the functions of target identification, aim point selection, and, in some cases, weapons steering. At the same time, missile and AAA fires, and ground avoidance compete for the crew's attention. The SAW fundamentally alters this situation by transferring the first three functions to the weapon, placing the aircrew a safe distance from ground based air defenses at the time of weapon delivery. SAW technology, then, decreases the complexity of the aircrew's primary job, and thus requires no significant new training to operate.

While the SAW would relieve the aircrew of many weapon delivery functions, it can not assume 100% of the burden, because the programming of the SAW on the ground still requires human interaction. But, here again, the flying unit realizes a benefit because any trained mission planner, not just aircrews, can load the appropriate target characteristics and program the weapon. What follows from this reduced aircrew workload is an increase in attack mission efficiency. For an aircrew, a large portion of the mission planning phase is spent preparing and studying the target attack. Depending on the type of mission, they commit to memory the visual, infrared, or radar identification features that point to the target, features of the target itself, and the nature of the threats. For a LGB delivery, the planning load increases even further. By removing these elements from the workload of the aircrew, mission planning time decreases, and crews are able to turn around between missions in less time. Therefore, in cases where mission turn around time is aircrew, not aircraft, driven, sortie rates would increase. The final factor reducing aircrew mission planning time would be the diminished complexity of planning simultaneous attacks on a single airfield. The greater flexibility resulting from dispersing the attacking aircraft with the stand-off capability of the SAW provides the mission planner with a reduced workload since he is no longer attempting to synchronize bombing runs from multiple aircraft.

While Bellamy's three point model highlights some very clear tactical level advantages of SAWs, such weapons may also create difficulties not encountered with current weapons. One must understand these problems, as much as the potential benefits, to recognize the true impact of this new technology.

Potential Drawbacks of SAWs: New technology never translates into ideal solutions, and SAW technology is no exception. Three problems associated with implementing these weapons may arise. They include the absolute necessity for accurate target intelligence information from which to program the SAW, the lack of bomb damage assessment (BDA) when the human operator is removed from the target area, and potential countermeasures which may disrupt the SAW flight. None of these drawbacks is insurmountable, but they must be understood to extract the full benefit from the SAW.

The potential intelligence related drawback stems from the level of accuracy required for SAW premission planning. In current LGB or data-linked systems, a key advantage lies in the capability of the human controller to redirect his aimpoint or otherwise modify the weapons delivery if the target area appears different than expected. A difference may arise when planners extract incorrect target coordinates during the planning process, when unexpected damage occurs to the target from a previous strike, or from undetected construction to the target area. When technology removes the human from the system, and with it the possibility for on-the-spot corrections, the burden shifts to the intelligence process to ensure that accurate and timely target information reaches the flying units. A GPS/INS-only SAW, which does not contain the "eyes" of a terminal seeker, must receive aimpoint coordinates less than the fifteen meter accuracy of the weapon. A terminal seeker equipped SAW can accept slightly less accuracy with its ability to make final steering corrections, but the weapon still requires a certain degree of precision to place the aimpoint in the field of view of the seeker. The intelligence state-of-the-art must keep pace with improvements in weapons development. Fortunately, similar requirements for programs like JDAM, JSOW, and TSSAM are prompting the Department of Defense to pursue this issue actively.[82]

The aircrew in the current weapon systems also serves as a valuable source of BDA. By removing this BDA, the potential exists to offset some of the improved mission efficiency offered by the SAW. Degraded efficiency could occur from the increased potential of ordering follow-up sorties to strike already damaged targets. The employment of SAWs will therefore require increased independent sources of BDA. With current BDA sources already considered a weak area based on ODS performance, the situation will only deteriorate until new Department of Defense initiatives are enacted.

The final potential drawback of SAWs is the possible impact of countermeasures on the weapons. Because the SAW is likely to rely on external steering information, either GPS satellite data or sensed target information, the potential will always exist for jamming or deceiving the weapon. While the technical details of potential countermeasures are classified, it is important to note that various organizations, including RAND and the Wright Laboratories (Armament Directorate), continue to place a great deal of emphasis on reducing the countermeasure susceptibility of the key SAW technologies. They conclude that the problem is not insurmountable.

SAW technology can clearly improve the tactical level efficiency and effectiveness of the airfield attack mission. As analyzed within Bellamy's model of technology, tactics, and training, SAWs offer the opportunity to strike airfields with fewer aircraft and weapons; greater flexibility, surprise, and mass; and with a reduced workload on the aircrew, both in planning and execution. However, the advantages do not come free. The increased requirements for accurate intelligence, loss of a BDA asset, and potential for countermeasures, if not properly addressed, could degrade the SAW's benefits. But, the potential gains clearly outweigh the potential drawbacks and apply to stealth as well as "lower technology" aircraft. The SAW does not compete against the F-117, F-22, and the B-2, but complements and enhances their capabilities. Thus, from an efficiency and effectiveness standpoint, production of these weapons offers obvious advantages in an age of shrinking force size and declining budgets.

SECTION 5: CONCLUSIONS AND RECOMMENDATIONS

> *Throughout the history of warfare, then, technology and man have always striven for harmony, and man has imposed his limitations on technology. Does this mean that we are on the verge of the greatest revolution of all: the augmentation and in certain cases replacement of human intelligence by artificial intelligence (AI)? Only with AI can air combat advance beyond the transonic engagements permitted by human reflexes.*
>
> Christopher Bellamy[83]

The Air Force's basic doctrinal manual, AFM 1-1, states "aerospace control normally should be the first priority of aerospace forces."[84] The future holds no change to this basic tenet. In fact, the necessity for control of the air, and subsequently OCA actions, will rise in importance as the proliferation of air launched weapons of mass destruction, stealthy weapons, and foreign cruise missiles, increases the need to prevent hostile air activity during any conflict. Concurrently, counterair technologies will continue to improve, making OCA missions with current tactics increasingly risky. This monograph examined the issue of whether a SAW, plus new tactics, could advance the effectiveness and efficiency of the airfield attack mission to ensure the U.S.'s ability to rapidly achieve command of the air in any future conflict. This section summarizes the results of the study and provides some considerations and recommendations on the future of SAWs.

The Israeli experience of 1967 and 1973 indicates how quickly airfield attack risks can take a toll on an air force that fails to keep ahead of air defense technologies. The U.S., prior to ODS, did recognize the increasing risks from air defenses and initiated or improved programs in stealth, low altitude and all weather aircraft, ECM, and SEAD to counter these risks. ODS results show that these efforts worked well, but did not compensate fully for tactical level limitations resulting from short stand-off, human-in-the-loop weapons. However, the evidence indicates that weapon advances could mitigate many of these limitations. Developing a moderate cost, medium range SAW can increase tactical flexibility, allow greater surprise, and improve the ability to mass weapons on a target, thereby improving the effectiveness of the airfield attack mission. Also, the use of SAWs improves mission efficiency by reducing aircraft attrition, the number of aircraft required per mission, and combat turn around times. In short, SAW development will improve the effectiveness and efficiency of the airfield attack mission over that achieved in ODS.

The discussion, thus far limited to the tactical level of war, permits only cautious conclusions because it does not incorporate operational and strategic level considerations. Before addressing recommendations, one must understand these considerations and their potential impact on the development of SAWs.

In reference to his tactical model, Bellamy states that in moving "from the tactical to the operational and strategic levels, it is necessary to combine this triangle with the best possible command, control, communications, and intelligence..., logistics and high mobility."[85] For SAW technology, a partial list of these considerations would include the impact on strategic mobility of a fighter or bomber wing if such weapons are developed; the cost of modifying aircraft weapon data busses to allow in flight data transfer to the SAW; how to rapidly gather, process, and disseminate the target intelligence required for the weapon; and how to balance the force structure after the addition of SAWs.

The force structure question is certainly the most critical and complex for it musters budget, force requirement, and emotional issues. In terms of budget, one needs to determine how many SAWs are necessary, what should be the impact on current weapons production, and, given a fixed budget, what will be cut to produce a new weapon. The force requirements issue seeks to balance the numbers of fighters, bombers, cruise missiles, SAWs, and other precision and non-precision weapons to maximize effectiveness and efficiency at the operational level. This also requires analyzing the impact of SAWs on target types (both fixed and mobile) other than airfields. Additionally, emotions enter into the debate. A December 1994 *Newsweek* article describes Defense Secretary William Perry's visionary attempts to promote a military revolution which will "produce weapons that are not only 'smart' but 'brilliant' - able to fly out scores of miles and choose their own targets;" however, within "the air force the fighter jocks scrap with bomber barons but both unite to defend the manned aircraft against the threat from computer-guided drones and missiles."[86]

The force structure issue also includes the question of whether SAWs are necessary given that stealth aircraft proved in ODS they could penetrate air defenses. The "stealth versus standoff" argument is fallacious because these technologies complement each other; they do not compete. Three factors support the need for both technologies. First, stealth aircraft in ODS exhibited weather limitations which SAWs would negate. Second, the cost of replacing all current combat aircraft with stealth versions is prohibitively expensive. Finally, even U.S. stealth aircraft are not immune from future risk. As history indicates, major asymmetries in weapon technologies are usually short lived, and stealth will not be exempt from this trend. Stealth reduces signatures in selected frequency bands, but does not eliminate them. In other words, stealth can be countered, albeit with complex technology, and to assume such efforts are not progressing outside the

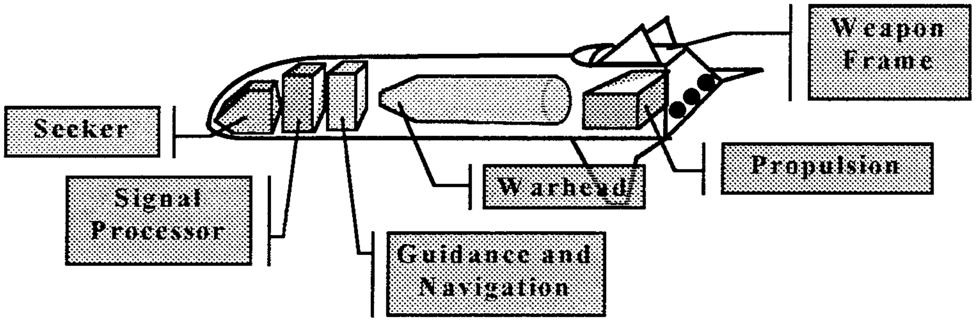
U.S. would be naive. In fact, such efforts are already underway in the Department of Defense.[87] Obviously, the decision to proceed with SAW development involves much more than the tactical level arguments of this monograph.

If unencumbered by budget constraints, recommendations pertaining to SAWs would be easy: SAWs so overwhelmingly benefit the effectiveness and efficiency of the airfield attack mission, that the U.S. should proceed with their development. These weapons should augment, not completely replace, current precision and non-precision weapons, for many scenarios exist that do not require the stand-off or precision of the more expensive SAW. The reality of budget tempers any procurement assessment, but only in terms of "how many," and not "if" these weapon should be built. Along with the recommendation to produce the SAW, comes the recommendation to upgrade the intelligence and BDA gathering assets to support the SAW in the field. By proceeding down this path, the U.S. Air Force can only improve its ability to seize and maintain control of the air in time of war, in spite of shrinking budgets and force sizes.

APPENDIX: SAW TECHNICAL PRIMER

Figure 2 below illustrates the typical elements of any standoff autonomous weapon, including cruise missiles. The variation in weapons comes from nature and mix of each of the individual components, and in some cases, whether or not the weapon uses a particular component. For example, the Phase I JDAM does not include seeker or propulsion modules, and the CALCM does not include a seeker. The level of sophistication in each module, as well as their ease of integration, and producibility will determine the manufacturing cost of the weapon: multi-mode seekers, such as combining infrared an millimeter wave imaging systems, will cost more than single mode; turbine propulsion, for long range, will cost more than rocket boosting. The design of a SAW, in other words, like all weapon system designs is a tradeoff between cost and performance. The purpose of this appendix is to provide a primer on the overall operation of a SAW, as well as the various component technologies, and their costs, to provide the reader a greater appreciation for the cost-performance issues.

FIGURE 2: SAW COMPOSITION



SAW Functions: The desired operation of a SAW includes launch capability from both low and high altitude. Although medium altitude missions inflicted the bulk of the air strike damage in ODS, they would not have been possible without the critical, higher risk, low altitude missions of the first three days. According to the Air Force's planning document on tactical employment, MCM 3-1, "Low altitude is the preferred option in a medium- to high- threat environment when substantial suppression, A/A [air-to-air] force protection and EC assets are not available. The advantages of surprise or unpredictability also demand that low altitude remains an option."[88] Low altitude employment adds greater complexity to the SAW by forcing the need for propulsion to achieve the required stand-off range, and by requiring a terrain avoidance function.

With the low altitude profile being the more difficult, an illustration of this profile serves to describe the functions occurring in a SAW mission. Figure 3 diagrams a generic low altitude profile. Upon release and start of propulsion, the weapon performs its preprogrammed terrain avoidance maneuvers. This may be a simple climb to a known safe altitude, or, with the appropriate sensors and computations, a terrain following flightpath which maintains the weapon at a fixed altitude above the ground. During the midcourse phase, the SAW performs navigation updates enroute to the target. The updates can vary in complexity (and cost) from INS only, to GPS aided INS, to imaging preplanned waypoint features on the ground to determine actual location. The latter method provides

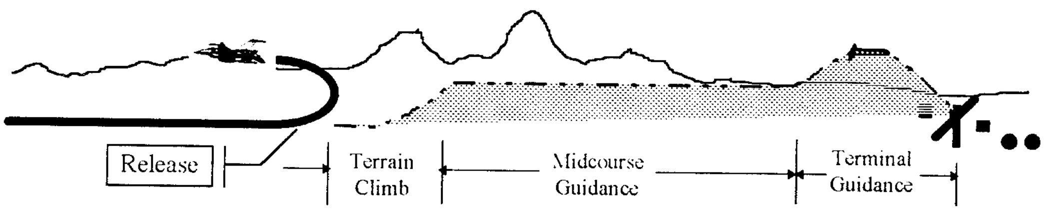


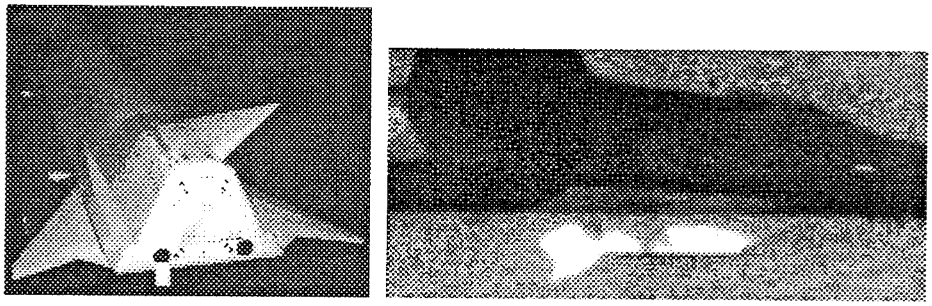
FIGURE 3: SAW FLIGHT PROFILE

the greatest accuracy and is independent of external information (i.e. GPS), and is in fact a form of cruise missile guidance, but it suffers from the tremendous complexity of planning the update points and loading them in the missile. The missile itself would require greater computing power than with other forms of midcourse guidance. The role of the midcourse phase is to provide accurate enough navigation so that when the missile enters the terminal phase, the target is in the field of view of the seeker (if any), and the missile is able to maneuver to the correct aimpoint. The missile performs other functions during this terminal phase. In the case of a unitary warhead missile attacking a hardened target, the weapon may have to perform a pop-up maneuver to achieve sufficient penetration. A submunition dispensing weapon would fly over a planned release point and eject the submunitions. To achieve precision, the rate of updates to the guidance computer will increase to provide smaller steering corrections. Finally, in the case of a seeker loaded weapon, the seeker "wakes up," begins to image the target area, compares the images to preloaded scenes or features, and locates the appropriate aimpoint.

Some research organizations are examining the feasibility of adding even more advanced features. One such feature provides the capability of sending updated coordinates to the missile after launch to strike mobile targets such as theater ballistic missiles. A second feature would add a satellite data link to have the missile beam back images of what it "sees" in the final moments of flight. This feature provides some degree of BDA by confirming to the user that the weapon struck the correct point. Of course, the level of damage would still be unknown.

Weapon Airframe: Vehicle shape plays a critical role in the range and accuracy of a SAW. Current conical shaped bombs provide reasonable stability at low manufacturing cost, but at the expense of low aerodynamic maneuverability and short glide (lift/drag) ratios. While converting these off-the-shelf bombs into autonomous weapons (such as with the JDAM) minimizes cost and risk, performance suffers. To realize the full potential of accurate guidance systems, and to increase range, requires a radical new weapon canister such as the HAVE SLICK experimental unit developed by the Wright Laboratories, Armament Division at Eglin Air Force Base, Florida, and shown in Figure 4. This composite airframe combines low construction cost, low drag, low observability, high maneuverability, and conformal carriage capability in one unit.[89] HAVE SLICK successfully completed six unpowered launches from an F-111E at both subsonic and supersonic speeds prior to 1991. While the glide mode performance is excellent, HAVE SLICK is also designed to incorporate solid rocket propulsion.[90]

FIGURE 4: HAVE SLICK AIRFRAME



(Source: Wright Laboratories, Armament Division)

Propulsion: The required stand-off range for low altitude employment of SAWs necessitates inclusion of some form of propulsion. Current weapons use two forms:

turbine engines, and solid rocket motors. The tradeoff is range vs cost, with the turbine engines (found in cruise missiles) capable of much greater distances for the same volume as rocket propulsion, but at a much steeper cost.

Warhead: This section will contain either submunitions or a unitary warhead depending on the mission and target. A SAW could employ current mine, incendiary, armor piercing, and high explosive submunitions, however, the potential to significantly raise the probability of destruction lies with new families of smart submunitions such as the Sensor Fuzed Weapon submunition and Brilliant Anti-Tank weapon (BAT), submunitions which steer to sensed targets on the ground after release. Variety also exists with the unitary warheads which could be any of the 500, 1000, or 2000 lb class of weapons, or the I-2000 hard target penetrating warhead.

Guidance and Navigation: The guidance and navigation (GN) system serves as the information manager for the weapon, performing the two key functions of stabilizing the weapon, and providing steering commands. This section performs the similar functions as that of the autopilot in an aircraft. The GN system accepts inputs from position, velocity, and acceleration sensors, and generates the corrective commands to maintain the stored flight profile. At the heart of this system lies the Inertial Measurement Unit (IMU), the series of acceleration sensing gyros. Recent progress in IMUs has been phenomenal, with current ring laser gyro devices capable of less than one degree per hour drift rates, costs under $4000, and sizes smaller than a baseball. For short flight times, an INS using only its IMU could achieve reasonable, though not precise, accuracy. The addition of GPS position information improves that accuracy to approximately fifteen meters. Six actual flight tests on an INS/GPS equipped GBU-15 body in 1993, exceeded this expected value and achieved hits between two and eleven meters.[91]

As an external source of data, GPS has the disadvantage of potential susceptibility to countermeasures. But, as an aid to weapon navigation, GPS contributions can be significant. It suppresses much of the gyro-only INS drift, thereby allowing accurate navigation over greater distances at a fraction of the cost of terrain or scene match midcourse updates, and is independent of weather. Current miniaturization of GPS receivers has allowed an INS/GPS device (ring laser gyro, GPS, plus all electronics) the size of a grapefruit.

A modification to GPS, known as Differential GPS (DGPS), could provide the less than three meter accuracy the Air Force desires in a SAW, without the need for a seeker. DGPS works on the principle of using a second GPS at a known, surveyed location as a reference to reduce the effects of satellite related errors (clock bias, ionospheric and tropospheric delays, and satellite positions errors).[92] While very high accuracies have been demonstrated, the problem is one of implementation; specifically how to have the reference station and missile GPS communicate to calculate the corrective values. One concept under investigation is to construct a global network of DGPS ground stations and computers which would constantly calculate the errors, and correct the satellite signals. Such a scheme requires a significant monetary investment.

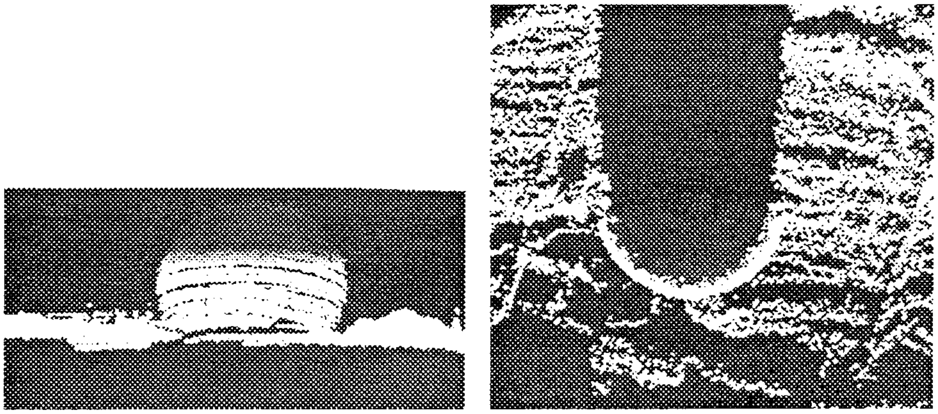
Seeker and Signal Processor: These sections allow the SAW to image a target area, recognize the target, select the aimpoint, and provide steering information to the guidance and navigation unit. These sections are necessary only if the mission and target require more precise accuracy than generated by INS/GPS devices. The SAW trades off cost and complexity to achieve this greater accuracy. The difficulty with selecting a seeker technology is determining an acceptable compromise between cost, degree of adverse weather capability, resolution, and countermeasure resistance. The laws of physics bound this problem, and make compromises necessary. In basic terms, the longer the wavelength of the electromagnetic radiation to be detected, the greater the penetration through adverse weather. But, the longer the wavelength, the lower the imaging resolution, and the larger the "antenna" or aperture required in the missile. Thus, IR and visible bands allow much higher resolution than millimeter wave, but are scattered and absorbed more in adverse atmospheric conditions. The leading seeker technology candidates include passive imaging infrared, real-ream millimeter wave, laser radar (LADAR), and synthetic aperture radar (SAR).

Passive Imaging IR: These devices use an array of IR detectors, scanned across the ground to image a scene from emitted thermal radiation. The sensors typically operate in one of the two key atmospheric transmission windows in the 3 -5 μm or 8 -12 μm wavelength bands. Temperature contrast between objects on the ground allows the processor to differentiate between these objects, and to search for the target features loaded into memory. Passive IR represents the most mature of the technologies, offers high resolution, and relatively low cost, but suffers from some key drawbacks. The most significant drawback is its inability to see through fog, thick haze, and smoke. Additionally, from the standpoint of programming the processor, thermal (IR) scenes are difficult to model as they depend on a number of variables, including season, time of day, cloud cover and amount of solar loading, and target and background material, to name a few.

Millimeter Wave: The millimeter wave frequency band between approximately 30 to 300 GHz offers a number of reasonable atmospheric transmission windows. Such frequencies allow transmission and detection with missile apertures between 5 and 20 centimeters. These systems are most commonly studied as active systems, but research is underway to also study passive millimeter wave imaging. In the active mode, the sensor can measure the reflected radiation from each scanned point on the ground, and, with the proper beam modulation, the sensor can measure the range to each point with approximately one meter rage resolution. Millimeter wave offers better weather penetration than imaging IR, but is still not "all weather," as it is susceptible to high attenuation in heavy rain. This technology also suffers from high noise of background clutter, resulting in low reflectance contrast between target and background; low range resolution, and a susceptibility to chaff and corner reflector countermeasures.[93]

Ladar: Ladar operates in the IR spectrum, but as an active system. The seeker scans a modulated IR laser beam across the ground and measures the range to each point, and the amplitude of the reflected laser radiation. The primary information comes from the range data. The seeker processes the less than one foot range resolution, and six to twelve inch spatial resolution data to create a detailed three dimensional (3-D) image of the target area. Note that unlike the passive IR seeker, the ladar seeker does not measure emitted thermal radiation, and is therefore not susceptible to the daily and seasonal heat cycle phenomena which plague imaging IR systems. The 3-D nature of ladar imagery provides it with key advantages in the target recognition and identification areas. First, because the processor knows the exact range to the object on the ground, variations due to scale are removed: the system knows the size of the objects in its view. Second, the information the seeker collects is geometry based, not thermal based. A building will look like a building no matter how long the sun has been out, or how strong a cooling breeze exists. This factor greatly simplifies the premission process of modeling the target to load features into the missile's memory. Figure 5 provides a sample of this imagery, in this case of a radar dome, and illustrates how the processor can use the 3-D nature of the data to rotate the image to any orientation. The image on the left shows the 3-D scene from the original orientation of the airborne seeker, and the image on the right shows a processed reorientation of the scene.

FIGURE 5: LADAR IMAGERY



(Source: Wright Laboratories. Armament Division)

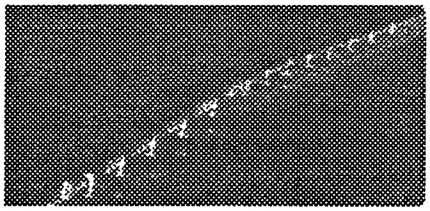
Captive flight tests of a CO_2 ladar seeker in 1992 under the Air Force's Armament Directorate's Advanced Technology Ladar Seeker (ATLAS) program demonstrated the successful identification of bridges, armored vehicles, and military and industrial facilities. Current work on miniature solid state lasers reduces the laser subset of the seeker to the size of a cigarette pack, and allows lower cost optics, and detectors. A ladar seeker using such a laser is predicted to cost under $15,000 per unit in a 5000 unit purchase.[94]

Operating in the IR spectrum, ladar suffers the same type of attenuation problems as imaging IR systems, but not to the same degree. The difference is in the strength of the detected signal. While the passive IR system has to detect relatively weak, emitted thermal radiation, the ladar produces up to 25 million watts of peak power per pulse, to reflect off a target. Only in heavy fog and smoke could the ladar experience unacceptable attenuation.

SAR: SAR uses forward motion of the missile and phase measurements between successive pulses to create an equivalent antenna length much larger than the actual radar antenna. The longer length translates to higher resolution than could be attained with the actual antenna alone. SAR is a relatively mature technology as compared to LADAR and is currently operational in such platforms as the F-15E and the E-8A JSTARS.

SAR seekers gather two dimensional information, unlike ladar, but collect it over greater ranges in virtually all weather. The resolution of small SAR seekers will typically be between 15 and 50 feet, sufficient to attack larger high value targets such as buildings, runways, and bridges, but insufficient for smaller targets such as mobile ballistic missile launchers. Figure 6 contains a sample SAR image of a bridge.

FIGURE 6: SAR IMAGERY



Source: Wright Laboratory, Armament Directorate

Two drawbacks of SAR technology for missile seeker use include cost and size. Early experimental units occupy over two cubic feet and had an estimated price tag over \$100,000 per unit. Recent advances in monolithic microwave circuits, however, should allow a 0.6 ft^3, \$70,000 seeker.[95] Even at that price it represents the most expensive of the technologies, but it is the only technology which offers all weather capability.

Summary: No one seeker technology offers *all* the desired characteristics for a SAW, but at least two come very close. Ladar holds the promise for an affordable, very high resolution, easily programmable seeker capable of identifying targets down to small vehicles, and can function in all but a small percentage of weather conditions. SAR offers the user all weather capability, but against a limited target set, and at a higher cost. Differential GPS, on the other hand, greatly reduces cost and volume by possibly eliminating the need for a seeker, but requires a major overhead investment, and relies exclusively on highly accurate target coordinates of known fixed targets.

GLOSSARY OF TERMS AND ABBREVIATIONS

AAA: Anti-Aircraft Artillery.

ATACMS: Army Tactical Missile System. Surface-to-surface missile system capable of 100+ km range.

BAT: Brilliant Anti-Tank weapon. A smart submunition currently under development. The munition uses acoustic and infrared sensors to locate and engage tanks.

BDA: Bomb Damage Assessment.

CALCM: Conventional Air Launched Cruise Missile. U.S. Air Force weapon which was first operationally employed in Operation Desert Storm where it was launched from B-52 bombers.

Counter Air: According to Air Force Multi-Command Manual 3-1, Tactical Employment, "Counter air missions are conducted to attain and maintain a specified degree of air superiority by destroying, neutralizing, or disrupting enemy air power. Counter air involves both offensive and defensive operations as well as the suppression of enemy air defenses. The ultimate goal is total air superiority."

DGPS: Differential Global Positioning System

EAF: Egyptian Air Force

ECM: Electronic Counter-Measures

EW: Electronic warfare.

GPS: Global Positioning System

GWAPS: Gulf War Air Power Survey. U. S. Air Force commissioned, independent research document designed to "provide a comprehensive and documented account of the war." Dr. Eliot Cohen of Johns Hopkins University School of Advanced International Studies directed the effort.

HARM: High speed Anti-radiation Missile

HAWK: Homing All the Way Killer. A U.S. designed surface-to-air missile.

IAF: Israeli Air Force

IMU: Inertial Measurement Unit

INS: Inertial Navigation System

IR: Infrared

JDAM: Joint Direct Attack Munition. Unpowered autonomous weapon currently under development by the U. S. Air Force.

JSOW: Joint Stand-Off Weapon. U.S. Navy unpowered, autonomous weapon which dispenses submunitions.

KARI: The French built, computerized command and control system developed for Iraq to control their integrated air defense network. The term comes from reverse spelling of "Iraq" in French.

LADAR: Laser Radar

LGB: Laser guided bomb.

OCA: Offensive Counterair. According to Air Force Multi-Command Manual 3-1, Tactical Employment, "OCA operations are normally conducted throughout enemy airspace and are designed to destroy or neutralize enemy air power close to the source. This may be accomplished through an air-to-air engagement or an air-to-surface attack of an enemy airfield and its facilities. Friendly forces have the initiative to conduct OCA at a time and place of their choice."

ODS: Operation Desert Storm

PGM: Precision Guided Munition

SAM: Surface-to-Air Missile

SAR: Synthetic Aperture Radar

SAW: Stand-off Autonomous Weapon. A term developed for the purpose of this monograph. It defines a class a proposed class of weapons which can be launched from bomber or fighter type aircraft, at ranges outside the low altitude point defense range (approximately fifteen to twenty miles), at low or high altitude, and which will guide to the target and impact the appropriate point without human input (after launch). Also called an autonomous precision guided munition.

SCUD: Soviet designed surface-to-surface missile.

SEAD: Suppression of enemy air defense

TLAM: Tomahawk Land-Attack Missile. U.S. Navy surface launched cruise missile.

TSSAM: Tri-Service Stand-off Attack Missile. A Northrop Corporation long range cruise missile-like weapon currently under development.

ENDNOTES

[1] B. H. Liddell Hart, "Armament and its Future Use," The Yale Review 19 (New Haven, CT: Yale University Press, 1930), p. 649.

[2] Charles W. Nystrom Jr., Air Base Attack: The Promise of Emerging Technology (Maxwell Air Force Base, Alabama: Air University Press, 1991), p. 38.

[3] Attempts were made to fund stand-off weapons, but none survived into full scale production. A partial list of canceled programs since the mid 1980s includes: medium-range air-to-surface missile (MRASM), stand-off attack weapon (SAW), modular stand-off weapon (MSOW), and autonomous guidance for conventional weapons (ACGW). In addition to these canceled weapons, numerous other initiatives never received funding to transition from DOD laboratory efforts.

[4] Based on U.S. Air Force Primary Aircraft Authorized (PAA) values as of 31 December 1993. This value includes only six B-2 stealth bombers out of a planned buy of twenty. "The US Air Force in Facts and Figures," Air Force Magazine, May 1994, p. 41.

[5] The same assumption equally applies to the U.S. Navy where, although they plan to retire the A-6 fighter, the current replacement is no longer a previously planned new stealth platform, but rather additional F/A-18s and ground attack modified F-14s.

[6] Christopher Bellamy, The Evolution of Modern Land Warfare: Theory and Practice (London: Routledge, 1990), p. 30.

[7] John A. Warden III, The Air Campaign, Planning for Combat (Washington: Pergamon-Brassey's, 1989), p. 10.

[8] Richard P. Hallion, Storm Over Iraq, Air Power and the Gulf War (Washington: Smithsonian Institution, 1992), p. 25.

[9] The other combat aircraft included 70 - 72 Mirage Mark III Js fighters, 40 - 45 Mystère IV A ground attack fighters, 20 Vatour II A ground attack aircraft, and 40 - 45 Ouragan fighter-bombers. The bulk of these aircraft were situated at only four airfields: Ramat David, Eqron, Hatserim, and Hatzor. B. L. Blustone and J. P. Peak, Air Superiority and Airfield Attack, Lessons from History (McLean, VA: BDM Corporation, [1984]), p. 124.

[10] Edgar O'Ballance, The Third Arab-Israeli War (Hamden, CT: Archon Books, 1972), p. 54.

[11] Ibid.

[12] The other combat aircraft included 60 - 80 MiG 19s, 150 - 180 MiG 17s and MiG 15s, and 20 - 40 SU-7s. The Israelis feared the TU-16 the most. With a 2200 mile combat radius, it out ranged all IAF aircraft and could carry a 20,000 pound payload. (source: O'Ballance, Arab-Israeli War p. 57.) Had the EAF exploited the range advantage prior to the war, they could have dispersed these aircraft to remote sites outside the range of IAF aircraft, and used them as a very potent counter-strike force. Fortunately for the IAF, this did not occur. Blustone and Peak, Air Superiority p. 122.

[13] Ibid.

[14] O'Ballance, Arab-Israeli War p. 57-58. This early variant of the SA-2 Guideline missile and its associated Fan Song missile control radar had a maximum effective range of 35,000 meters but the minimum effective altitude was 450 meters, a limitation the IAF would take advantage of during the war. (Source: Tony Cullen and Christopher F. Foss, ed., Jane's Land-Based Air Defence 1989-90 (Coulsdon, UK: Jane's Information Group, 1989), p. 257-59.)

[15] The remainder of the Syrian Air Force included twenty MiG-19s, and thirty to sixty MiG-17s. Blustone and Peak, Air Superiority p. 123.

[16] Other aircraft included fifteen MiG-17s, fifteen MiG-15s, and twenty Provost trainers. O'Ballance, Arab-Israeli War p. 61 - 62.

[17] Blustone and Peak, Air Superiority p. 126.

[18] The initial waves concentrated only on Egypt, considered to be the key threat. A prime consideration for initiating the preemptive strike was that Israel did not believe she had enough air assets to attack all

Arab players simultaneously with sufficient effect. Their objective, then, was to cripple the EAF in the four hours they believed it would take the other countries to launch their aircraft, then redirect assets to the north and east. O'Ballance, Arab-Israeli War p. 62.

[19] Ibid., p. 65.

[20] O'Ballance and the BDM report disagree over whether the high angle dive bomb passes against the runways came before or after the strafing passes against the aircraft. While the high angle pop-up (the Israelis used a 2500 ft release altitude and a 1000 ft pull-out) affords the pilot better acquisition of his aimpoint, and releasing the bombs first affords the aircraft more maneuverability and less drag, the disadvantages of starting with this maneuver are greater. First, the highest priority targets were aircraft, not runways, and therefore should have been attacked first in case the pilot had to leave the target area early (or was shot down). Second, the high angle pop-up maneuver provides the airfield defenders an easier target to shoot down. From the tactical standpoint, then, O'Ballance's account of cannon attacks followed by runway attacks seems more plausible. O'Ballance, Arab-Israeli War p. 64; and Blustone and Peak, Air Superiority p. 133.

[21] The "dibbler" was the forerunner to the French Durandal, purchased by the U.S. and currently the only dedicated runway cratering weapon in the U.S. inventory. O'Ballance, Arab-Israeli War p. 53.

[22] Ibid. p. 66.

[23] According to O'Ballance, the Egyptians claimed, in official communiqués, to having shot down 75% of the attacking IAF aircraft. Key military advisors were afraid to tell Nasser the true nature of the Israeli success until almost midnight on 5 June. The Israelis, fearing UN intervention if the level of their rapid success was known, kept quiet about their mission success, and did nothing to counter Egyptian claims. The disadvantage to Israel for such actions, however, was the Egyptian claims enticed Jordan, Syria, and Iraq to get in some "easy kills" before the war ended. O'Ballance, Arab-Israeli War p. 68 - 72.

[24] Blustone and Peak, Air Superiority p. 136.

[25] Ibid., p 137.

The breakdown of the IAF first day airfield attack missions is:

	AIR TO GND KILLS	AIR TO AIR KILLS	TOTAL
EGYPT	280	20	300
SYRIA	52	0	52
JORDAN	20	0	20
IRAQ	15	0	15

[26] Ibid., p 139.

[27] O'Ballance, Arab-Israeli War p. 67.

[28] The IAF combat aircraft inventory breaks down as follows: approximately 130 F-4E, approximately 165 A-4E/H, 60 Mirage III and modified Mirage III, 12 to 18 Super . 23 Mystère IV, 10 to 12 Vautour, and 30 Ouragan. The decision to switch to American equipment was more political than operational as the French imposed an embargo on military sales to Israel after the 1967 war. Blustone and Peak, Air Superiority p. 148 - 149.

[29] Each HAWK battery contained six launchers. Blustone and Peak give the number of HAWK batteries as 10 to 12. With either these or O'Ballance's numbers, the density of SAM sites is small compared to the Egyptians. O'Ballance, Yom Kippur War p. 289.

[30] O'Ballance, Yom Kippur War p. 285 - 286; and Blustone and Peak, Air Superiority p. 146.

[31] Blustone and Peak, Air Superiority p. 233.

[32] While the SA-7 missiles proved very successful, damaging numerous aircraft, the Egyptians employed them primarily in support of ground units, and not in the airbase defense role. In Egypt, the number of SA-2 sites increased to forty (240 launchers), and they added seventy-five to eighty-five SA-3 sites (four launchers per site), and forty-six SA-6 batteries (four launchers per battery). The number of AAA pieces increased to 1575, including 125 ZSU-23-4s. Edgar O'Ballance, No Victor, No Vanquished. The Yom Kippur War (Novato, CA: Presidio Press, 1991), p. 147, 282.

[33] Blustone and Peak, Air Superiority p. 233 - 235.

[34] Even though sufficient warning existed, Israel did not launch a preemptive air strike due to the political ramifications of appearing as the aggressor, plus pressure from the United States. Blustone and Peak, Air Superiority p. 60 - 61.

[35] O'Ballance, Yom Kippur War p. 290.

[36] Blustone and Peak, Air Superiority p. 154.

[37] Ibid., p. 159.

[38] Blustone and Peak, Air Superiority pp. 137-140, 161-162.

[39] Ibid., p. 162.

[40] Ibid., p. 161.

[41] Ibid.,

[42] Eliot A. Cohen, director, Gulf War Air Power Survey, Vol. II: Operations, Effects and Effectiveness (Washington: Department of the Air Force, 1993), p. 135 - 136. (Referred to as GWAPS from this point forward)

[43] The GWAPS provides three different types of data in various tables. A "strike" is defined as a "weapon or weapons employed by one aircraft against an individual target," a "sortie" is defined as "an individual aircraft flight from takeoff to landing," and a "mission" is "mounted by a finite number of aircraft, usually two to four, against a target." Therefore, a mission would consist of multiple aircraft, each performing one sortie, and each sortie could contain multiple strikes. Cohen, GWAPS, Vol. V: A Statistical Compendium, p. 517.

[44] The F-15Es only had six operational laser targeting pods for the two squadrons of aircraft deployed. The majority of the F-15Es employed general purpose, not laser guided, bombs. GWAPS, Vol IV, Weapons, Tactics, and Training p. 46.

[45] The Tornados would be able to drop laser guided bombs starting on the 17th day of ODS with the arrival of British Buccaneer aircraft which could lase targets for the Tornados. Such a procedure required meticulous planning and was difficult to execute. In the last ten days of the war, the British Royal Air Force did receive two newly developed laser designating pods for the Tornado which allowed the aircraft to lase their own targets. GWAPS, Vol IV, Weapons, Tactics, and Training p. 64.

[46] Ibid., pp. 19-21.

[47] Of particular concern were the Iraqi Mirage F-1s which carried the Matra Super 530 air-to-air missile, the Armat anti-radiation missile, the Exocet anti-shipping missile, laser guided bombs, or a variety of general purpose bombs. Ibid., pp. 25.

[48] Cohen, GWAPS, Vol. II Operations, p. 151.

[49] Ibid., p. 150.

[50] Christopher M. Centner, "Ignorance is Risk. The Big Lesson from Desert Storm Air Base Attacks," Airpower Journal (Winter 1992): 29.

[51] The SAM inventory for Iraq consisted of SA-2s, SA-3s, SA-6s, SA-8s, SA-9s, SA-13s, SA-14s, and the French Roland I/II. Cohen, GWAPS, Vol. V: A Statistical Compendium, p. 19.

[52] Department of Defense, Conduct of the Persian Gulf War. Final Report to Congress (Washington: Department of Defense, April 1992), p. 266. (Document classified SECRET/NOFORN/WNINTEL. Quoted sections are UNCLASSIFIED.)

[53] The French-constructed system derived its name from reverse spelling of "Iraq" in French.

[54] Cohen, GWAPS, Vol. IV: Weapons, Tactics, and Training, pp. 6-9.

[55] Ibid., p. 47.

[56] Ibid., p. 51.

[57] Cohen, GWAPS, Vol. II Effects and Effectiveness, p. 145.

[58] The move to targeting shelters supported two objectives for the planners. First, it supported the operational and strategic objective of eliminating Saddam's post war offensive capability. Second, it was meant to prevent a "last ditch" large scale air offensive against large American troop concentrations. Cohen, GWAPS, Vol. II Effects and Effectiveness, p. 146.

[59] Department of Defense, Conduct of the Persian Gulf War, p. 221.

[60] Ibid.

[61] Cohen. GWAPS. Vol. V A Statistical Compendium . p. 414.

[62] Ibid., Table 204. p. 642 - 649.

[63] a) The first 19 January loss could possibly have been over an airfield given that the Jalibah deployment air base, an air base which was attacked during the war, lies approximately fifty nautical miles southeast of Tallil. however, the GWAPS information is not specific enough to draw such a definitive conclusion.
b) The OCA losses came from a total of 3819 Coalition OCA ground attack sorties. or 10.670 total OCA sorties with SEAD and escort missions included.

[64] Of the 38 aircraft lost in combat for all mission types. 9 were lost to AAA. 13 to IR SAMs. 10 to radar SAMs. 1 to a MiG-25. and 5 to other or unknown reasons. Of the 48 damaged. 23 were due to AAA. 14 to IR SAMs. 4 to radar SAMs. and 7 to other reasons. Cohen. GWAPS. Vol. V A Statistical Compendium . pp. 642-649.

[65] Cohen. GWAPS. Vol. IV Weapons. Tactics. and Training. p. 166.

[66] Cohen. GWAPS. Vol. II Operations. p. 174.

[67] Cohen. GWAPS. Vol. IV Weapons. Tactics. and Training. p. 141.

[68] Cohen. GWAPS. Vol. II Operations. p. 163.

[69] Department of Defense. Report to Congress. p. 250.

[70] Cohen. GWAPS. Vol. V A Statistical Compendium. pp. 405-420.

[71] Alvin Toffler. and Heidi Toffler. War and Anti-War (Boston: Little. Brown and Company. 1993). p. 108.

[72] The CEP is defined as the radius of the circle around a desired aim point within which 50% of the weapons would impact. The term is used as a measure of weapons delivery precision.

[73] GWAPS quotes the following prices from the Directorate of Supply. Headquarters Air Force Combat Support Division: CALCM (FY 91$) = $1.500.000 per unit. and TLAM = $1.100.000 per unit. For comparison. the GBU 24/B (standard bomb body) laser guided bomb cost $65.000. and the GBU 24A/B (hard target penetrating body) cost $85.000. The cruise missile costs are mostly driven by the need for a turbine engine. fuel. and sophisticated guidance packages necessary to travel one thousand plus miles. Cohen. GWAPS. Vol. V A Statistical Compendium. pp. 578-579.

[74] As examples. the 500 lb MK 82 bomb costs $498. and the 2000 lb MK 84 costs $1871 in fiscal year 1990 dollars. Cohen. GWAPS. Vol. V A Statistical Compendium. pp. 578-579.

[75] John D. Morrocco. "Pentagon Pushes TSSAM Despite Technical Problems." Aviation Week & Space Technology 139 (October 18. 1993): 99.

[76] John D. Morrocco. "First TSSAM Test Flight Completed: Northrop Faces Substantial Loss." Aviation Week & Space Technology 136 (June 29. 1992): 23.

[77] Zachary A. Lum. "New Concepts in Precision Air-to-Ground Targeting." Journal of Electronic Defense 16 (July 1993): 35.

[78] Stand-off range for laser guided bombs is a function of the glide range of the bomb. the range of the laser. and the range of the Forward Looking Infrared (FLIR) system used to view the target and aim the laser spot. Depending on atmospheric conditions and the emissivity of the target. the stand-off range may be limited by the crew's ability to see the target and the bomb's ability to detect a laser reflection.

[79] Lum. " Air-to-Ground Targeting." p. 34.

[80] Cohen. GWAPS. Vol. II Effects and Effectiveness. p. 354.

[81] Department of Defense. Conduct of the Persian Gulf War. p. 270.

[82] Myron Hura. and Gary McLeod. Intelligence Support and Mission Planning for Autonomous Precision-Guided Weapons. (Santa Monica. California: RAND. 1993). pp. 52-53.

[83] Bellamy. Evolution of Land Warfare. p. 37.

[84] Department of the Air Force. Air Force Manual 1-1. vol. 1: Basic Aerospace Doctrine of the United States Air Force (Department of the Air Force. March 1992). p. 10.

[85] Bellamy. Evolution of Land Warfare. p. 31.

[86] "The Battle Over Warfare." Newsweek. December 5 1994. p. 27.

[87] John D. Morrocco. "Horner: U.S. Pursuing Counter Stealth." Aviation Week & Space Technology 141 (August 1. 1994): 56.

[88] United States Air Force. Multi-Command Manual 3-1. Tactical Employment. Vol I: General Planning and Employment Considerations (Department of the Air Force. 1 December. 1991). p. 6-7.

[89] The exact values for each of these parameters remain classified even though this program has terminated. (Source: Interviews with Bob Brown. former HAVE SLICK program manager; and Dr Bruce Simpson. Technical Director. Weapon Flight Mechanics Division. Wright Laboratories. Armament Directorate. Eglin AFB. Florida)

[90] "Have Slick Detailed." Jane's Defence Weekly 16 (October 26. 1991). p. 746.

[91] "USAF Holds Pre-JDAM Test." Aviation Week and Space Technology 139 (July 5. 1993). p. 27.

[92] John L. Dargan. Autonomous Weapon Guidance. Eglin Air Force Base. Florida: Precision Strike Office. Wright Laboratory (Armament Directorate. May 1994). pp. 17-24.

[93] North Atlantic Treaty Organization Advisory Group for Aerospace Research and Development. AGARD Conference Proceedings No. 320. Precision Guided Munitions. Technology and Operational Aspects. (Norway: 4-7 May 1982). pp. 10-2 to 10-10.

[94] Interviews with Capt Todd Steiner. Capt Jim Brandt. Capt Jodi Mandeville. and Lt Ken Dindorf. Wright Laboratory. Armament Directorate In-House LADAR Research Team. 12 August 1994.

[95] Philip J Klass. "SAR Seeker Seen as New Contender to Guide 2.000-lb. Mk. 84 Bomb." Aviation Week & Space Technology 136 (March 30. 1992). p. 66.

BIBLIOGRAPHY

BOOKS

Bellamy, Christopher. The Evolution of Modern Land Warfare. London: Routledge, 1990.

Churchill, Randolph S., and Churchill, Winston S. The Six Day War. London: William Heinemann Ltd., 1967.

Cohen, Eliot A., director. Gulf War Air Power Survey. 6 vols. Washington: Department of the Air Force, 1993. Vol I: Planning and Command and Control; vol. II: Operations and Effects and Effectiveness; vol III: Logistics and Support; vol IV: Weapons, Tactics and Training and Space Operations; vol V: A Statistical Compendium and Chronology; vol VI: Summary Report.

Cullen, Tony, and Foss, Christopher F. Jane's Land-Based Air Defence 1989-90. Coulsdon, United Kingdom: Jane's Information Group, 1989.

Hallion, Richard P. Storm Over Iraq, Air Power and the Gulf War. Washington: Smithsonian Institution, 1992.

Herzog, Chaim. The War of Atonement. October, 1973. Boston: Little, Brown and Company, 1975.

O'Ballance, Edgar. No Victor, No Vanquished. The Yom Kippur War. Novato, California: Presidio Press, 1978.

O'Ballance, Edgar. The Third Arab-Israeli War. Hamden, Connecticut: Archon Books, 1972.

Toffler, Alvin and Toffler, Heidi. War and Anti-War. Boston: Little, Brown and Company, 1993.

Warden, John A. III. The Air Campaign. Planning for Combat. Washington: NDU Press, 1988; reprint ed., Washington: Pergamon-Brassey, 1989.

Westenhoff, Charles M., ed. Military Air Power. The CADRE Digest of Air Power Opinions and Thoughts. Maxwell Air Force Base, Alabama: Air University Press, 1990.

MANUALS

United States Air Force. Air Force Manual 1-1. Vol 1: Basic Aerospace Doctrine of the United States Air Force. Department of the Air Force, March 1992.

United States Air Force. Multi-Command Manual 3-1, Tactical Employment. Vol I: General Planning and Employment Considerations. Department of the Air Force, 1 December, 1991.

ARTICLES

"Aerospatiale, Matra Standoff Proposals." Aviation Week & Space Technology 139 (November 15, 1993): 67.

"BAT Begins First of 20 Flight Tests." Aviation Week & Space Technology 139 (July 5, 1993): 26.

Beal, Clifford, and Sweetman, Bill. "Bolt from the Blue. Stand-Off Weapon Developments." International Defense Review 25 (August 1992): 757-762.

Beal, Clifford, Hewish, Mark, and Sweetman, Bill. "Bolt from the Blue Part 2. Making Dumb Bombs Smart." International Defense Review 25 (December 1992): 1173-1180.

"The Battle Over Warfare," Newsweek, December 5 1994, pp. 27-28.

Bond, David F. "Navy Weighs Tomahawk Block 3 Buy; Further Upgrades Face Cost Squeeze." Aviation Week & Space Technology 136 (January 6, 1992): 27.

Bond, David F. "Stealth-Standoff Issue Looms in 21st Century Weapon Choices." Aviation Week & Space Technology 136 (January 13, 1992): 64-65.

Centner, Christopher M. "Ignorance is Risk. The Big Lesson from Desert Storm Air Base Attacks." Airpower Journal VI (Winter 1992): 25-35.

Cook, Nick. "Long-Range ASMs. Case For a New Priority." Jane's Defence Weekly 15 (March 16, 1991): 387-397.

Fulghum, David A. "Loh Outlines Bomber Plans." Aviation Week & Space Technology 139 (July 5, 1993): 26-28.

Fulghum, David A. "Loral Vought Develops Small, Smart Ladar." Aviation Week & Space Technology 137 (October 26, 1992): 67.

Fulghum, David A. "Shark to Target Silent Missiles." Aviation Week & Space Technology 139 (July 26, 1993): 25.

Glosson, Buster C. "Impact of Precision Weapons on Air Combat Operations." Airpower Journal VII (Summer 1993): 4-10.

"The Guided Dispenser: The Ultimate Attack Weapon?" Armada International 15 (1991): 6-14.

Hart, B. H. Liddell "Armament and its Future Use." The Yale Review 19 (New Haven, CT: Yale University Press, 1930), pp. 649-667.

"Have Slick Detailed." Jane's Defence Weekly 16 (October 26, 1991): 746.

Hewish, Mark, Sweetman, Bill, and Robinson, Anthony. "Precision-Guided Munitions Come of Age." International Defense Review 24 (May 1991): 459-472.

Hilgendorf, Heinz. "Are Stand-Off Air-to-Ground Weapons a Necessity?" Military Technology XVII (June 1993): 57-62.

Hughes, David. "New Laser Radar Detector Shows Promise in Field Tests." Aviation Week & Space Technology 137 (September 14, 1992): 57-58.

Hughes, David. "Raytheon Capitalizes on Microelectronics in BAT Seeker, Other Smart Munitions." Aviation Week & Space Technology 136 (March 2, 1992): 49-51.

Kandebo, Stanley W. "Cruise Missile Updates Pending." Aviation Week & Space Technology 140 (January 17, 1994): 56-58.

Klass, Philip J. "SAR Seeker Seen as New Contender to Guide 2,000-lb. Mk. 84 Bomb." Aviation Week & Space Technology 136 (March 30, 1992): 64-66.

Lenorovitz, Jeffrey M. "Italians Redesigning Skyshark to Improve Stealth Qualities." Aviation Week & Space Technology 136 (February 17, 1992): 22-23.

Lenorovitz, Jeffrey M. "European Forces Seeking Better Standoff Capability." Aviation Week & Space Technology 140 (January 17, 1994): 59-60.

Lum, Zachary A. "New Concepts in Precision Air-to-Ground Targeting." Journal of Electronic Defense 16 (July 1993): 32-36.

Morrocco, John D. "British Aerospace Developing MANTIS to Meet Need for Stand-Off Missile." Aviation Week & Space Technology 136 (February 24, 1992): 132-133.

Morrocco, John D. "First TSSAM Test Flight Completed; Northrop Faces Substantial Loss." Aviation Week & Space Technology 136 (June 29, 1992): 23-24.

Morrocco, John D. "Horner: U.S. Pursuing Counter Stealth." Aviation Week & Space Technology 141 (August 1, 1994): 56-57.

Morrocco, John D. "Pentagon Pushes TSSAM Despite Technical Problems." Aviation Week & Space Technology 139 (October 18, 1993): 99.

Morrocco, John D. "U.S. Tactics Exploit Advances in Avionics, Air-to-Surface Weapons." Aviation Week & Space Technology 134 (February 18, 1991): 52-53.

Scott, William B. "High Demand Stretches NRO Intelligence Assets." Aviation Week & Space Technology 138 (February 1, 1993): 49-52.

Scott, William B. "USAF Considers Laser Radar System for Low-Cost Bomb Guidance Package." Aviation Week & Space Technology 136 (April 20, 1992): 59.

"United Kingdom Takes Key Role in Attacks Against Iraqi Targets." Aviation Week & Space Technology 134 (February 18, 1991): 47-48.

"USAF Holds Pre-JDAM Test." Aviation Week & Space Technology 139 (July 5, 1993): 27.

"The US Air Force in Facts and Figures," Air Force Magazine, May 1994, pp. 27-45.

Walters, Brian. "Precision Weapons--A Gulf War Lesson Which Should Not be Forgotten." Asian Defence Journal no. 8 (August 1993), pp. 28-30.

REPORTS AND PROCEEDINGS

Air Force Armament Laboratory. Airfield Attack Study and Analysis. Eglin Air Force Base, Florida: Analysis Division, Air Force Armament Laboratory, October 1975. [Classified SECRET]

Blustone, B. L., and Peak, J. P. Air Superiority and Airfield Attack. Lessons from History. McLean, Virginia: BDM Corporation, May 15, 1984.

Bodenheimer, Clyde E. Impact of New Technology Weapons on SAC Conventional Air Operations. Maxwell Air Force Base, Alabama: Air University Press, June 1983.

Coulter, Dennis M., and Fry, Douglas W. "A Methodology for Comparing a Standoff Weapon with Current Conventional Munitions in a Runway Attack Scenario." Masters thesis, Air Force Institute of Technology, March 1986.

Counselman, C. C. Millimeter-Accuracy Satellite Navigation. Cambridge, Massachusetts: Massachusetts Institute of Technology, April 8, 1991.

Dargan, John L. Autonomous Weapon Guidance. Eglin Air Force Base, Florida: Precision Strike Office, Wright Laboratory (Armament Directorate), May 1994.

Department of Defense. Conduct of the Persian Gulf War. Final Report to Congress. Washington: Department of Defense, April 1992. [Classified SECRET/NOFORN/WNINTEL]

Diehl, V., Shields, F., Swan, J., and Cassidy, T. Smart Weapons Independent Evaluation Contract. Arlington, Virginia: Science Applications International Corporation, July 1992.

Hura, Myron, and McLeod, Gary. Intelligence Support and Mission Planning for Autonomous Precision-Guided Weapons. Santa Monica, California: RAND, 1993.

North Atlantic Treaty Organization Advisory Group for Aerospace Research and Development. AGARD Conference Proceedings No. 320, Precision Guided Munitions. Technology and Operational Aspects. Norway: 4-7 May 1982.

Nystrom, Charles W. Air Base Attack. The Promises of Emerging Technology. Maxwell Air Force Base, Alabama: Air University Press, April 1991.

Schaffer, Marvin B., and Smith, Robert M. Conventional Airbase Attack and Defense Technologies. Santa Monica, California: RAND, December 1984. [Classified SECRET]

Stoehrmann, K. C., DiCecca, P. O., and Piepenburg, A. E. Airfield Attack Options for NATO. McLean, Virginia: BDM International Inc., October 1991. [Classified SECRET]

Worrell, S., Chockley, H., Lipcsey, M., and Tekiela, J. Passive Millimeter Wave Imaging Sensor Assessment. Huntsville, Alabama: IIT Research Institute, September 1993.

Zipfel, Peter, Baker, Allen, and Wilder, Greg. JDAM PIP Performance Evaluation. Eglin Air Force Base, Florida: Aeronautical Systems Center, May 27, 1994.

INTERVIEWS

Brandt, Jim; Dindorf, Ken; Mandeville, Jodi; and Steiner, Todd. Wright Laboratory, Armament Directorate In-House Laser Radar (LADAR) Research Team, 12 August 1994.

Brown, Bob. Former HAVE SLICK Program Manager, Wright Laboratories (Armament Directorate), Eglin Air Force Base, Florida. Interview, 12 August 1994.

Jolley, Vince. Global Positioning System (GPS) Engineer, Wright Laboratories (Armament Directorate), Eglin Air Force Base, Florida. Interview, 11 August 1994.

Jones, Tim. Advanced Synthetic Aperture Radar Guidance (ASARG) Program Manager, Wright Laboratories (Armament Directorate), Eglin Air Force Base, Florida. Interview, 10 August 1994.

Loewer, Dave Lt Col. Chief, Joint Direct Attack Munition (JDAM) Branch, U.S. Air Force Air Combat Command, Langley Air Force Base, Virginia. Phone interview, 22 Jul 1994.

Mansfield, Bob. Advanced Technology Ladar Seeker (ATLAS) Program Manager, Wright Laboratories (Armament Directorate), Eglin Air Force Base, Florida. Interview, 12 August 1994.

Schwietzer, Bernie. Precision weapons specialist, RAND. Interview, 2 August 1994.

Simpson, Bruce. Technical Director, Weapon Flight Mechanics Division,

Wehling, Martin F. Technical Director, Advanced Guidance Division, Wright Laboratories (Armament Directorate), Eglin Air Force Base, Florida. Various interviews, 10-14 August 1994.

Wise, Pete. Chief, Inertial Technology Section, Wright Laboratories (Armament Directorate), Eglin Air Force Base, Florida. Interview, 11 August 1994.