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THE SA-2 AND WILD WEASEL:

THE NATURE OF TECHNOLOGICAL CHANGE

IN MILITARY SYSTEMS

By
Patrick K. Barker
Captain, United States Air Force

A Thesis

Presented to the Graduate and Research Committee

of Lehigh University

in Candidacy for the Degree of

Master of Arts

in

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Dedication

This thesis is dedicated to Captain Tony Stefanik, who lost his life while supporting international efforts in Somalia. Tony and I shared many months together as members of Crew E-12, 20th Bombardment Squadron. His memory is but one reminder of the high price often paid by members of the armed forces and their families.

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Research for this thesis was performed at several locations: The Center for Air Force History at Bolling AFB, The Air Force Studies and Analysis Agency at the Pentagon, and the Air Force Historical Research Agency (USAFHRA) at Maxwell AFB. I spent a week at the AFHRA and was most impressed by the professionalism of their people, especially Joe Caver and Marvin Fisher. Also, although I never met any of them, I'd like to show my sincere appreciation to the Southeast Asia Declassification Team at the AFHRA, who in the past few years allowed tons of Vietnam-era documents to be brought from the cloak of secrecy out into an open forum. Without their tireless efforts at declassification, I wouldn't have had a master's thesis. I also thank Wild Weasel I EWO Major Jack Donovan, USAF (Ret), who patiently answered my questions over many telephone calls and provided me with great insights into that test program.

Long conversations with my father helped to shape the original direction of my study, and I have already mentioned his editing duties. My children, Chelsea and Dalton, quickly brought me out of the world of historical analysis and into reality during the many hours we spent together at any hour of the day or night. Many an idea has come to me between diapers, bottles, changes of clothes and walks to the park. Above all, I owe an infinite debt to my wife, Tracey. Marriage is a partnership at all levels, and though we may not share the same historical interests we do share a wonderful life together, and she was with me every step of the way.

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Abstract

This thesis examines how the US Air Force responded to the first combat firing of the SA-2 surface-to-air missile over North Vietnam in 1965. That response included the deployment of aircraft specifically designed to jam radars, the production of jamming pods for tactical fighters, borrowing the US Navy's anti-radiation missile, and the introduction of the unique Wild Weasel aircraft. Together, these technologies represented a nascent form of tactical electronic combat that helped the Air Force to regain control of the air over North Vietnam. Four questions are asked in this study: (1)How might a system initially react to a new opposing technology on the battlefield? (2)What might make a system choose one set of responses to that technology and not others? (3) How might a system change as these technological responses are incorporated within it? (4) In what ways might the story of technological change within a system be instructive if it includes the perspectives and actions of the operators -- a "bottom up" approach -- and not just those of the high-level decision-makers?

This study reaches two general conclusions. First, integrating a new technology into a military system is a very complex task. Many factors, including national culture and military doctrine, influence a system's flexibility, that is, the ability of a military system to react to change. Thus, two similarly structured systems may well have different degrees of flexibility. The process of integration and possible considerations pertaining to how well a system might react to a changing environment are shown by a detailed look at tactical combat between the US Air Force and the North Vietnamese air defenses in 1965. Second, probably the most important step of integration is ensuring that the technology can be used to its full potential. This is accomplished through adaptation. The operators adapt the technology to the needs of the system through proper training efforts while the system is made to adapt to the technology through development of doctrine. This study reveals the complexity of adaptation through a "bottom-up" look at the Wild Weasel I test program.

Preface

War is not what it used to be, or so it seems. A new kind of warfare with advanced technology like "black boxes" and "smart" bombs has taken on an increasingly impersonal aura in popular American culture. In the opening months of 1991, televisions across America were painted with cross-hairs and black-and-white images. A nation watched as video bombs silently neared their targets. No explosions were heard when the weapons detonated. Instead, the screen went blank or a cloud of smoke billowed from a single gaping hole.

The television and print media, beguiled by these sterile images, attached labels like "Nintendo War" to the kind of warfare carried out by modern combat aircraft. These images and labels obscured the fact that the advent of black boxes and other "high-tech" equipment had not yet changed the human realities of warfare. The confusion and horror inherent in war have remained despite these leaps in technology and the growth of integrated combat systems. The shiny new gadgets, however, seemed to attract the most attention.

Despite all the intervening technology including radars, computers, electronics and CRT displays, combat remains a struggle between people. The aviators, radar operators or weapons controllers who fight the ubiquitous electronic video wars face a very personal war unique to the technology that surrounds them. To the outside observer it appears as a clean, sterile war capable of making awesome strikes with surgical precision and little mess to clean up afterwards, but this image is deceiving. Calling attention to this electronic war is in no way meant to detract from the living hell typically faced by combatants on the ground, an environment vividly portrayed by many authors over the years, including John Keegan and E.B. Sledge.* Whether in the air, at sea, or on the ground, humans continue to remain on both the sending and receiving end of modern technology.

The following essay shows the wielders of this relatively recent electronic combat technology to be in two locations. One was a crowded radar control van and the other a cramped cockpit of an aircraft. It is in both these places where, in July of 1965, our story begins.

* John Keegan, The Face of Battle New York: Penguin Books, 1978.
E.B. Sledge, With The Old Breed: At Peleliu and Okinawa, New York: Oxford University Press, 1990.

Introduction

This paper examines the process by which the United States Air Force (USAF) responded to the first combat firing of a North Vietnamese surface-to-air-missile in July of 1965.(1) Two related and recent scholarly studies have painted a far more comprehensive picture of political and doctrinal aspects of the use of airpower in Vietnam than this study could ever hope to accomplish.(2) Therefore, what follows remains strictly within the realm of Air Force tactical operations over North Vietnam during a bombing campaign more commonly known as "Rolling Thunder" that began in early 1965 and continued into 1968. This study focuses primarily on the time period between July and December, 1965 when a relatively new air defense technology, a surface-to-air missile known as the SA-2, caused a collective shudder within the ranks of the US Air Force.

The Air Force reaction to this weapon was not solely the introduction of a new technology or set of technologies designed to neutralize the missile threat. Rather, it entailed an advanced form of tactical air warfare characterized by a dependence upon electronic combat. In other words, the battle of the skies over North Vietnam included duels with radar pulses and other electromagnetic transmissions as well as the more familiar engagements between opposing aircraft or between aircraft and aerial defenses. Although initially comprised of rather desperate actions, the United States Air Force's response to this SA-2 came to include the deployment of aircraft specially configured to jam, or disrupt, North Vietnamese radars, the production of jamming pods for tactical fighters, and the borrowing of the US Navy's anti-radiation missile. In addition, the Air Force retrofitted a small number of fighter aircraft to hunt down the elusive North Vietnamese surface-to-air missile units. These aircraft came to be known as "Wild Weasels," and the name most certainly matched the dangerous nature of the mission. Each of these new technologies required the simultaneous development of new tactics with which to employ them. Together, these technologies and tactics formed a nascent version of the tactical electronic combat espoused by current United States Air Force doctrine.(3) Understanding the dynamics of this situation requires a closer examination of military systems and a look at the nature of technological change within them.

Although much of the popular and historical focus on military technology has been on individual weapons, the relationships between new technologies and the larger combat systems within which they must perform has not been widely studied. A number of historians have written about the relationship between technology and war.(4) Martin Van Creveld, in his sweeping four-thousand year survey of technology and warfare wrote that modern military forces integrate many different weapons technologies into a large system mainly because of cost. High costs precluded retiring older systems when their successors came on line. Integration, then, involved finding the right "mixture" of old and new, superior and inferior, to create the "greatest combat power," or the biggest bang for the available buck.(5)

Integration also brought with it a paradox with respect to a weapon's success. Van Creveld asserts that, "there were some indications that the inexorable drive towards integration was not only symptomatic of the declining effectiveness of each individual element but was, at the same time, acting as its cause." (6) In other words, a weapon's effectiveness was directly related to its degree of independence from such a system. Ever-increasing degrees of integration beyond a certain threshold seemed made that system more and more rigid, ultimately suffocating the individual weapons within it. However, an individual weapon, if it was not mired in the greater military system, could dominate the enemy in a particular place and time. Therefore, the most effective weapon would have the correspondingly greatest degree of autonomy, for it would be the least affected by integration's pernicious influence. Van Creveld's thesis is important because of its powerful suggestions concerning the ramifications of technological change. However, an important term in his thesis, integration, lacks the clarity necessary for a general application to military systems.

Integration is the foundation upon which a military system rests. Military weapons, whether they have mechanical linkages, vacuum tubes, or solid state electronics, require integration into larger systems partly because of cost, but also because modern war necessitates this high degree of integration. Although advances in technology might induce an "inexorable" drive toward a system's integration, neither a new technology nor integration itself necessarily determines the degree of the system's flexibility. Rather, flexibility is defined more by the nature of the system and less by the degree of integration. A system's nature, shaped primarily by social and cultural forces, is the force that determines the ability of a system to adapt to its changing environment. Regardless of the nature of a particular combat system, the relationship between an element -- a weapon, for example --and its system tends to be mutually beneficial, not mutually degrading.(7)

At the heart of the relationship between the weapon and its system lies the people -- the operators or users -- who employ the weapon in battle. (8) Opposing operators in aerial combat rarely, if ever, see each other face to face but each is often exposed to imminent danger and their respective skills with their modern weapons usually determine the battle's outcome. An operator's survival in this kind of combat depends upon how well he knows his own equipment and tactics, as well those of his adversary. There are plenty of historical examples that show how technological ignorance has resulted in poor training, inadequate combat tactics, or a disastrous combination of the two.(9)

The following essay attempts to accomplish two broad objectives: one, expand upon Van Creveld's ideas and two, aid historians' efforts in assessing technological change in military systems by detailing specific examples of integration. The systems I will use to illustrate these concepts are the North Vietnamese air defense system and the US Air Force tactical combat system that evolved in response to the guided surface-to-air missile. Specifically, four basic questions are asked. How might a system initially react to a new opposing technology on the battlefield? What might make a system choose one set of responses to that technology and not others? How might a system change as these technological responses are incorporated within it? Last and most important, in what ways might the story of technological change within a system be instructive if includes the perspectives and actions of the operators rather than solely the high-level decision-makers? Possible answers to these questions are revealed by studying the impact of the SA-2 on the American tactical air forces and in particular by a detailed study of an Air Force program called Wild Weasel I. Hopefully, some light will be shed not only on how a new weapon becomes a part of a large system but also how weapons are used by their operators in war. It seems that the tools of war are continually changing, but the successful prosecution of battle remains, as always, with its human participants.

Chapter One

24 July, 1965: A Fateful Mission

On 24 July, 1965, a Soviet-built surface-to-air missile exploded at approximately 23,000 feet altitude, northwest of Hanoi, amid a flight of four USAF F-4C Phantom fighter aircraft.(1) One F-4C was destroyed and the other three were damaged as a result of the blast. Code-named the SA-2 Guideline by the North Atlantic Treaty Organization (NATO) and known to the Soviets as the S-75, this missile had only recently arrived in North Vietnam. The first of these Soviet-built missiles arrived earlier that spring accompanied by advisors from the Soviet Army. The decision-makers responsible for conducting tactical air combat operations over North Vietnam were not prepared to counter this weapon.(2) Until these decision-makers, the Pacific Air Forces (PACAF), could integrate into their air combat system a technology or technologies (and applicable tactics) capable of neutralizing this new threat posed to their aircraft, PACAF could not hope to reclaim the sky over North Vietnam.(3)

The Cold War had accelerated the development of the first operational guided anti-aircraft missile systems in both the United States and Soviet Union. In the 1950's the American government, for example, contracted with Bell Laboratories to produce the Nike surface-to-air missile system to defend the North American continent from Soviet bombers.(4) The existence of Soviet air defense missiles was known to US Air Force leaders since the early 1950's, after the first radar-guided missile site was built near Moscow in response to the threat posed by long-range strategic bombers.(5) NATO intelligence organizations named this first missile system the SA-1.(6) A few years later, a second unique missile system, the SA-2, appeared in a 1957 May Day parade in Moscow. With each passing year more SA-2 sites were established near major Soviet cities and other potential strategic targets even in Soviet satellite countries such as Cuba. The SA-2 was exported by the Soviet Union to North Vietnam early in 1965 soon after the Johnson

Administration initiated the "Rolling Thunder" aerial bombardment campaign. The imported SA-2 missile systems and their attendant crews quickly became integrated into the blossoming North Vietnamese air defense system.

The 1965 shooting was the first time a surface-to-air missile had brought down an aircraft during a major combat operation, but it was not the first time this weapon was fired in anger. In May 1960, Francis Gary Powers' U-2 reconnaissance aircraft -- and an unlucky Soviet fighter-- fell victim to SA-2s over the Soviet Union.(7) Approximately fourteen missiles were fired that day. Twelve of the missiles never hit anything, the thirteenth hit the Soviet pilot and the fourteenth got Powers.(8) Less than a year earlier, a Communist Chinese SA-2 had downed a Taiwanese RB-57D.(9) These were the first of similar incidents that followed in both Cuba and China where reconnaissance, or "spy" planes were brought down by this weapon. Even though surface-to-air missiles systems on both sides had been operational for about a decade, it wasn't until after July 1965 that Air Force tactical operations would be significantly transformed.

Leopard Zero-Four was the radio call-sign of the particular Phantom hit by the first SA-2. Leopard flight consisted of four F-4C's. Each aircraft carried two airmen, a pilot and a systems officer.(10) After takeoff from Ubon Air Base in Thailand and subsequent aerial refueling with KC-135 tankers, Leopard flight's leader herded his aircraft into a fingertip formation. Poor visibility necessitated this formation in which the aircraft were positioned like the four fingertips of one's hand. As little as thirty-six inches separated the wingtips of any two of Leopard's aircraft. (11)

Leopard flight, and a sister formation called Panther flight, totaled eight F-4C's whose task it was to patrol for North Vietnamese jet fighters. Known as MIG Combat Air Patrol, or MIGCAP, this mission provided protection from MIG's (North Vietnamese fighter aircraft) for a much larger force of F-105 Thunderchiefs that was striking an explosives plant approximately fifty-five miles northwest of Hanoi. There had been little North Vietnamese MIG activity since Rolling Thunder began in February 1965, and today appeared to be no different than most of the others. The atmosphere was one of "tense calm" when suddenly the radios came to life.(12)

The radio call "bluebells ringing, bluebells ringing," echoed through the ears of all the attacking airmen, including Leopard 04's pilot, forty-year-old Captain Richard P. Keirn. Keirn, a veteran of World War II, had spent ten months as a prisoner of war after his B-17 was downed by German anti-aircraft fire in the late fall of 1944.(13) The "bluebells" radio message warned of a weapon which Keirn had not seen over wartime Germany. It meant that there were radar transmissions detected from an SA-2 surface-to-air missile site.(14) It did not mean that a missile had been launched, rather this warning indicated that the primary radar, known as a Fan Song, with which SA-2 missile crews used to continuously track potential targets was in operation. The Phantoms' crews had been warned of SA-2 sites under construction near Hanoi, and had planned their flight path to circumvent the suspected positions.(15)

The North Vietnamese SA-2s, staffed with Soviet technicians, were forbidden targets for US Air Force and US Navy air strikes. President Johnson and his closest advisors, worried about killing the Soviet technicians, felt that by not bombing the missile sites he would send the proper "signal" to the North Vietnamese, inducing the latter into not using the missiles against American aircraft. Bombing the sites would, in this view, escalate this war as well as court the possibility of Soviet or Chinese intervention in Vietnam. (16)

Unfortunately, Leopard flight did not know that on the outskirts of Hanoi a fire control battery of an SA-2 battalion commanded by Soviet Army Major F. Ilyinykh tracked Leopard's Phantoms across the North Vietnamese sky.(17) The battery commander and all the rest of the site personnel were also in the Soviet Army, who performed their duties under the watchful eyes of North Vietnamese trainees. The battery commander had already determined where to search for the American aircraft after his battalion headquarters provided the approximate location, course, and speed of the Phantoms. After ordering his crew to transmit with the SA-2's Fan Song radar, he probably very quickly found the flight of American aircraft and tracked their progress on his radar scopes.(18)

As soon as the Fan Song was in operation, or shortly thereafter, its signals were picked up by the sensitive radar receivers of EB-66Cs, aircraft specially configured to monitor radars and other electromagnetic transmissions. EB-66C's and other specially modified aircraft often patrolled the periphery of the Soviet Union and China, listening for and locating radar sites, always on the watch for new and unusual signals which indicated new radar developments. These electronic intelligence, or ELINT, missions were often classified at the highest level and usually approved directly by the President.(19) The EB-66C's, orbiting at about 25,000 feet altitude somewhere near the strike force but safely beyond the range of North Vietnamese ground-based weapons had the task warning the strike aircraft of any imminent danger posed by North Vietnamese radars, particularly those radars which directed anti-aircraft artillery. The Fan Song was added to their "to do" list after 24 July, 1965. The Fan Song's radar pulses were translated into audible, rattlesnake-like tones by the EB-66's electronics. These transformed pulses reverberated inside the headsets of the aircraft's four electronic warfare officers.(20)

These officers, skilled in analyzing and identifying radar signals, were products of many long months of highly classified training.(21) The new signals associated with the SA-2 had been observed by an EB-66C crew only the day before Leopard flight took off on this mission The distinct sounds of the Fan Song radar had been correlated with unique cathode-ray tube (CRT) displays on the electronic warfare officers' equipment, indicating to them that these SA-2 sites near Hanoi were indeed occupied, operational, and probably tracking the US aircraft. The question as to whether or not Hanoi had received the proper political "signal" associated with the avoidance of SA-2 sites was about to be answered.

A second call of "bluebells ringing" came about five minutes after the first. By now, a second SA-2 fire control battery was tracking Leopard flight. This time, however, the Phantoms had closed to within the range of the Guideline missiles, and the order came down from the Hanoi control center to fire upon the American jets. At about the same time the EB-66C crew probably heard the radar's pitch in their headsets jump an octave higher. The Fan Songs had changed their operating modes, sending out pulses even faster to obtain more accurate tracking information. Each SA-2 fire control battery was now ready to guide its missiles skyward.

With a huge cloud of smoke and dust, the first Guideline missile roared off its launch rails. Two more Guidelines followed the first toward the Phantoms, at least one of those from the other SA-2 site. The Guideline, according to Colonel Jack Broughton, Deputy Commander of the 355th Tactical Fighter Wing (F-105's) in 1966, created "a good-sized dust storm on the ground, so if you just happen to be looking in the right direction when it blasts off, you know that Sam (sic) is airborne and on the prowl."(22) These are appropriate words when applied to the surface-to-air missile, for it was what amounted to an electronic hunter in search of airborne prey. Its launch obscured by the intervening cloud layers, the missile swiftly closed the distance to the unsuspecting Phantom aircraft.

Within six seconds after launch the lead missile's UHF antenna received the radio steering commands transmitted from its fire control battery. The Guideline is a command-guided missile, which meant that the operators on the ground tracked the both the missile and the intended target on radar. A computer predicted the point in the air where the missile would intercept the aircraft based on the aircraft's current heading, speed and altitude. Designed for a high success rate against bombers and other slow-maneuvering aircraft, the SA-2 system usually required a high degree of operator skill to engage fighters, for there was an appreciable delay between the time a need for a directional change was recognized and when the missile responded to the new flight path.(23) The non-maneuvering F-4C's of Leopard flight, however, presented easy targets.

The SA-2 was "soldier proof," durable in nature with large knobs and switches. It required little training in the basics of operation when compared to similar Western systems. Each operator in the fire control battery had a highly specialized function, and only the battery commander could make the decisions for the crew based on the battalion's orders. Despite the simple mechanisms of their system, the North Vietnamese SA-2 crews became notorious for their combat savvy as the war progressed. In 1965, however, the SA-2 was a relatively new weapon in Southeast Asia and both sides had much to learn about how it was to be used effectively in combat.

Tracking the F-4C's on the cathode ray screen in the cramped control van, the missile's ground operator transmitted corrections to the Guideline's course based on the continuously-updated predictions of the F-4C's flight path. Soon after launch the first-stage solid-fuel booster expended its energy, detached itself from the Guideline, and fell back to earth. The huge, thirty-five foot missile was probably flying at about mach two, that is, twice the speed of sound or about 1400 miles per hour, by the time it reached ten-thousand feet altitude. By twenty-thousand feet the SA-2's internal rocket, using liquid fuel, propelled the missile to almost two-and-one-half times the speed of sound when it shot out of a cloud less than a thousand feet or so below the Leopard flight. The missile continued to accelerate as it zoomed upward toward the fingertip formation of fighters, a distance covered in about a second or two.

Leopard 02 recalled what appeared to be a "flying telephone pole" suddenly streaking upwards from the clouds towards the right side of his formation. The F-4's began violent maneuvers away from the missile's path, but this was all too late to do Leopard 04 any good. "Before I could press the mike button (for the radio)," recalled Leopard 02's pilot, "it had detonated under the formation."(24) The missile's proximity fuse, sensing that it was as close to Keirn's aircraft as it could ever logically be, triggered the detonation of about three-hundred pounds of high explosive. Hundreds of metal shards were shotgunned from the missile's nose in a conical pattern. The fiery blast engulfed the doomed Phantom, while the metal fragments ripped apart the aircraft's fuselage and control surfaces. Leopard 04s back-seater Captain Roscoe Fobair, was probably killed outright. Keirn, relatively unscathed but fighting high G-forces induced by the now-tumbling aircraft, recalled witnessing "fire coming around my head."[4] Pulling his ejection handle, both he and his dead partner were catapulted through the air in their rocket-fired seats. Keirn again became a prisoner of war, this time for almost eight years. The two other SA-2s exploded harmlessly below and behind the rest of Leopard flight, but the remaining three aircraft had already been hit by shrapnel from the first missile. The US Air Force had been rudely introduced to the latest technology in the North Vietnamese air defense system.

Chapter Two

Integration: A Discussion

Every so-called black box, space-age satellite or cruise missile is part of a greater military system. A military system like that of the North Vietnamese in 1965 includes not just technological hardware but the individuals and organizations that use it in battle. Scholars have shown various interpretations of the word "system" over the years.(1) Most of them, however, would probably agree with what one might find in one of Webster's dictionaries, where a system is "a complex unity formed of many diverse parts subject to a common plan or serving a common purpose." (2) Two specific examples of such systems that operate in the realm of air warfare are those of aerial attack and of aerial defense. Both of these systems will be explained in more detail in subsequent chapters, but it would be useful to first establish a framework for discussion of military systems.

This chapter provides a close look at the relationship between individual weapons and their parent systems, as well as a clarifying the terms: element, flexibility, autonomy, coordination and, most importantly, integration. These terms need to be defined in relation to combat systems before this essay proceeds. The diverse parts, or basic building blocks of systems are here referred to as elements. Flexibility and autonomy will be associated with a system and element, respectively. Flexibility refers to the ability of a given system to respond to changes in its environment. Autonomy is the degree of freedom of action allowed to the individual elements of a system. Coordination is the process by which all the system's elements work toward a common goal. Integration, however, requires a more detailed explanation because it is the foundation upon which a system rests.

All aspects of a system's activities are directly affected by integration. In a typical combat system integration could include, among other things, the buying of new weapons and their placement into particular positions within the system. In a macro-perspective this could be seen in the organizational structure. Batteries of heavy artillery would sooner be attached directly to regimental commanders than they would be to platoon commanders or squad leaders. In a micro-perspective integration could mean not only ensuring that a radar warning receiver's electronics were compatible with those of the fighter aircraft in which it was to be installed but also that the receiver's cathode-ray tube (CRT) display was positioned on the instrument panel so that the pilot could see it easily.

Integration of most elements into combat systems can be generalized in terms of these elements meeting three basic conditions. These conditions fall under the general headings of mutual support, inter-system communications and successful adaptation to the system. Although this characterization is by no means the final word on integration, it provides a convenient framework for analyzing air combat systems. This chapter will define these conditions and subsequently apply each to both the North Vietnamese air defense system of 1965 and the US Air Force tactical combat system that faced it.

First, the distance between each element must not be so great as to preclude their mutual support. Guided missile batteries, for example, have finite effective ranges and altitudes at which they can engage targets and the deployment of any two of these beyond these ranges precludes any mutual support between them. In other words, the missile batteries could not protect each other. An example showing the role played by physical distance between individual elements is the Israeli success in defeating SA-6 surface-to-air missile batteries during the Yom Kippur War in 1973.(3) By bombing politically sensitive targets in Syria, Israel forced the Syrians to divert SA-6 batteries away from the battlefield to protect those targets from future attacks. In order to maintain their battlefield air defenses, the Syrians were forced to spread out their remaining SA-6's, leaving some gaps in the air defense coverage. The Israeli Air Force then proceeded to pick apart the Syrian missile umbrella by exploiting these gaps. Each battery was subsequently destroyed one at a time. Mutual support is only one factor in integrating the elements of a large system.

Second, the individual elements must also be able to communicate with each other. This enables concerted action by all the elements. Lines of communication, whether they be physical cables or electromagnetic waves in free space, are a key factor in maintaining an effective, cohesive system of integrated weapons. Severed or blocked communication lines break up the systems into smaller and usually less effective groups of elements operating in isolation from each other. Just as in the Syrian SA-6 example, isolation in communications also means that a system is vulnerable to defeat in detail. That is to say an opposing force can often easily overwhelm and defeat a system if it attacks a few isolated elements at a time rather than taking on the entire system at once. It should come as no surprise, then, that communications facilities are usually critical targets for planners of aerial campaigns. One of the first Iraqi targets bombed by US Air Force F-117 "stealth" fighters in the opening minutes of Desert Storm in 1991 was a communications center dubbed the "AT&T Building."(4) Physical distance and communications are perhaps the most obvious and easily-measured aspects of an integrated system. The last condition of integration is more difficult to assess.

The third and probably most important condition to be met is that the elements must have been adapted by the system. The new weapon must be adapted to the larger system while, simultaneously, the system is adapted to the particular weapon. The former is accomplished in part through training and the latter through development of combat tactics. Certainly, the process by which any military system procures and integrates a new weapon is far more complex than the above definition of adaptation. However, assuming that the new weapon was designed to meet the system's specifications and appeared to work as advertised, training and tactics development will have the most direct bearing on integration and ultimately, combat performance. Historical examples abound.

This need for this adaptation can been seen in the case of the French-built mitrailleuse. An automatic weapon related to the Gatling gun, it was available to the French army when they faced the Prussians in the Franco-Prussian War in 1870.

Unfortunately, the secrecy surrounding the weapon was so great that few in the French army knew what the weapon could do, much less how it operated. For all practical purposes, nobody had been trained in the use of the weapon. Therefore there was no hope of integrating this weapon into the French units, let alone figuring out how to use the thing effectively in actual combat. The result was that the millatreuse became an ineffective, highly vulnerable weapon. The weapons hardly fired any shots and were instead left vulnerable to attack. They were quickly blown apart by Prussian artillery.(5)

When a new technology, such as the millatreuse or any other weapon, is brought into a system, the operators are usually responsible for making the technology "fit" into the system. These individuals must first become familiar with this new technology before they can properly deduce how to best use it in battle. It is important to stress that operators learning the basics of a technology -- how to turn it on, recognize and fix problems -- is an entirely different process than their learning how to apply the technology to tactical combat operations. Even if these operators succeed in developing new tactics for the new weapons, they might not have the power to make the necessary decisions that adjust the system in response to that technology's capabilities. Historians accustomed to the hierarchical nature of military systems usually assume that lowly operators are not so empowered. A deeper investigation into the workings of a military system, however, might not always support that assumption. Understanding the often complex relationships between the technologies, the operators, and the larger system is an important step in comprehending the process of military technological change. These internal relationships are often affected directly by how well the system is able to respond to external forces, an ability controlled by a system's nature.

All systems -- whether they be economic, political, biological or ones designed for military combat -- demonstrate unique responses to their respective environments. A system senses an environmental change through inputs from its various elements, and subsequently initiates a process of adjustment. This process is possible through proper coordination. It is intuitively obvious that an uncoordinated response would be rather detrimental to the system. Military historian S.L.A. Marshall documented many accounts of American infantry combat in World War II where key defensive positions were lost because of a lack of coordination. An infantry company, for example, if unaware of friendly companies positioned on its flanks, would often withdraw when an enemy force was seen to threaten its "unprotected" flanks.(6) The process of coordination in response to external forces is accomplished by the people within the system. Both the individual elements and the system itself react -- or are made to react -- to their changed surroundings. Who ultimately initiates this process of change? At what level of the system's decision-making hierarchy rests the authority to initiate such coordinated actions? Possible answers might be found in examining the nature of a system, for this governs the rather complicated process through which a system responds to change.

The nature of a system falls somewhere between two opposed boundaries: order and chaos.(7) These varying degrees of order or chaos govern the actions of elements within a particular system. A highly ordered system exercises an extreme degree of control from its center which greatly restricts the autonomy of the individual elements. If each element is constrained in this fashion then the system itself becomes rigid and unable to respond quickly -- if at all -- to a rapidly changing environment. By contrast, a system in total chaos amounts to anarchy. Each element in this case works independently from, often in opposition to, others in the same system. This causes a rather inefficient and wildly unbalanced response to change. Some elements will react to a greater degree than other elements, with some elements not reacting at all.

Having thus established a framework for studying systems, it can now be applied to the North Vietnamese integrated air defense system and the air attack system of the US Air Force. This framework is not intended to be all-inclusive; it cannot adequately explain every aspect of a military system. What it does do is highlight two important factors, a system's nature and the process of adaptation, to be considered in the study of system integration. These will be studied more closely in subsequent chapters.

Chapter Three

Integration: The North Vietnamese Air Defense System

The North Vietnamese air defenses were comprised of many different weapons technologies, warning devices, communications equipment and associated personnel.(1) Elements like the Guidelines were themselves small, self-contained systems encased in aerodynamic bodies. They were filled with radio guidance equipment, electronic circuits, both solid and liquid propellants, and high-explosives. All this was further embedded in a larger system of missile launchers, control vans, missile crews, maintenance personnel, guidance and acquisition radars known collectively as an SA-2 battalion. Three SA-2 battalions comprised a larger entity called an SA-2 regiment, which was but one small part of the huge defense network. Also included in this air defense system there were command elements, those who were empowered to make tactical decisions. Major Ilyinykh, the Soviet SA-2 battalion commander on 24 July 1965, would be a specific example of a command element, but so would larger entities like a battalion command post or regimental headquarters. There were other major categories of elements in this air defense system, two of which are detailed below. These are categories of detection and response.

Detection refers to elements capable of providing advanced warning by either active or passive means of an imminent air attack. Early-warning radars are examples of active detection elements because in order to locate hostile aircraft the radars must transmit electromagnetic energy. These radars are typically positioned near the periphery of a nation to maximize the range at which aircraft can be detected prior to crossing that country's sovereign territory. Detection methods need not be very sophisticated, for a lone observer with a pair of binoculars, stationed at a remote outpost, serves a similar purpose. Observers are representative of passive measures. Radar detection devices, designed to give warning of and in some cases locate distant radars, are additional examples of passive means.(2) The inputs from each detection device provides a specific piece of information to the commander of the system. After assessing these inputs the commander decides upon a response.

Air defenses in place prior to the introduction of the surface-to-air missile, Pre-July 1965 North Vietnam included, had two basic kinds of responses at their disposal. One form of response was anti-aircraft artillery, or AAA (pronounced "Triple-A"). Other response elements were interceptor aircraft. Anti-aircraft artillery fired unguided shells at a point in the sky, based on either the gunner's judgment or radar-based predictions. Almost all of the US aircraft lost over Vietnam were due to AAA.(3) The sizes, tactical ranges and rates of fire of these weapons varied.(4) The medium and heavy guns, like 57 millimeter (mm), 85 mm and 100 mm cannon, typically used radar guidance. When a particular aircraft or formation was detected by the air defense system, a fire control radar -- a radar working directly with a gun battery to provide for accurate aiming -- searched for and acquired the intended target. Once the fire control radar "locked on" to the aircraft, an analog fire-control computer predicted where the target would be by the time the guns were fired and the rounds reached the aircraft's predetermined position. There were, however, some limitations to these radar-directed heavy guns.

There was no correcting the shell's flight path once it left the barrel. Each round followed a ballistic path at the complete mercy of gravity and winds aloft. Despite radar guidance, anti-aircraft fire tended to be less accurate at high altitudes (20,000 feet and above) than it was at medium or low altitudes approximately (10,000 to 20,000 feet and below 10,000 feet, respectively) Also these heavier guns were only somewhat effective against targets at lower altitudes since their large caliber precluded high rates of fire and it was also difficult for the large, heavy barrels to traverse quickly enough to follow fast, low-flying jets. Radar-directed artillery was, however, a very lethal threat to attacking aircraft despite these limitations. Other weapons were available to the air defenses that compensated for the low-altitude weaknesses of the heavier guns.

Low altitude flight, especially under 4500 feet, was pretty much a living hell in the face of the smaller caliber weapons like the 14.5 millimeter (mm), 23 mm, and 37 mm guns. These weapons featured extremely high rates of fire could traverse rapidly and were the most numerous of all the air defense weapons. Over half of the aircraft losses due to anti-aircraft artillery came from these lighter guns. In approximately two years of combat from January 1965 through December 1966, anti-aircraft fire downed 384 US aircraft.(5) For every one of these downed, three suffered battle damage from this fire. Of those aircraft lost, over fifty-three percent were initially hit by these weapons once the aircraft descended below 4500 feet, and an additional six percent were hit between 4500 and 5000 feet altitude.(6) The sheer volume of shells flying through the air at these low altitudes was enough to make even the most stalwart of pilots to think twice before commencing their bomb runs.

"Our only defense," recalled former F-105 pilot Jack Broughton, "was to keep moving, or jink. We would keep moving up and down...side to side...slipping and skidding to avoid coordinated flight on a steady track." This complicated the gunners' predictions. Anti-aircraft gunners preferred to shoot at aircraft on the bomb runs, because uncoordinated, jinking flight would be held to a minimum to allow for accurate bomb-aiming. This also allowed for better aiming of the anti-aircraft guns. The scores of US aircraft that had been victims of this ground fire by 1965 convinced the Air Force and Navy to make low-altitude flight under 4500 feet taboo for their jets.(7)

By the time the SA-2 was launched in July of 1965, Air Force bombing missions were flown at medium altitudes such as 15,000 feet. An aircraft usually commenced its attack by diving from this altitude, releasing its weapons at the proper point in the dive, and then pulling out of its bomb run while at least 4500 feet above the ground. The higher initial altitude provided a greater measure of safety from most AAA fire and the pull-out altitude shortened the exposure time to all anti-aircraft weapons after the bomb run began. The radar-jamming EB-66 aircraft generally had good success against the anti-aircraft guns' fire control radars so the threat from heavier, radar directed artillery was minimized.(8) The lighter weapons, however, could throw up walls of lead regardless of radar effectiveness. The higher altitude also allowed the aviators to locate their targets from great distances, provided that both the weather was cooperative and the target wasn't hidden in the jungle. This allowed for plenty of time to align the aircraft into a proper bomb-run heading. In 1965 pilots also had another threat to consider in Southeast Asia. This was the threat posed by the second element of response, airborne interceptors.

An interceptor is a fighter aircraft that defends friendly airspace from attack. North Vietnamese interceptor pilots, like the North Korean, German and British pilots from wars past made extensive use of ground-based radars -- known as ground-controlled intercept, or GCI, radars-- in order to locate and intercept hostile attacking aircraft.(9) North Vietnam did not have an interceptor force at the time of the Gulf of Tonkin incident in 1964. Two days later, some Chinese MIG-15 and MIG-17 aircraft were deployed to an airfield near Hanoi. These were older jet fighters and considered obsolete, but their relatively successful use during the Rolling Thunder campaign, especially the MIG-17, taught the American pilots some valuable lessons about air combat that had been lost in the age of supersonic jets and air-to-air missiles.(10) The newer, more capable Soviet-built MIG-21 would not appear in Vietnam until December 1965 and would not be used in combat until the following April. Although heavily outnumbered, the North Vietnamese fighters operated safely from airfields that were restricted from American bombing attacks by President Lyndon Johnson. Throughout 1965, North Vietnamese MIG-15 and MIG-17 attacks were sporadic in nature, and even then were usually directed at the last flights of a bombing mission after they targets had been struck and when the American fighter escorts were low on fuel.(11) The fighters and anti-aircraft guns were officially joined by a third element in July of 1965 as soon as Ilynykh's first Guideline thundered off its launch rails.(12)

The SA-2 offered a new dimension to the air defense system (See Figure I). Although the accuracy and effectiveness of anti-aircraft artillery fire decreased as the target's altitude increased, the SA-2's lethality increased with higher altitudes. The Guideline, did not reach its full speed of about Mach 3.5 until well over 25,000 feet in altitude; it was less responsive to the controller's maneuver commands at the slower speeds and correspondingly lower altitudes.(13) Therefore, attacker's tactics based on negating or minimizing the effect of anti-aircraft artillery -- flying at higher altitudes -- invariably favored the SA-2 battalions. Conversely, low altitude flying to avoid the missiles' coverage brought attacking aircraft into the lethal range of the anti-aircraft artillery. Unlike the predicted artillery fire, an SA-2 fire control battery could compensate for its target's evasive maneuvers by using electronic guidance. The missile itself was guided by a ground operator to its intended target. In addition to its own merits as a weapon, the SA-2 greatly enhanced the effectiveness of the entire air defense system because the missile battalions were quickly integrated within it. Aiding in this fast process was the continuous construction of missile sites.

Soviet advisors, North Vietnamese Army troops, and civilians combined efforts to construct SA-2 sites in preparation for each battalion's arrival. Each site was carved out of the surrounding countryside, and designed to allow for quick set-up of an SA-2 battalion's radar vans, service vehicles, and missile launchers. A typical site was made in what was called a "Star of David" pattern, similar to those seen in Figure II. The lines of this six-pointed star were roads and pathways for the various service vehicles included in an SA-2 battalion, and there was a missile launcher at each of the star's points. Electric and communications cables were also laid out ahead of time to allow for fast connections. Most importantly, these sites were quickly and expertly hidden.

The North Vietnamese quickly proved themselves as masters of hit and run missile attacks from camouflaged sites. The shuttling of the missile battalions between these sites was what amounted to a deadly shell game. The SA-2 battalions often remained in a

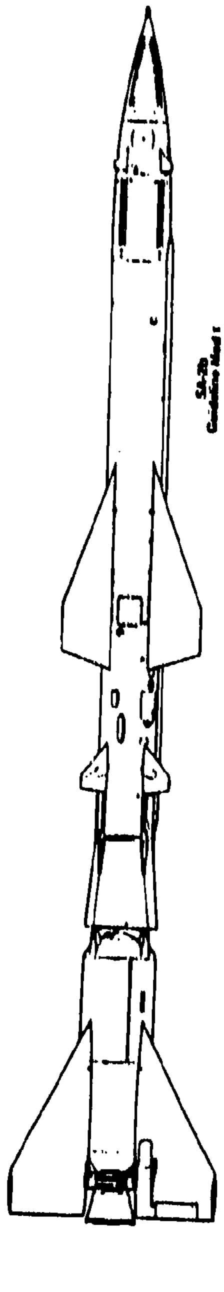
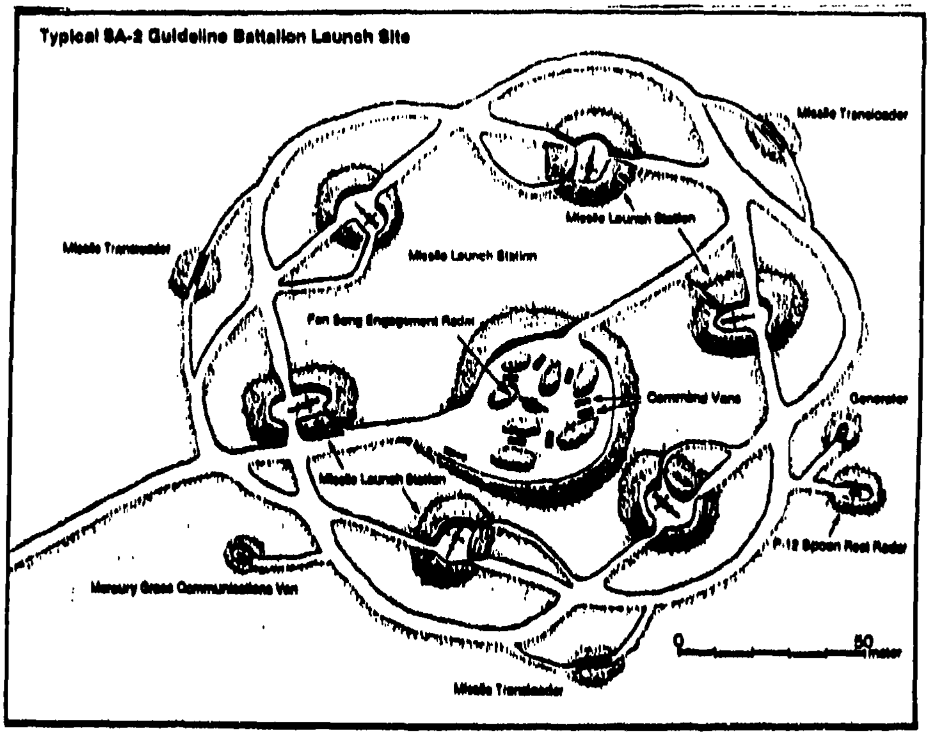


FIGURE I
SA-2 Guideline Missile



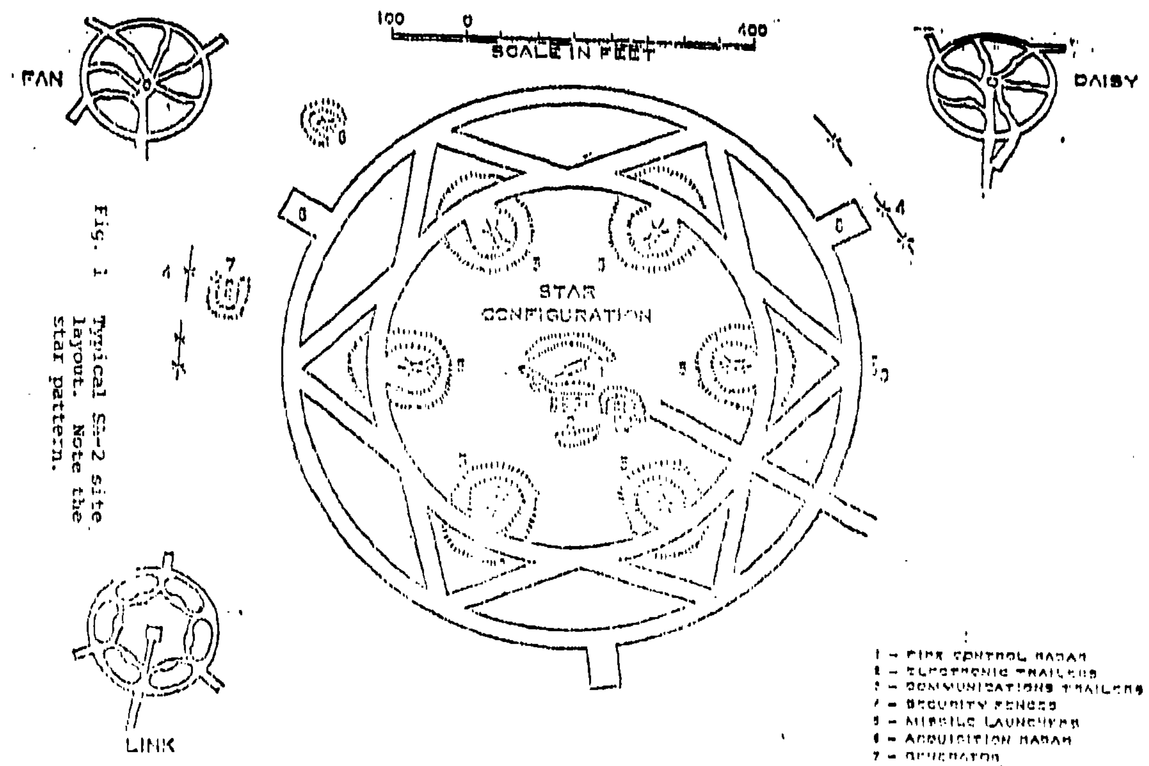


Fig. 1 Typical SA-2 site layout. Note the star pattern.

FIGURE II Typical SA-2 Sites

dispersed status (i.e. not in a firing configuration) and hidden in the countryside. Battalions would only set themselves up in a prepared site when they were going to fire. There were also a number of cases where some SA-2 battalions only fired at the end of the day, dismantling their equipment and re-deploying to a new location under the cover of darkness. A three-month intelligence study of four SA-2 battalions showed that they shuttled between twelve prepared sites during this time, taking about three hours to "shut down and pack" and four to six hours to unpack and begin operations.(14)

Each newly-arriving Soviet SA-2 battalion gave the system a greater degree of mutual support. The airborne interceptor had traditionally been the only weapon facing attacking aircraft which was able to strike at any altitude, but the surface-to-air missile when combined with the anti-aircraft artillery enabled ground-based weapons to pose a similar threat. This combination made for an overlapping of weapons' coverage, or mutual support between weapons. Now, more than one weapon of finite range could be effectively brought to bear against a target at any altitude. This greatly complicated the task of penetrating air defenses with an attacking force. Missile sites were occupied in such a way that at least two missile battalions had overlapping coverage, and each site was well-protected by scores of anti-aircraft artillery pieces. Mutual support also applied to early warning and ground control radars.

Each additional radar imported within the confines of this small country led to an overlapping radar coverage due to the sheer density of radar sites. The number of radars deployed by late 1965 alone practically doubled the number present when the first SA-2s were discovered. This meant that at least two --and probably more-- radars could search the same volume of airspace, which was a characteristically Soviet practice of extreme redundancy in radar coverage. The tremendous radar density allowed the North Vietnamese to make almost continuous observations of the airspace above their territory as well as regions beyond it.

This mutual radar support, combined with efficient communications, made the North Vietnamese air defenses quite formidable in 1965. Radar density greatly complicated the task of penetrating these air defenses for an attack, especially in light of the limited available electronic warfare assets. Electronic warfare aircraft like the EB-66's now had more radars to handle and, more importantly, more distinct frequencies for their jammers to cover. With only a finite number of jammers available on each aircraft, the EB-66's quickly became overwhelmed.(15) Originally employed in 1964 to jam most of the then-rudimentary North Vietnamese radar network, by late 1965 the EB-66's could only focus on but a small part of it. Communications in the North Vietnamese air defenses ran the gamut from radio relays to telephone lines to air-raid sirens. These linked all the system's elements together and provided for a coordinated response to an air attack. Unlike the American fliers, the air defense elements were positioned relatively close to their higher headquarters, which eased the air defense commander's task of controlling all the forces at his disposal.

North Vietnam constructed a very efficient system of air defense in a relatively short time. When US air strikes began in August 1964, the North Vietnamese air defenses were quite unsophisticated, resembling those of Korea in 1950. An estimated 1426 anti-aircraft guns were available, supported by twenty-two early-warning radars and four fire-control radars. The latter were capable of providing firing solutions for the medium and heavy guns. By November 1968, when the dragged-out, sporadic Rolling Thunder campaign came to an end, the North Vietnames defenses were as follows: 8050 AAA guns; 152 fighters (106 of these safely based in China); 40 "active" SA-2 Battalions; and over 400 radars of all types.(16) The numbers and interlocking ranges tell only part of the story about how this system grew so quickly. Most important was the fact that this air defense technology was successfully adapted almost as soon as it arrived in North Vietnam

The North Vietnamese system was aided greatly by China and the Soviet Union in adapting this air defense technology. The North's air defense elements had been tied into the Chinese air defense network, which added greatly to the total number of radars available to the air defense commander. According to a contemporary Air Force report, "the North Vietnam-China border ceased to exist when it came to air defense."(17) In fact, one of the alternate control centers for the air defense system was inside China, lest the Americans knock out the primary center in Hanoi. This North Vietnamese air defense network was also loaded with Soviet radar and missile technology and practiced Soviet tactical doctrine with the aid of the latter's advisors. Former Soviet advisor to the Vietnamese Air Force, General-Major Mikhail Ilyich Fesenko wrote: "In the beginning, the Vietnamese only watched our specialists work and learned from their experience." (18)The North Vietnamese operators quickly learned their art.

The ground control radar controllers MIG-21 fighter-interceptor pilots were prime examples of this adaptation process. Shortly after MIG-21's were offloaded in crates from Soviet ships in Haiphong harbor they were reassembled and test-flown by Soviet pilots before being brought into the North Vietnamese active inventory. Two-seat MIG-21's were used for a new Vietnamese pilot's initial training flights over North Vietnam. A Soviet instructor accompanied his North Vietnamese student pilot. Sometimes, the Soviet instructor and his student were "unwillingly" forced into combat with US aircraft!(19)

The fighters were under strict positive control during each training flight. Even when the North Vietnamese pilots flew on their own, the Soviet radar operators -- and Vietnamese operators under close Soviet supervision -- directed every action of the fighter pilots other than the necessary tasks for take-off and landing. Throughout 1965 and during the early months of 1966 North Vietnamese interceptors would be skillfully vectored by ground controllers into attack positions behind US strike forces, but would usually break off the attack before the American fighter escorts could respond.(20) While the radar operators and pilots adapted to the newly imported Soviet technology, the North Vietnamese system also displayed ever-increasing levels of coordination.

It became obvious to the Americans that the various air defense elements acted in concert to confront various air strikes. The SA-2 fire control batteries, for example, usually did not turn on their Fan Song radars until a prospective target was already well-within missile firing parameters. This was despite the fact that the Fan Song radar was capable of searching sectors of the sky alone for its own target. Other elements of the air defenses such as early warning radars or even fire control radars for nearby anti-aircraft guns passed target information via the Hanoi control center to the waiting SA-2 battalion. Late in 1965, Wild Weasel crews would observe North Vietnamese radars "handing off" tracking responsibilities on their radar detection equipment.(21) As the aircraft passed by one tracking radar that radar went off the air and another would begin to transmit and track from a position somewhere off the aircraft's nose. When that was passed by, yet another radar would pick up the aircraft.

Coordination also served to enhance combat tactics. Electronic reconnaissance aircraft like the EB-66C would have problems pinpointing transmitting Fan Song radars not only because their detection equipment was limited in accuracy but also because the other air defense elements would warn the Fan Song of the approaching EB-66C's, allowing the former plenty of time to stop transmitting and remain undetected. American airmen also noted that in some areas or on certain days, the MIG interceptors and the SA-2 battalions would trade-off responsibilities for the air defenses or work in concert. Some days were "MIG days" and other days were "SAM days." Also it was not uncommon for MIG's to act as bait and lure US aircraft into SA-2 defended areas. In late November, North Vietnamese MIG's attacked Air Force strike aircraft and then turned tail to allow the pursuing American aircraft to chase them. The Vietnamese interceptors led them right into airspace defended by some waiting SA-2 battalions. Conversely, SA-2's fired to force strike aircraft into airspace defended by MIG's. In a very short period of time, the various elements in this system had been skillfully brought together to act as one entity.(22)

While showing an exceptionally high degree of integration and coordination, the North Vietnamese integrated air defense system in 1965 also showed a high degree of order. Possible social, doctrinal and ideological conflicts between Soviet advisors and their North Vietnamese trainees as well as other issues involving the transfer of one country's technology to another are unanswerable until a significant number of Soviet and North Vietnamese records are released. However, given that this system possessed a relatively high degree of order, it can be further postulated that the North Vietnamese system was to some degree inflexible in combat operations.

This air defense system featured centralized decision-making in battle; all decisions for the tactical employment of the air defenses were usually made in Hanoi control center.(23) For example, while an SA-2 battalion commander might wish to engage a flight of aircraft as they entered the Guideline's lethal range, the decision to fire generally could not be made until he was ordered to do so by an authority many times removed from the battalion in the command center at Hanoi. Success often depended upon a fast, unobstructed flow of information both to and from the Hanoi command center. The individual elements in such a system would not necessarily be prepared to conduct autonomous operations should communications to their higher headquarters be obstructed or hindered.(24)

A doctrine that calls for such a centralized decision-making process may be more influenced by social and cultural forces than technology. The North Vietnamese integrated air defense system was very much like that of the Soviet Union. The Soviet tendency for centralized control may have been influenced by a number of social factors present in what was then a totalitarian form of government. The virtual absence of personal freedom in Soviet society, mutual feelings of distrust, a lack of either initiative or desire to accept responsibility, or even a pessimistic view an officer might have for the skill of the troops under his command are just a few of many possible social forces which, when combined induced such a doctrine.

That the North Vietnamese used a similar form of command and control in 1965 was in part because it was the doctrine espoused by the Soviet advisors and technicians who were sent to North Vietnam along with the exported Soviet air defense technologies. The Soviets operated these technologies themselves and also trained and closely supervised the North Vietnamese operators. It was only natural that the Soviets emphasized the doctrine which they themselves had been taught and used daily. That these air defenses denied free use of the sky to the American aircraft in 1965 is due in large part to an American air combat system that never quite found a workable balance between relative extremes of order and chaos

Chapter Four

Integration: The United States Air Force Air Attack System

Facing the North Vietnamese air defenses in 1965 was the aerial attack system of the Pacific Air Forces (PACAF). This system was spread out across the entire Pacific Ocean. The headquarters of this body (HQPACAF) was located in Hawaii and was responsible for the employment of most of the Air Force assets in Southeast Asia, particularly those participating in Rolling Thunder strikes.(1) Ultimately, the responsibility for these assets was with the stateside-based Tactical Air Command (TAC). Tactical Air Command met the combat needs of PACAF by providing the latter with aircraft, personnel and other assets. For example, when additional F-105 squadrons were ordered to Southeast Asia in 1965, most of these came from stateside-based Tactical Air Command units. Upon reaching their forward bases in Thailand, these F-105 units came under the immediate operational control of the Pacific Air Forces, and remained in that status until their return to the United States where TAC resumed control.

As will be discussed, measures taken to counter the SA-2 originated from Tactical Air Command, but were actually used in combat by the Pacific Air Forces. This chapter will be confined to the day-to-day war over the skies of North Vietnam, and therefore will focus on PACAF. To aid in prosecution of the air war, HQPACAF established the Second Air Division, a forward-based command near Saigon, South Vietnam. The combat units, or wings, flying the Rolling Thunder missions were situated in various bases throughout South Vietnam and Thailand.(2) This system grew quickly.

The year 1965 saw ever-increasing numbers and types of Air Force aircraft being deployed to Southeast Asian air bases. This Air Force system appeared to become relatively more inflexible as it grew in size. The reasons for this have less to do with the technology and more to do with the people in this system The Air Force command structure had problems not only in coping with demands imposed by Washington's political constraints, but also in keeping pace with the changing nature and scope of air combat in Southeast Asia. This chapter takes a closer look at the Air Force tactical combat system employed over North Vietnam. The American strike force arrayed near Hanoi in July 1965 was typical of what the North Vietnamese air defenses saw on a daily basis.

The F-4C Phantoms of Leopard and Panther flights provided protection for this strike force against opposing aircraft. The threat from North Vietnamese fighters, however was sporadic at best in 1965. In fact, it wasn't until early 1966 that the tactical air units were subjected to periodic, aggressive air attacks, but the threat of opposing fighters in 1965 was real enough to warrant continuous friendly fighter escort.(3) The Air Force was not about to drop its guard and devote the Phantoms to other duties. This protective mission, the aforementioned MIGCAP, was designed to ward off threatening fighters that attempted to shoot down or at least disrupt either the strike aircraft or the heavy support aircraft, like the EC-121 "Big Eye" and KC-135 "Stratotanker."

An EC-121 Big-Eye aircraft was equipped with a large radar on top of its fuselage to electronically scan the sky for North Vietnamese jets. The Big Eye worked closely with the MIGCAP. These EC-121 aircraft had arrived from McClellan AFB in the spring of 1965 and began combat operations by May.(4) The Big Eye orbits were "racetrack," or oval patterns flown at very low altitudes. The Big Eye would typically fly only fifty to three-hundred feet above the surface. In this fashion the Big Eye "looked up" at the sky rather than "looked down" from above, a sharp contrast to modern airborne early warning aircraft that typically operate at high altitudes.(5) Since the Big Eye radar was at its optimum performance when the radar beam was enhanced by being "bounced" directly off water's highly reflective surface, these orbits were situated about fifty miles off the coast of Vietnam, over the Gulf of Tonkin. At best, EC-121's could spot aircraft and track them out to 140 miles away.(6) Other large aircraft required protective escort for marauding North Vietnamese fighters as well.

Huge KC-135 Stratotanker refueling aircraft orbited at pre-designated locations to provide fuel to the gas-hungry fighter engines both before and after the strike. Their orbits were usually over Thailand or the Gulf of Tonkin. Without the tankers, the Rolling Thunder operations would have been severely constricted in their range and scope. These tankers also helped to diminish greatly the possibility of aircraft crashing because they burned too much fuel during unplanned combat maneuvering. Effecting an aerial rendezvous between tanker and receiver was not always easy, however, and ground radar was of considerable assistance.

Aiding considerably in these tanker-fighter rendezvous were ground-controlled intercept, or GCI, radars. Unfortunately, these radars had only limited coverage. They could scan the skies over South Vietnam and the Gulf of Tonkin but not the heavily-defended areas of North Vietnam such as Hanoi, where many Rolling Thunder strikes took place. Tankers flew to a specific point in the sky and circled, waiting for the fighters to join with them and refuel. The GCI radar operators, broadcasting instructions over a designated radio frequency, directed the fighters to the tankers' locations.(7) This separate radio frequency was used so as not to interfere with other nearby aircraft formations. Once the fighters had sighted the tankers and closed to within three to five miles of the latter, both the fighters and tankers switched their radios to a pre-designated refueling frequency and started refueling. This freed the ground controllers for other tasks.(8) Refueling was an ever-present concern, as was the possibility of being shot down over hostile territory.

The Aerospace Rescue and Recovery Forces stood ready to recover downed American airmen. Orbiting at approximately ten-thousand feet over central Laos was "Crown," a heavy, multi-engined HC-54 or HC-130 aircraft serving as the airborne mission controller for the rescue forces. These forces consisted of rescue helicopters and close air support aircraft to provide air cover for the former's operations. On alert also over Laotian airspace were two large CH/HH-3 Helicopters, called "Jolly Green" in reference to the famed giant. Four A-1E Skyraider aircraft at Udorn Air Base, Thailand sat on the flight ramp, on alert, waiting for an emergency call from Crown to assist in a rescue attempt.(9)

If an aircraft went down, the entire strike would often be called off then and there. This decision depended greatly upon the intensity of opposing defenses in the vicinity of the downed airmen. The mission would proceed, for example, if the strike force was busy dodging intense flak while striking a target near Hanoi.(10) The relatively less-defended western mountainous regions of North Vietnam would be a more typical location for a rescue mission. The primary task for all aircraft in the vicinity became an effort to get to the airman before the North Vietnamese captured him.

Once an aircraft like an F-105 went down, the downed pilot's wingman would call Crown on the radio and explain what happened and where the airman was thought to be. All nearby strike pilots would at this point be looking for a descending, or landed, parachute. Crown carried radio direction-finding equipment on board, and would attempt to pinpoint the pilot's location by homing in on the pilot's "beeper" or emergency radio beacon. Meanwhile the Jolly Greens and A-1E "Sandy" aircraft would be directed to the scene. The remaining strike pilots would orbit the pilot's location, each flight of four F-105's occupying distinct altitudes in order for the lower aircraft to cover the pilot while the higher aircraft conserved fuel. When the lowest-altitude flight ran low on gas, it would depart the scene and hook up with a tanker, while the next "stack" of fighters would descend and repeat the process. Meanwhile Crown arranged for at least two flights of MIGCAP F-4C's to provide cover and also redirected tanker aircraft to fly orbits near the rescue scene. Shortly after arriving in the area, the Sandys typically talked to the downed pilot over the radio while surveying the surrounding countryside for enemy forces. The A-1E's attacked those who were an immediate threat. The helicopters would go in to pick up the pilot after the Sandys had cleared the area. The rescue teams often received help in driving off threatening ground forces from the F-105's.(11)

The F-105 "Thunderchiefs," known more commonly as "Thuds", were the primary strike aircraft of the Rolling Thunder campaign. The aircraft was originally designed for a high-speed low altitude penetration of enemy air defenses in all weather conditions. Thuds first rolled off the production lines in the late 1950's and soon took the role as Tactical Air Command's premier carrier of nuclear weapons because there was room reserved inside the F-105's bomb-bay for a single nuclear bomb. During the conflict in Southeast Asia, this bomb bay held an extra fuel tank instead of ordnance.(12) Nothing airborne in Southeast Asia could out-run a Thud flying below ten-thousand feet. The Thud relied on this high speed to escape enemy air defenses. However, it was hard to outfly a barrage of bullets and shells. By 1968, over one-third of the losses of USAF aircraft in Southeast Asia were F-105's, the losses being almost double that of any other aircraft in the theater.(13) Still, the F-105 performed admirably in daily combat flights over a period of three years, a role for which it was not intended. The F-105 had no capability to counter the North Vietnamese air defense radars, and for this the strike pilots relied on the aging EB-66 aircraft.

The EB-66 aircraft were formerly B-66 bombers that had been reconfigured to perform electronic reconnaissance and radar jamming duties. Some EB-66's monitored the North Vietnamese radars and provided warnings when imminent danger was suspected, while other EB-66's jammed certain air defense radars based on the route of the strike force. These aircraft were the key elements in the tactical air combat system, because they had the ability to disrupt the North Vietnamese radars. Until the SA-2 appeared over the skies in July, the EB-66's were successful in harassing the opposing radar operators, particularly those who worked directly with the anti-aircraft artillery.(14) The growing North Vietnamese radar system posed a more formidable obstacle as the year wore on.

One version of this aircraft, the EB-66C's had been deployed to Southeast Asia prior to 1965. This version accommodated four electronic warfare officers and carried radar receivers, direction finding gear, radar pulse analyzers recording equipment, and self-protection radar jammers. At this time the EB-66 was being phased out of TAC's inventory due to its age, but the expanding North Vietnamese defenses halted the phase-out. In May 1965, newly modified EB-66C's arrived in the combat theater with improved capability against the North Vietnamese radar defenses.(15) The addition of the guided missiles to the air defenses, however, rapidly made even the improved EB-66C's much less effective by the end of 1965. It was difficult, for example, for an EB-66C to pinpoint the location of an active SA-2 missile site accurately enough for a strike to be directed against it.(16) The aircraft's lack of speed and maneuverability made it vulnerable to the SA-2's Guideline missile, so the EB-66 crews had to be careful not to fly near the sites and provoke a launch.(17)

Another version, the EB-66B "Brown Cradle", was first deployed to Vietnam in October, 1965, several months after the first SA-2 launch. Tactical Air Command managed to send five of these aircraft for use by the Pacific Air Forces. The EB-66B carried twenty three pre-set jammers and a single operator for all the equipment. These Brown Cradles were products of joint US Navy --US Air Force electronic warfare exercises in 1958 and 1959. For these exercises, the bomb bays of a handful of B-66 bombers had been stripped at the Brookey AFB, Alabama air depot and therein a pallet full of the jamming equipment was installed. Additional EB-66's were given the Brown Cradle conversion after those exercises. The B-model's equipment operator merely turned his radar jammers' power switches to the "on" position when the time came for jamming the radars. Unlike the electronic warfare officers of the C-models, he had no ability to adjust the frequency of the jammers in flight. Therefore, if the North Vietnamese radars changed operating frequencies, the effect of any jamming pretty much would be negated.(18) Nevertheless, both versions of the EB-66 were the workhorses of Rolling Thunder operations.

Although the EB-66's played important roles in countering the radar-based air defenses, the entire strike mission was doomed to failure if the tactical combat system was not effectively integrated. The various elements of the air combat system flew in relatively close proximity to one another to provide mutual support. All were tied together through radio communications, and all the air crews were highly trained in the use and employment of their respective technologies. The system also had adjusted combat tactics to some degree based on the strengths and limitations of these technologies.

In many respects this Air Force system tended towards inflexibility making it difficult to respond well to changes. At times, most elements lacked autonomy, while at other times many elements were prone to act quite independently to the detriment of the whole system. Relatively efficient mechanisms for instituting technological and doctrinal change were not formally in place.(19) The integration of, and the relative inflexibility shown by the tactical air combat system is evidenced by detailing a typical F-105 strike mission of 1965.

The flight path of each strike aircraft was designed to provide mutual support for the other elements of the combat system; in fact the very heart of American tactical doctrine regarding fighter operations was based on this support with the combat-proven concept of wingmen where the lead aircraft generally initiated an attack while the wingman proved cover. Not only was it necessary for mutual support to occur between the F-105's, but other aircraft like the EB-66's , Phantoms and tankers had to be at the right place at the right time, immediately available to respond to unplanned changes. This was accomplished through detailed planning of each strike mission. Even if communications between the various elements broke down for some reason during the flight, this immense effort at coordination would allow the mission to proceed with some degree of efficiency.

For a typical strike mission over North Vietnam the overall plan of attack would be made at a command level higher than the flying units, often at the Second Air Division in Saigon or even HQPACAF in Hawaii. This plan was analogous to a huge puzzle; each F-105 wing in Thailand would receive only the piece of the puzzle that was necessary to plan their wing's missions. This came in the form of a "frag" or "frag sheet", which was slang for "fragmentary order." Information on frag sheets would contain information such as: the latitude and longitude coordinates of the target, the time at which the target was to be struck, recommended (or even mandatory) routing to the target, radio frequencies and call-signs of other types of aircraft operating in the area, information for air refueling, information pertaining to alternate targets in case the primary could not be attacked, and any other special instructions required for the completion of the mission.(20)

The force commander for a particular strike mission was one of the most seasoned flight leaders in the entire fighter wing. He was responsible for the planning of the mission and that all the necessary mission information was made available to the strike pilots, usually by the evening prior to the mission. It was not unusual, however, to have last-minute changes in missions while the aircraft were preparing to take-off, but the essential mission information could often be gleaned the night before the strike. This information was passed to the flight leaders, each a highly experienced instructor pilot in his own right.(21) Each flight leader led a flight of four F-105 aircraft and made sure that his flight was familiar with all the necessary mission details.

Details were by no means trivial. On their individual maps, or charts, the F-105 pilots marked special locations in addition to their route of flight. For example, these locations might include predicted locations of the tanker aircraft for post-strike refueling and locations of support aircraft like MIGCAP or EB-66's. Photographs of the target area and surrounding countryside were closely studied, as were the anticipated locations of the air defenses. Other factors were given careful consideration as well. These included: the time of day, position of the sun, and unusual terrain features near the target. The value of pre-mission study was constantly driven home to each pilot.(22) "Mission planning," according to a fighter wing's tactics manual, "will determine whether the mission will be well executed or a confused sequence of events ..."(23) Those not familiar with the mission courted the possibility of making costly, even deadly mistakes during the flight.

Once he was confident that his flight had digested the necessary information about the mission, the flight leader conducted what was called a flight briefing. Here, the basic information regarding the mission was reviewed together by all the flight members. A key point covered was determining who was to lead the flight if the flight leader had to abort the mission. Another very critical area to be reviewed by the flight was what they were going to do in the target area. Each had to be familiar with the planned approach to the target, how each would maneuver, or "roll in" to attack and how all four were to re-form their flight afterwards. The use of proper radio procedures was also a very important detail. A large strike force needed to use a single radio frequency, called a "strike frequency," common to all strike aircraft. The mere fact that scores of airmen would be conversing on this frequency at one time or another, often simultaneously, meant that radio calls needed to be as short and to the point as possible.

These radio communications kept each airman in almost continuous contact with the others in the strike force. Typically, the aircraft radios were limited in range, often less than one-hundred fifty miles. Because of this, strikes over much of Vietnam, especially in the North, would be out of contact with Second Air Division Headquarter near Saigon. Most certainly, the tactical radio communications would never reach PACAF Headquarters. Since Rolling Thunder missions extended beyond the range not only of the higher headquarters' tactical communications but also the American ground control radars, forward-based central coordinating authorities were established to handle unplanned circumstances.

A typical example of a coordinating authority was the Tactical Air Control System, or TACS. It was designed to allow aircraft to effectively respond to changing situations on the ground. For example, if an Army unit urgently needed an unplanned air strike, the TACS would direct nearby aircraft to the scene. This system took root with the Army Air Forces in World War II, but largely died out with the cessation of hostilities. Although a ground-based Tactical Air Control System had been re-established for the Korean conflict, the system was again left to rot in the post-Korea years.(24) Even in the very early stages of American involvement in Vietnam 1962 an Air Force report characterized the TACS as being "incapable of handling the expanded air operations throughout this (pre-1965) period," which was small compared to the American force in place by the end of 1965.(25)

Although the TACS typically coordinated close air support and interdiction missions in South Vietnam rather than in the north, its sorry state in the early 1960's was indicative of an Air Force system geared toward full-scale nuclear conflict where large-scale, sustained conventional operations like that had occurred in Korea were but "aberrations."(26) The Air Force in Southeast Asia spent much of the 1960's relearning past lessons and trying to improve their at-the-scene tactical coordination.(27) The aerial conflict over Southeast Asia set the slow-turning gears of doctrinal and technological change in motion, and new airborne technologies appeared in attempts to address problems of coordination and allow fast response to changing threats.

There were several new technologies of these types that appeared during Rolling Thunder. For example, the EC-121 Big Eye provided a measure of warning from enemy aircraft and could direct forces to engage them. Crown took control of unforeseen hazards such as combat rescue operations. The year 1965 also saw the initial deployment of the Airborne Battlefield Command and Control Center (ABCCC), which was essentially an airborne extension of the Second Air Division. The ABCCC purpose was to make sure the strikes went according to plan while also coordinating last-minute strikes of secondary targets. Later during the Rolling Thunder Campaign, large aircraft with names like "Rivet Top" and "College Eye" would orbit the skies, looking for radar emissions from surface-to-air missile sites and enemy fighters, respectively.(28) These developments were indicative of the most important process in integration where new technologies and the system are made to adapt to each other. It is a process that begins and ends with the operators of the technologies, and relies much on the skills of these individual operators.

The level of experience and professional competence of the operators is tremendously important in a military system. In this particular air combat system, pilots had to be familiar not only with the capabilities and limitations of their aircraft but also the "rules of engagement" pertaining to their combat flights. What targets could be hit? What could not? For example, most airfields were off limits to American strikes, and it took a high degree of American tactical discipline not to pounce upon North Vietnamese fighters while the latter waited on the airstrips, armed and engines running, in complete safety. Adaptation also applied to the immediate problems of combat.

Each weapon carried on board required a different bombing technique. Napalm tanks or CBU-2A cluster bombs, for example, required relatively level flight at low altitude in order to drop them accurately and effectively.(29) Standard "iron" bombs, like the five-hundred pounders, were best delivered in a dive. Actual combat missions were often used for training opportunities. Some flight leaders were in their position for the first time under the watchful eye of an flight lead-qualified wingman. Even the most experienced of fliers needed time to adjust to the "local procedures" of a combat zone, far different than what one encountered stateside.

These aircrews were well-trained in aircraft operations and combat tactics. For example, over fifty percent of the USAF fighter pilots flying in Southeast Asia prior to 1966 had over 2,000 hours total flight time. The average pilot had almost ten years of flying experience and had over 500 hours in the particular aircraft they were flying in combat.(30) The wing commanders were typically veterans of the Second World War and Korea. Many of the squadron commanders were at least veterans of Korea. Authors including Earl Tilford have convincingly argued that the Vietnam air war, Rolling Thunder included, was prosecuted with a World War II mindset by higher headquarters officers in organizations such as the Headquarters, Pacific Air Forces and the Pentagon's Air Staff.(31) Decision-makers' doctrinal liabilities aside, the operators in Southeast Asia were familiar with the dynamics of tactical air combat. These airmen were no neophytes. There were, however, problems to be overcome.

The Air Force's system in 1965 was technologically limited in carrying out conventional air operations. Many weapons were outdated and the airmen were far more familiar with flying procedures appropriate for a nuclear environment than they were for the "brushfire war" ablaze in Vietnam.(32) Rolling Thunder pilots too often were plagued by problems with their bombs. Many of the available bombs were of World War II vintage, designed to be carried either internally, in a bomb-bay, or externally at much lower airspeeds than what the jet fighters typically experienced. Bomb fins cracked under the strain of the powerful air flows and some fins were simply blown off. Fuze arming wires broke and, even worse, some caused the bomb to be armed while it was still carried on the aircraft. Close formations often altered the air flow to the point where it caused these bombs to detonate. (33) In November, for example, an F-105 of the 335th Tactical Fighter Squadron exploded in mid-air on its way to a combat mission, an incident caused by faulty fuzing. Further use of those fuses was immediately suspended by that squadron, which meant a lot of bombs could no longer be dropped.(34) A strike force did not need to lose aircraft in needless accidents. Most certainly they did not need to toss bombs wildly off target due to cracked funs, or worse yet, hit a target with duds after penetrating heavy air defenses. One F-105 pilot recalled a 1965 mission where he saw his six bombs hit squarely on his target, a bridge, and then bounce and skid across it into some nearby huts without exploding. (35) A further concern was that most of the bombs could only be dropped in daylight.

Although the F-105 was the primary strike aircraft and had an "all-weather" bombing ability, it was designed for dropping a nuclear bomb. The Thud was not well suited to the role of an "iron hauling" conventional strike aircraft, because the F-105's radar did not have the resolution required for all-weather, day or night conventional bombing operations. There is a common expression pertaining to the value of accuracy: "being close only counts in horse-shoes." This also applied to nuclear weapons delivery in the 1950's and 1960's where pinpoint accuracy was not important. The Thud's radar scope did not have to depict a corner of a building to allow a nuclear weapons release, it merely had to display the city. This meant that the Thuds could not usually find specific targets very well while flying either in cloud cover or at night in Southeast Asia. EB-66's had a better bombing radar than the F-105's and were sometimes used to lead F-105 strikes over areas outside of SA-2 range beginning in 1966. Although some F-105 and also some F-100 fighter pilots were well-trained in night operations, their number was few and consequently, so were the night missions by fighter-bombers.(36)

Night operations in Southeast Asia during the 1965-1968 time period were more often seen over South Vietnam and Laos because the ground-based anti-aircraft defenses there against high-flying aircraft were relatively weak. These missions could be conducted by aircraft like the B-57 Canberra medium bomber and the huge, heavy B-52 Stratofortress.(37) Neither aircraft was allowed by the USAF to fly in the SA-2 dominated areas of North Vietnam mostly because the B-57 lacked adequate speed and had no radar jamming devices while the B-52 was also relatively slow but also had poor maneuverability. The Navy possessed the only true night-capable fighter bomber in the form of the A-6 Intruder. Night missions were to increase as aircraft like the AC-130 and F-111 appeared later in the war, but throughout Rolling Thunder fighter bombers like the Thuds would have to rely upon good weather, which, unfortunately, is what most of the anti-aircraft artillery and small arms fire preferred. The previous chapter showed how the effectiveness of anti-aircraft artillery stimulated tactics changes within the air combat system. How fast and effectively the Air Force system responded to change appeared to be mostly affected by forces other than technology.

Air Force operations in Vietnam were but one picture of a much larger puzzle that involved the entire Defense Department. The combined operations of the services were marked by a distinct lack of centralized authority. For example, overall authority for all

Vietnam operations might logically have rested with the Commander of the United States Military Assistance Command in Vietnam (MACV), who at this time in 1965 was General William Westmoreland. Westmoreland, however, had little opportunity to step back and look at how all the American forces could best be used in Vietnam. He was directly in charge of all ground operations in Southeast Asia, a task that consumed so much of his effort that, according to an Air Force report, he had little time to devote to the full use and exploitation of air power.(38) In other words, there was nobody at MACV who could speak with full authority for all the military forces committed to Southeast Asia nor was there a single voice for the air assets.

The Commander of the Second Air Division was in charge of all US Air Force operations over Vietnam, but did not have direct control of all the Air Force's aircraft.(39) Aircraft like B-52's and KC-135's were still directly attached to Strategic Air Command, the headquarters of which was in Omaha, Nebraska, and not under PACAF control. This required another bureaucratic layer to be penetrated just to coordinate actions with these aircraft. There was no hope of merging Air Force aircraft with Navy aircraft, as each service jealously guarded its assets. Control of Navy aircraft remained ultimately with the Commander-in-Chief of the Pacific Fleet, but for all practical purposes control rested with Task Force 77 floating in the Gulf of Tonkin. Marine air operations were practically autonomous, concentrating primarily in support of Marine ground forces. Chaotic, haphazard arrangements "permitted varying degrees of confused responsibilities, overlapping authority, and inadequate controls" between these agencies were the order of the day.(40)

Further exacerbating the command and control situation in 1965 was the way in which North Vietnam was divided between the Air Force, Navy and Westmoreland's MACV. North Vietnam was geographically divided on a flight chart into six "Route Packages", known as "Route Packs", each labeled one through six. Route Pack "Six" was further divided into "Six-A"(6A) and "Six-B"(6B). Generally speaking, the air defenses grew in intensity as the Route Pack number grew. Thus Route Packs 6A and 6B, the areas around Hanoi and Haiphong, had the highest concentration of air defenses. Westmoreland had jurisdiction over Route Pack 1, since that was closest to the ground troops fighting in South Vietnam. The Navy presided over Packs 2,3,4, and 6B, and the Air Force had Route Packs 5 and 6A.(41) Operations by the Air Force into zones "controlled" by the Navy and vice versa did occur but were relatively infrequent when compared to operations within a service's own zone. Coordination between the various agencies was done on an ad hoc basis. There was no formal mechanism for inter-service coordination. Even within a single service there were problems of command and control. These problems became manifested in the system's inflexibility, as seen by the tight control over mission planning.

Although the strike force spent a great deal of time studying the plan for each mission, the details of each strike plan were usually products of an Air Force planning staff located in Saigon or at PACAF Headquarters in Hawaii. In either case, actions seen as relatively minor details on one end were major events on the other end. One example of this occurred on a strike of 27 July, 1965. The strike was set to hit the missile sites that fired on Leopard flight earlier in the week. Mission planners from the higher headquarters imposed routes of flight that the strike pilots believed, correctly as it turned out, to be unnecessarily dangerous. Ordnance loads on the aircraft were changed frequently prior to takeoff, up until the very last minute. It got to the point that the maintenance crews could not keep up with these changing weapons requirements. As a result, some aircraft were made to fly without any bombs. Despite the fliers' strenuous objections and suggestions for change, neither Second Air Division nor PACAF budged.(42) By itself, the centralized control of Rolling Thunder mission planning was not necessarily causing the system to be either inflexible or inefficient. The problems arose when the centralized control took hold of the execution of the plans as well.

It wasn't until the Rolling Thunder strikes had gone on for over a year that the tactical fighter wings finally convinced somebody above them in the pecking order that the wings doing the flying might best provide inputs as to how these strike missions might be accomplished. The wings proposed that a list of potential targets be sent ahead of time so that the wings might develop a detailed plan to include routes, timing, and ordnance loads based on the latest information concerning tactics and aircraft capabilities. This plan could then be forwarded back up the chain of command for consideration.(43) There is little evidence that suggestions like these were heeded during Rolling Thunder. The intransigence of higher headquarters later led to bitter condemnations, like those of Colonel Jack Broughton, who saw this inflexibility as leading to an unnecessary waste of life in tactical air operations.(44)

Much of this inflexibility resulted from political control over the military's activities in Vietnam.(45) "The military," according to a post-Rolling Thunder Air Force report on the conduct of Southeast Asia air operations, "must not only acknowledge close political control but understand the necessity of it in the modern world and then get on with the job of operating within the established bounds."(46) These boundaries were not well-defined in 1965. For example, the selection of most tactical targets was a function more appropriately and effectively performed by teams of specialists trained in fields such as air tactics, intelligence, and weaponeering. Instead, Rolling Thunder target selection took place at intimate Tuesday luncheons between Johnson and his closest advisors, without the Joint Chiefs of Staff.

President Johnson and his staff micromanaged the air war and selected every Rolling Thunder target in 1965. "By keeping a lid on all the designated (bombing) targets, " recalled Johnson, "I knew I could keep control of the war in my own hands."(47) This meant attempting to control not only the pace of the war but also its scope. Johnson was greatly concerned about accidentally bringing China or the Soviet Union into the war. "Johnson," wrote Doris Kearns, "lived in constant fear of triggering some imaginary provision of some imaginary treaty (between North Vietnam and the Communist superpowers)."(48) The controls were politically justifiable but tactically insane. Missile sites under construction were off-limits to bombing, as were airfields full of North Vietnamese fighters. Many SA-2 sites found a comfortable refuge within the thirty nautical mile restricted ring around Hanoi or the ten mile circle drawn about Haiphong. The end result was a severe constriction on tactical air combat operations.

It remains open to debate whether or not Rolling Thunder, as either the President or the Joint Chiefs envisioned it, would have ever achieved its lofty objectives of stopping the flow of men and supplies from North Vietnam into South Vietnam and compelling the North Vietnamese to negotiate an end to the conflict.(49) Regardless, it is clear that the airmen flying these missions were hampered not only by the restraint of force associated with limited political objectives, but also by their own Air Force leadership. This is not a new revelation, but in light of this discussion on air defenses these restraints are of great importance with respect to the nature of PACAF's air attack system. Neutralization of the North Vietnamese air defenses was absolutely essential to achieve the limited, if even unreachable, political objectives. The North Vietnamese defenses, rather than being neutralized, were instead allowed the opportunity to deny the use of their airspace to the Air Force. The defenses took every advantage given to them.

Those manning the North Vietnamese air defenses were as familiar with the rules of the game as the Rolling Thunder pilots: where to bomb and where not to bomb, where to fly and where not to fly. As a result, the North Vietnamese could shift their defenses and concentrate them along the predictable American air routes. Long after the Rolling Thunder strikes ended, the Soviet advisor to the commander of the North Vietnamese air defense forces noted how the stereotyped missions made the task of defense far easier than it could have been.(50) Because tactical flexibility had been forfeited by the United States Air Force, the need for an effective technological solution to the air defense problem became of paramount importance to the Air Force decision-makers.

Chapter Five

Decision: Choices Made To Counter The Air Defenses

"SAMs probably cannot be eliminated from Vietnam," wrote the Pacific Air Forces Commander to his immediate subordinate, "but must be lived with."(1) The problems of "living with" SA-2 battalions in late 1965 will be shown in the next chapter. The commander, however, also knew that back in the States, methods of neutralizing the missile sites were being studied. Silencing these SA-2s would enable a medium-altitude strike mission to safely ingess and egress the target areas that were within the missile's lethal envelope.(2) Since every SA-2 battalion was integrated into a larger air defense system, the battalion's supporting elements, such as long-range target acquisition radars, anti-aircraft artillery, and fighters also had to be degraded, or somehow inhibited from passing vital information to the waiting SA-2 battalions. Therefore, the Air Force was faced with the task of neutralizing an entire combat system, or at least many of its key components. There were a number of possible ways to do this.

Were these options necessarily "logical" or "right" responses? To imply that there would be a logical technological response to the SA-2 would be to assume that social factors, like human judgment were relegated to a minor role in the Air Force's decision-making process.(3) For example, historian Robert O'Connell viewed the surface-to-air missile as a "natural, tactical opponent to the bomber." (4) Thus, the nature of the strategic bomber and the way in which bombers were employed in combat were more responsible for the evolution of these missiles than any particular social factor, like national characteristics, ethnic culture or tactical doctrine. Bombers, according to O'Connell, waged predatory warfare on cities and civilians.

O'Connell characterized predatory warfare by the drive for pure destruction and annihilation of the opponent than by traditional political or tactical military objectives. Accordingly, combat during the Second World War on the Eastern Front and in the Pacific was far more predatory in nature than in France, Africa or Italy. On the Eastern Front, neither German nor Soviet troops gave any quarter nor expected any from their opponent. The Pacific island-hopping campaign waged by American forces was a continual struggle to dig out fanatical defenders at places like Iwo Jima, Peleliu or Okinawa. The word predatory was also used by O'Connell in reference to specific weapons technologies designed to attack relatively defenseless targets.

Predatory weapons were also unique in that they generated a counter-response from the opponent. German U-Boats, for example, waged predatory warfare against Allied merchant shipping. In response to the marauding U-Boats, Allied navies developed, not other submarines, but sonar equipment and depth charges to install in fast escort ships and airborne radar for maritime aircraft. The counter-response was a different class of weapon entirely, designed at first not to overwhelm but to neutralize the looming technological threat.(5) A counter response triggered a volatile series of developments in efforts to hold the technological "high ground" on the battlefield. Neither side held a permanent edge, for each new response that gave an advantage was immediately followed by a counter-response designed to neutralize it. Radars and radar-countermeasures in the U-Boat campaigns of World War II are particularly illustrative for counter-response patterns, for the submarine was a prime example of a predatory weapon. (6)

In 1942 German U-Boat commanders surfaced at night to recharge their batteries and even conduct attacks on convoys, since darkness brought some measure of safety from attack. Soon the Royal Air Force (RAF) employed airborne metric radars that transmitted radio waves of about one and one-half meters in length. A surfaced U-boat after having been located by one of these radars was illuminated by an 22-million candlepower "Leigh Light" from the same aircraft. This technique sent a number of U-boats to the bottom of the ocean, while merchant shipping losses to submarines began to decrease accordingly. Shortly thereafter, a radar detection device for these metric radars was installed on U-boats. Merchant shipping losses again skyrocketed because German U-boat commanders were forewarned of marauding Allied bombers. By 1943, revolutionary microwave radars operating on centimeter length radio waves were installed on RAF bombers and U-Boat losses climbed dramatically because the submarines were not forewarned of the bombers' presence. It would take a year of frightful U-Boat losses before the Germans received appropriate detection gear. (7) The SA-2 missile systems, like the German U-Boats, can be viewed not only as counter-responses to strategic bombers but also as predatory weapons because slow, lumbering bombers were exceptionally vulnerable to the much faster guided missiles.

SA-2 battalions deployed near a likely American bombing target in Vietnam were much like duck hunters near a body of water. The hunters waited patiently in their blinds for the ducks to show up, and opened fire when the birds were within range. Each shot was aimed at a particular duck. How would ducks respond? The natural response in such a desperate situation would seem to be what is popularly known as a "fight or flight" response. Let us assume that the ducks decided upon the former: to shoot back in self-defense to stop -- either by pinning down or killing -- all the hunters. Is this the limit of a natural response, to neutralize the immediate threat? What if instead these ducks chose to go beyond shooting just to keep the hunters' heads down? What if they also decided to be predators themselves by flushing the hunters out of the blinds so as to get a clearer shot? These particular ducks would then attempt to evict all the hunters out of the area, dead or alive, so future flocks could come and go as they pleased. What started out as the ducks' attempt at simple neutralization would in this case evolve into a systematic method of wholesale disruption and destruction.

In this analogy did the hunters' guns alone motivate the ducks to go to such an extreme? Translating the analogy back to Vietnam, then, what would be a "natural tactical opponent" to the predatory SA-2 missile systems? Was it to be a different airplane, another missile, a sophisticated radar jammer or simply different tactics? That it came to be a combination of all these possible responses indicates the complexity of the situation, rather than that the Air Force's response was overkill. The dynamics of a combat system are such that its responses to a certain outside stimulus, such as new enemy weapons, are not always so straightforward and easily anticipated. It is difficult, if not impossible to predict a response from a system like that used by the Pacific Air Forces, much less assume that what seems logical must have been right, or natural.(8) Trying to mold the specific historical or decision-making model of counter-responses onto this situation is useful but fails to adequately explain why certain choices were made.

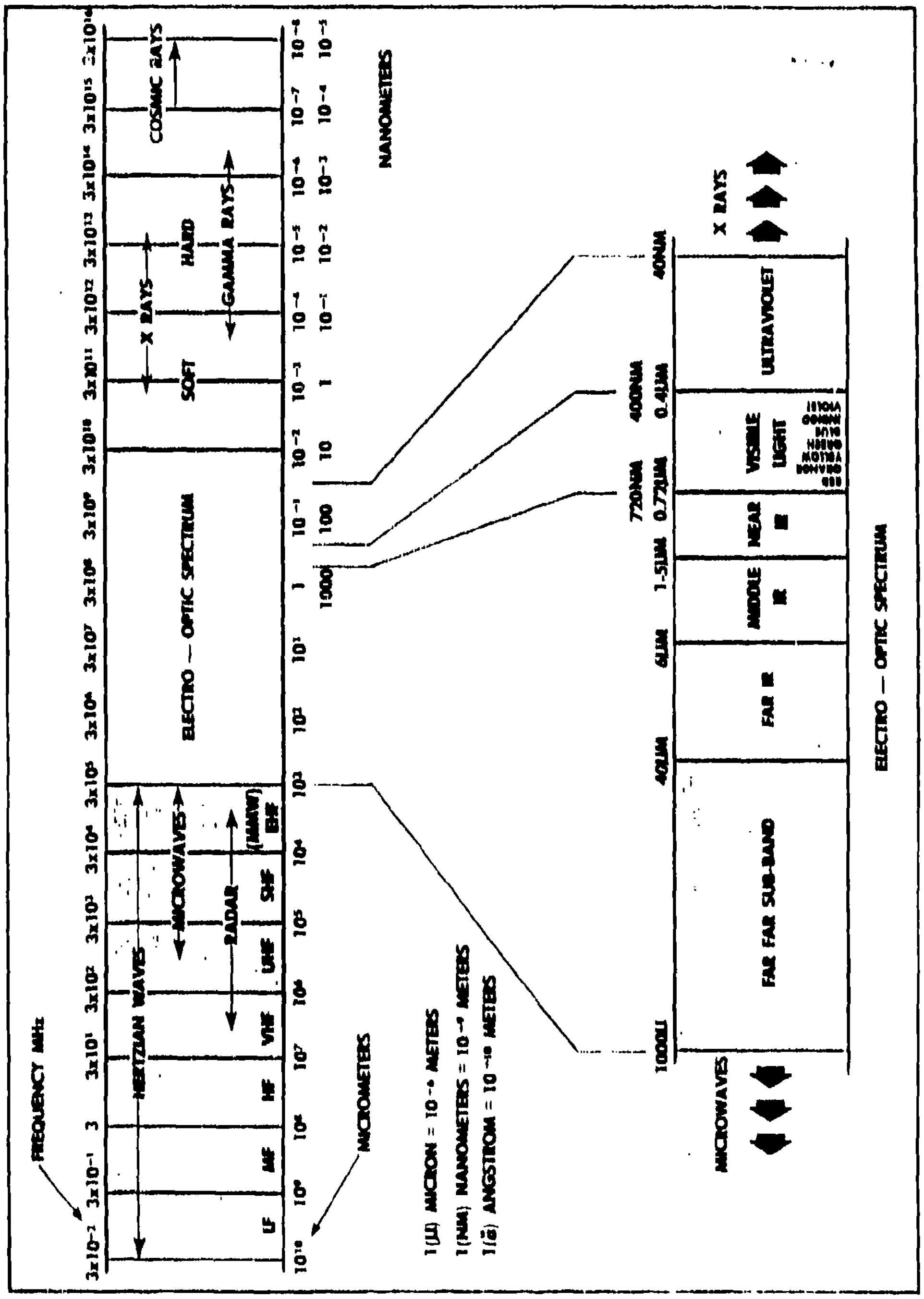
Many possible American responses to the SA-2 were logical.(9) For example, one could simply take one's chances and fly at medium altitudes near active missile sites. This would present a single SA-2 system with more targets than it could possibly attack. This tactic was questionable in 1965 given that evasive maneuvers, the jettisoning of ordnance, confusion, and the loss of flight integrity were results of many medium-altitude flights by ill-equipped aircraft near SA-2 sites, as will be shown in the next chapter. Another approach would be to deny the SA-2 battalions their reserve of missile supplies. This was not possible because these supplies were usually located in restricted zones. For example, the North Vietnamese could store new missiles in the port of Haiphong where Soviet ships offloaded them, because the city was off-limits to American air strikes. Because of these problems, neither of these alternatives appeared to have been practical.

There were other options available. Blinding the Fan Song radar was a possibility, as was disrupting either the SA-2 battalion or the entire air defense system by severing the links between the various elements. The most obvious, but also most difficult option was to lash out and destroy active SA-2 sites. Blinding the radars, disrupting the systems and seeking out and destroying active SA-2 sites required expert knowledge of radar operations and characteristics.

Neither the American military nor most major world powers were strangers to radars or electronic warfare in 1965. Simultaneously but secretly, radars were developed in several countries during the 1930's primarily because of an international boom in short wave radio research that began during the First World War and continued through the 1920's and into the early 1930's.(10) Radar, of course, was one of the major technological breakthroughs of the Second World War. In every year since that war, new developments in radar technology continued to be secretly and continuously introduced by most of the world's military powers, particularly the United States and Soviet Union. Finding out details of the adversary's new radar developments was of particular interest to these countries, for such knowledge was paramount for success in a highly dynamic yet invisible battle known as electronic combat.

Spying on the adversary's radar development represents just one of the many struggles in electronic combat. Electronic combat, also commonly referred to as electronic warfare or electronic countermeasures, actually involves the entire electromagnetic spectrum including radio, radar, visible light and infrared waves, among others, as seen in Figure III. Probably the most famous description of this kind of warfare is Sir Winston Churchill's "Battle of The Beams," which referred to successful British radio countermeasures in 1940. British "beams" confused the Luftwaffe's night bomber crews by disrupting their air navigation systems.(11) This study will be concerned mainly with electronic warfare as it applies to radar and the radar-related options for dealing with the Soviet-built SA-2 missile system. These options involved the merging of electronic countermeasures with tactical combat operations. Radar jamming is the most common of these electronic countermeasures.

It was possible to jam the Fan Song radar in order to "blind" it, given either sufficient power to saturate the Fan Song's radar receivers or the proper jamming technique to prevent the fire control battery's radar operators from distinguishing between what was real and what was not. The ultimate goal of electronic warfare is to create confusion in the opposing forces by denying them either correct or timely information pertaining to one's own combat forces. In modern aerial warfare, where aircraft often fly at high subsonic speeds, only a few seconds' worth of confusion may be all that is needed for an attacker to



Electromagnetic Wave Spectrum

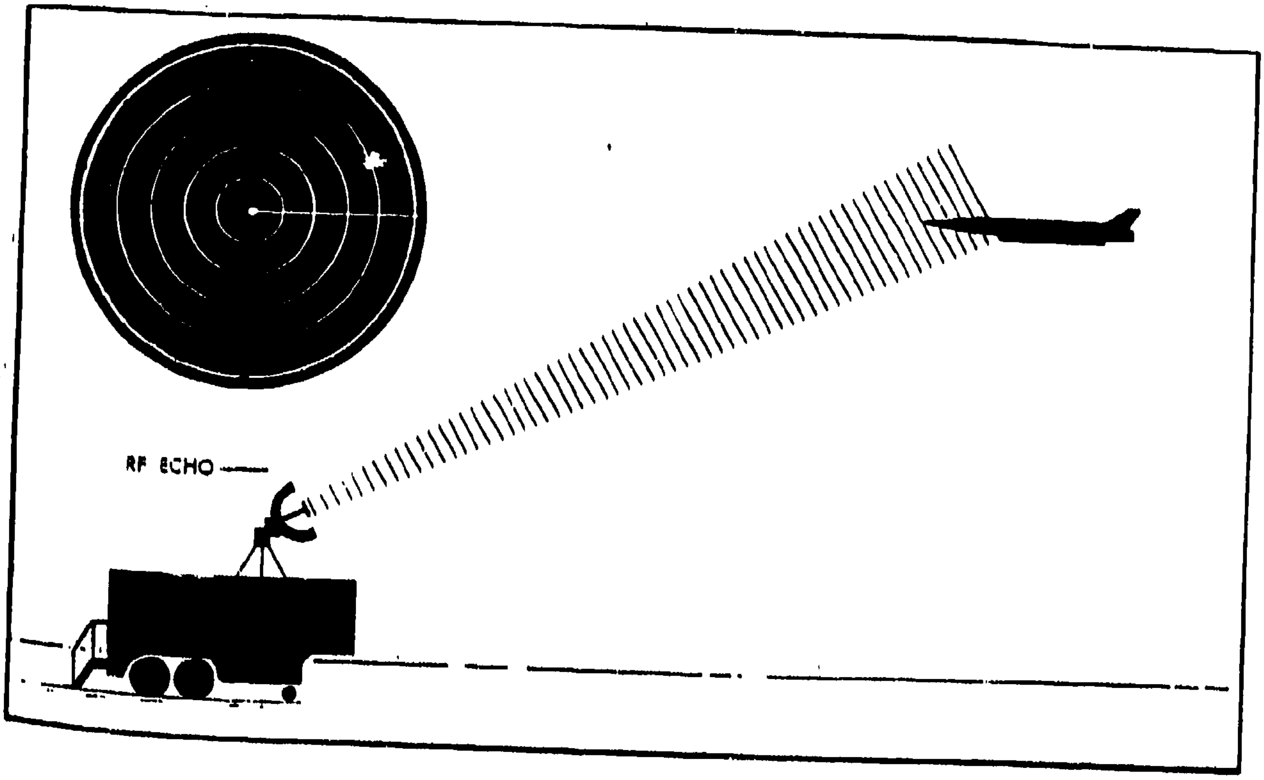
FIGURE III The Electromagnetic Spectrum

remain unscathed. Confusion works both ways, for electronic countermeasures can induce the attacking force into hitting the wrong target or even no target at all.

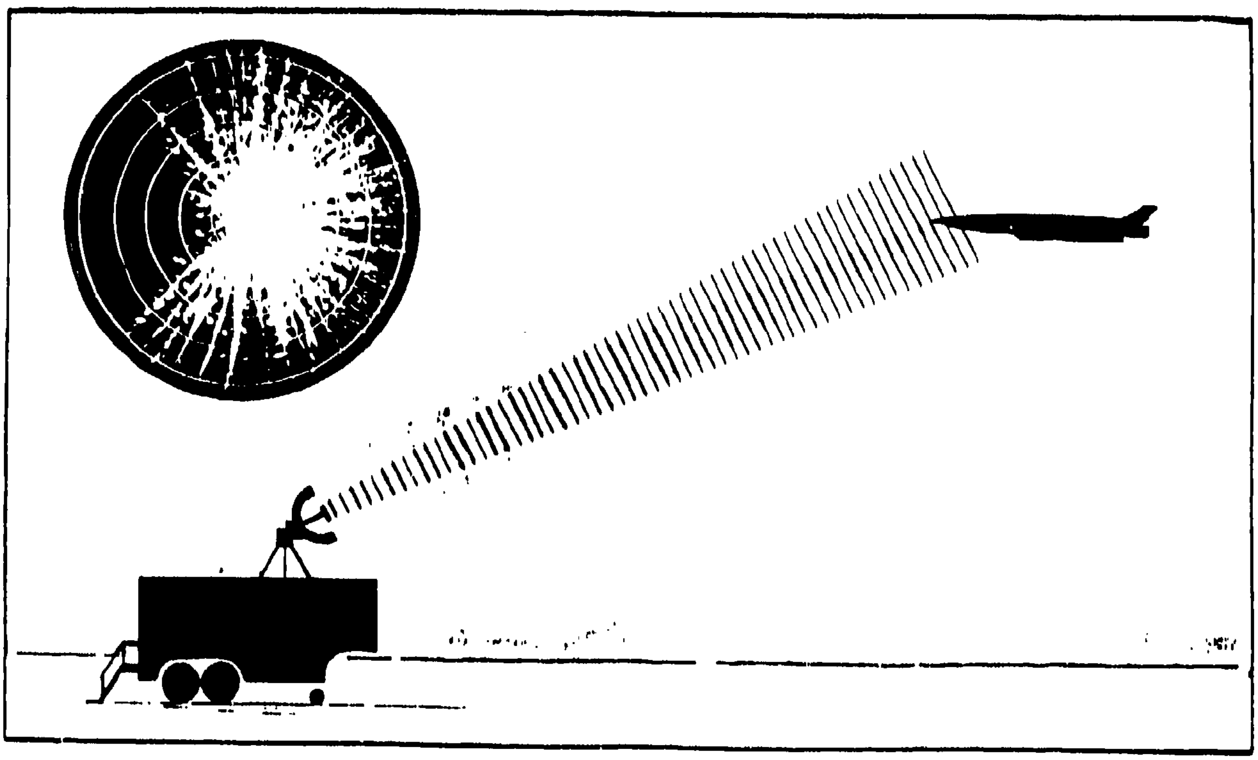
There are two fundamental types of electronic countermeasures known as active and passive. For the purpose of this study, active countermeasures refer to actual transmission of electromagnetic energy whereas passive countermeasures involve the reception of electromagnetic energy. Passive countermeasures like ground-based radar reflectors or the more well-known World War II-era "window" or "chaff" (radar reflective material dispersed from aircraft) will not be treated in this study.(12) Active countermeasures such as radar jamming will be covered here. These countermeasures can be further divided into two basic types called noise jamming and deceptive jamming.

Noise jamming is designed to saturate radar receivers with excess electromagnetic radiation, or noise. This noise, in order to be effective in preventing a radar from detecting a target, must be greater in power at the receiver's antenna than the radar's own pulse that is reflected off the target and returned. The receiver will thus be overwhelmed by this intrusion of jamming energy. The radar operator's scope will immediately become unusable, because any potential targets will literally be "washed out" and therefore impossible to see, as in Figure IV. A typical employment of noise jamming is most clearly illustrated in EB-66 operations during Rolling Thunder.

During Rolling Thunder strikes, the EB-66's would orbit between twenty-five thousand and thirty-thousand feet in altitude in elliptical, or "racetrack" patterns. These orbits would be positioned so that the EB-66's were out of range of any known operational SA-2 sites. In day-to-day Rolling Thunder operations from late 1965 through 1966 the EB-66C's typically provided SA-2 warnings for the strike forces while the EB-66B's flew radar-jamming orbits. These orbits would be flown in such a way that the EB-66B's forward-directed jammers would be radiating along the same path as the attacking force when the latter penetrated the NVN air defenses. Ideally, this would hide the strike force "underneath" the EB-66B's noise jamming that interfered with the North Vietnamese radar



Radar Scope Without Jamming.



Radar Scope With Jamming.

FIGURE IV RADAR SCOPE DISPLAYS: JAMMING VERSUS NON-JAMMING displays. Additional EB-66s, if available, would be radiating from other directions to confuse the North Vietnamese radar operators and help to screen the attacking force. It is important to understand, however, that different kinds of radars are different in their susceptibility to noise jamming. Some radars are less vulnerable than others.(13) This gives rise to the use of deceptive jamming that relies more on "finesse" and less on "brute strength."

Deceptive jamming, like noise jamming, is designed to confuse the enemy. It takes advantage of the peculiarities of specific radars by turning these characteristics into weaknesses. For example, the particular scan pattern of a radar antenna -- how it physically moves and searches the sky -- might lend itself to a particular technique of jamming as would the specific pattern in which pulses are transmitted from the antenna. A radar's electronic hardware or signal processing methods might be another potential weakness. This is why radar development has been characteristically secretive because to know how a radar works is to also know how it can be jammed.(14)

In order to successfully disrupt a radar, the equipment doing the jamming must meet some conditions. First and foremost, the jamming transmitter must be matched to the correct frequency. All the jamming power in the world is of little value unless it is tuned into the correct "channel." This requires detailed intelligence from electronic reconnaissance aircraft or other gatherers of electronic information. This data is called electronic intelligence, or ELINT. The Navy, for example, had ELINT ships in the Gulf of Tonkin to monitor North Vietnamese air defense radars and record their operating frequencies. The Air Force's ELINT efforts date back to World War II.(15) Matching the frequency is only part of the battle.

Jamming also needs to be continuous and, especially with respect to deception jamming, able to match the characteristics of the victim radar. Competent radar operators are often able to "work through" or compensate for jamming and still identify and track their targets.(16) If the jamming is not continuous, for example, these operators can gather the necessary information from the "breaks" in the jamming, when the true targets present themselves. Deception jamming must be able literally to mimic the radar's own pulses so they will be processed normally by the radar's logic circuits to present false information, often without the operator realizing that something is amiss. If these deception signals do not exactly match the outgoing radar pulses, they will be rejected by the radar's processor just as soon as they are received through its antenna. Deceptive jamming can be clearly illustrated in the case of a track-while-scan (TWS) radar.

There have been many TWS radars developed throughout the world over the years, with the SA-2 being among the first of these ever employed.(17) A track-while-scan radar typically uses two radar antennas, each operating on different radar frequencies and both capable of scanning a section of sky at a rapid rate, as seen in Figure V. One radar antenna determines the range and elevation of the target, while the other determines the range and azimuth. Once a target is selected for missile launch, the information, combined from the two antennas, is fed into a computer and converted into a guidance signal for the outgoing missile. The radar is called a track-while-scan because it is able to provide this missile guidance information on one target while simultaneously tracking many other potential targets. Most other types of radars in that time period immediately lost the ability to "see" other targets once they were "locked on" to a specific target of interest. By contrast, a TWS radar technically did not "lock on" to its target.

One kind of jammer that can be used against a track-while-scan radar is called a modulated noise jammer. What this jammers does is deny tracking capability to the victim radar. To accomplish this, the jamming waves are modulated, or shaped, by a modulating signal in a process roughly similar to the way in which music being transmitted from a commercial radio station is superimposed onto a frequency modulated (FM) or amplitude modulated (AM) wave. The shape of the modulating wave is determined by certain scan characteristics of this radar. The effect on the victim radar can be devastating.

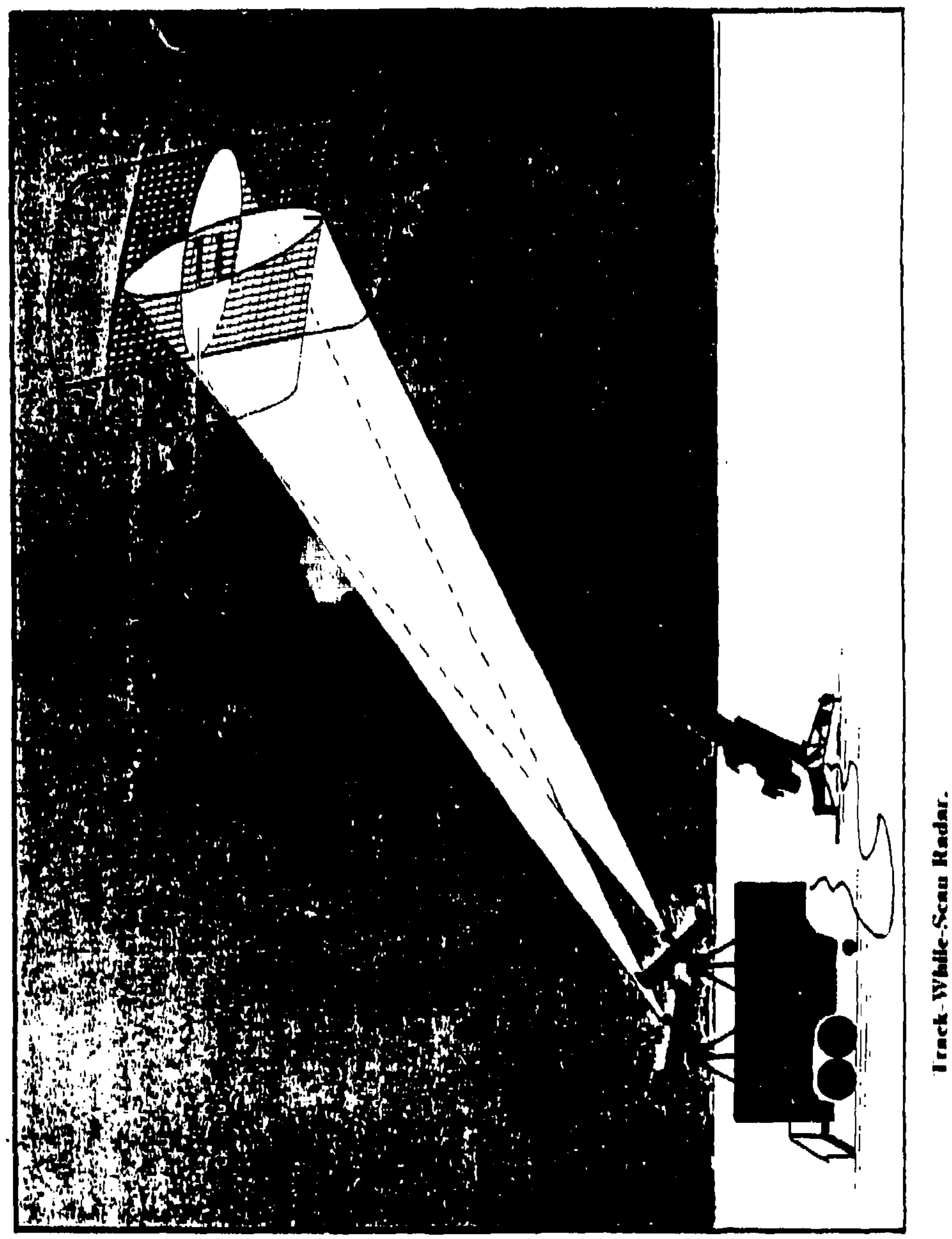


FIGURE V A TYPICAL TWS RADAR SCAN PATTERN

Every track-while-scan radar is unique, and there are vast differences between their electronics and methods of operation. The following example illustrates what might occur during active jamming of such a radar. In Figure VI, we see what might be seen as a "typical" operator's radar scope of a track-while-scan radar. The target is clearly seen at ten degrees of elevation at a range of five miles. Noise jamming, when introduced, immediately denies range information.(Figure VII) The operator knows that something is out there at 10 degrees elevation, but not how far away it is. Figure VIII shows the effect of modulated noise jamming. Range information continues to be denied, but now the operator has four possible elevations from which to choose.(18)

In 1965, the specific jamming techniques required to jam an SA-2 were known in the American military, but testing efforts had almost always involved Strategic Air Command (SAC) bomber aircraft, like the B-52 Stratofortress and B-58 Hustler. Rarely were Tactical Air Command (TAC) fighter aircraft like the F-105 or F-100 participants in these tests. The bombers were outfitted with extensive arrays of electronic warfare equipment and had an electronic warfare officer on each crew to operate it. SAC B-52's often flew simulated bombing runs in special training ranges where "surrogates" of Fan Song radars operated.

These surrogates were American-made copies of the SA-2's Fan Song radar. The design was based on the best intelligence information available. General Dynamics Corporation in Fort Worth, Texas had what was called an Electronic Warfare Evaluation Simulator, which, after technical help from Cornell University researchers, was able to evaluate many different American radar jammers and countermeasure techniques.(19) Through a computer, this equipment was pitted against most every known Soviet-built radar and radar-guided missile system. "By 1964," recalled a Cornell researcher, "we had a very good handle on what would jam an SA-2. The knowledge was there, ready for when it would be needed."(20) Tactical Air Command and the Pacific Air Forces had been rudely awakened to the fact that they very much needed that knowledge.

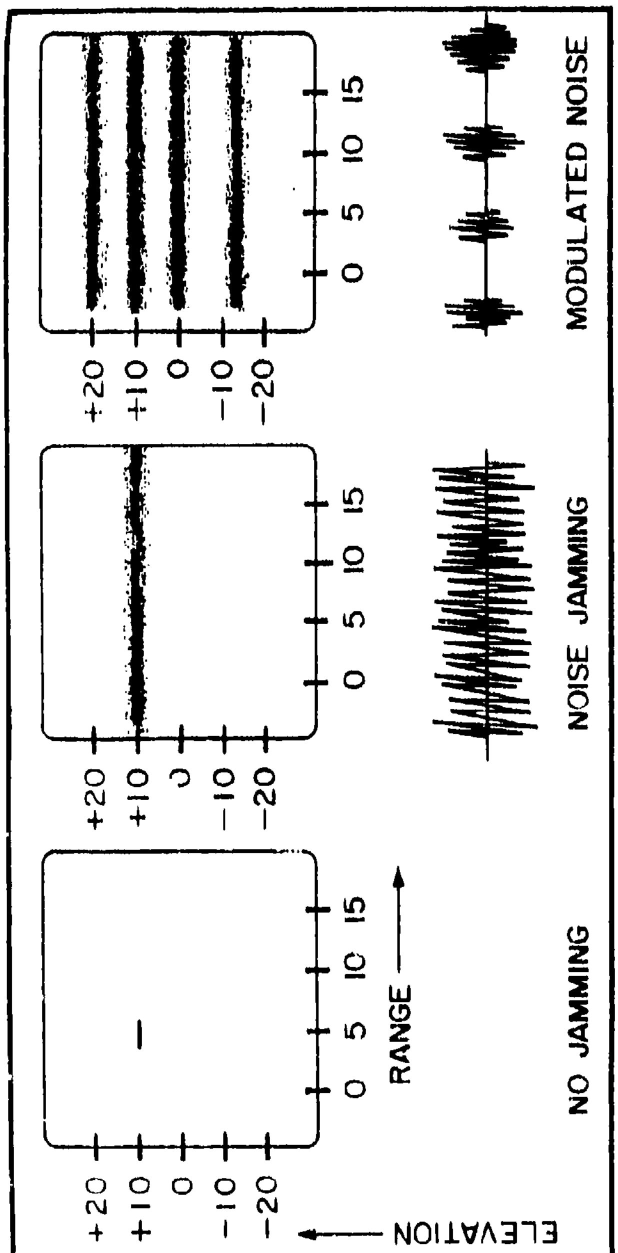


FIGURE VI: NO JAMMING: FIGURE VII NOISE JAMMING
FIGURE VIII MODULATED NOISE JAMMING

Radar jamming was not the only way to neutralize the SA-2. Another alternative was to sever or at least disrupt the links between the elements that made up the SA-2 system. For example, Radio transmissions within the SA-2 battalion or between the SA-2 battalion and its commanding regiment could have been vulnerable links. These links could be jammed, provided the frequencies were known and the appropriate jammer with enough power could be positioned close enough to the SA-2 site to be effective. If the SA-2 had been in position for any appreciable length of time, then certainly the crew could have connected communications cables, thus hampering attempts at radio jamming. Missile sites, it will be recalled, were built with these cables already laid out and only in need of attachment. There were other vulnerable links that could not protected by a cable.

One of these links, for example, could have been the radio commands from the ground to the missile. If it were unable to receive various guidance commands from the fire control battery, the missile might simply follow a ballistic flight path and miss its target entirely. Another link might be the proximity fuse of the Guideline missile itself. This fuse could be fooled through the use of decoys or actual jamming of the missile's fuzing radar. Feeding the wrong information into the fuse could cause a premature detonation of the warhead. This was not new knowledge in the American electronic warfare community because similar options were considered almost three years before the missile's deployment to North Vietnam during the 1962 Cuban Missile crisis.

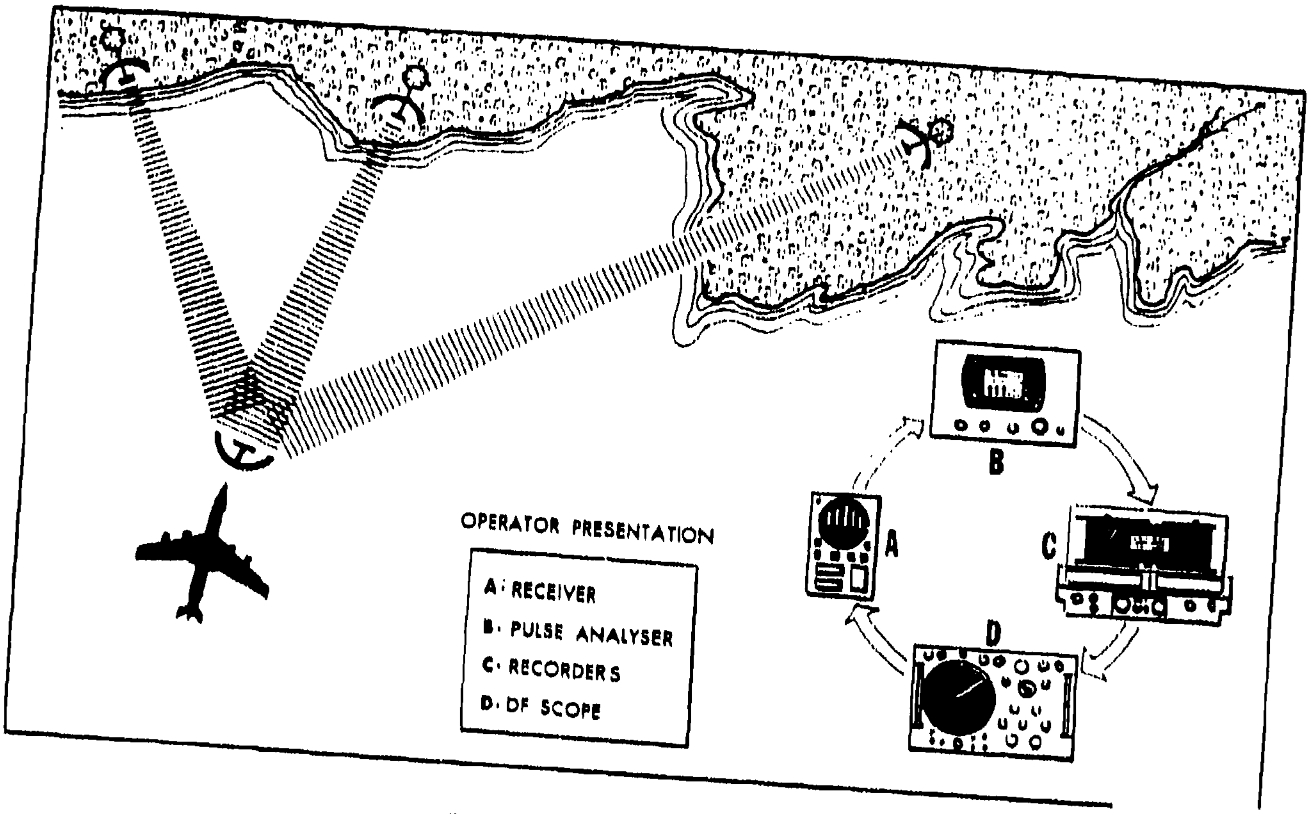
Cuban SA-2's directly threatened the reconnaissance flights by U-2 aircraft, which generated a crash program within the American military to find out what radio frequencies were used on the Guideline missiles' proximity fuse. This required monitoring activity near the Cuban SA-2 missile sites. The US Army had become adept at intercepting electronic emissions from Soviet tests and exercises in Europe. One of the most sought-after Soviet frequencies was that for radar proximity fuses in artillery shells. (21) Finding such a frequency in a guided missile was relatively more difficult than in a artillery shell's fuse, because the former's radar fuse transmitted in a limited direction. This transmission was confined to a narrow "cone" projecting forward from the missile's nose. Unfortunately, the only way to intercept this frequency was to send up a juicy target for a missile crew, provoke a launch, and record the radar transmission just prior to the missile's detonation next to the aircraft doing the recording. Although the Air Force often got volunteers for a variety of dangerous missions, this one exceeded what might be considered "above and beyond" the call of duty. It was highly unlikely that anyone would knowingly fly as a sacrificial lamb to record proximity fuse transmissions just prior to vanishing in a large fireball. The solution, therefore, came in the form of a target drone modified not only with special radar detection gear, but also deception equipment which made the drone appear on radar to be a large aircraft. These drones were on hand by 1965.

Starting in October, 1965, the Air Force launched four of these drones under the code-name of "United Effort."(22) A drone was sent at high altitude right over the North Vietnamese air defenses on each occasion to collect and re-transmit the proximity fuse frequency. Nearby, but far out of the range of SA-2 missiles, orbited a Strategic Air Command RB-47H, a B-47 bomber re-configured for electronic intelligence missions, which would receive and record the drone's signals. All four United Effort drones succeeded in provoking missile launches and were subsequently shot down by SA-2 battalions. Although the RB-47's gathered important guidance signals from SA-2 fire control batteries, it wasn't until the fourth mission, on 13 February, 1966 that the missile's proximity fuse radar transmissions were successfully collected. That particular drone was blown to pieces by two Guidelines over Thanh Hoa, North Vietnam.(23) Countering the SA-2's electronics was a significant but incomplete solution to the problem faced by the US Air Force.

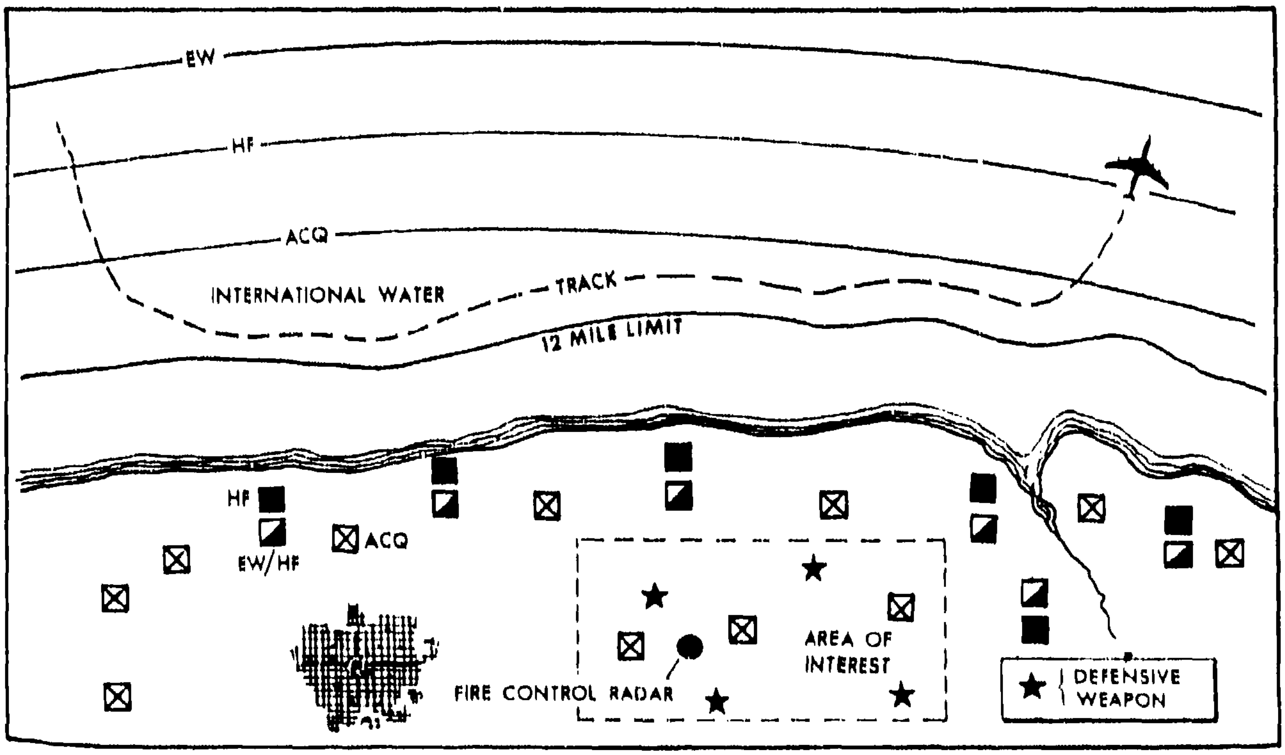
Consideration also had to be made for the North Vietnamese integrated air defense system. Even if an SA-2 battalion did not bother to turn on its Fan Song radar, chances were good that the other defense elements could provide the battalion with accurate tracking data regarding the attacking force. A hidden SA-2 site could therefore remain in ambush until the last possible moment, turning on its radar only to effect a missile launch since the battalion already would know the direction in which to point its rada.. Efforts to blind or destroy large radar-based air defenses, or even attempts to sever certain key links of that system, were correspondingly massive, complex tasks.(24) Less massive, but no less complex, were attempts to destroy occupied SA-2 sites.

The physical destruction of an SA-2 system would first require knowledge of its precise location. Visual identification of a site, either through photo-reconnaissance or pilot observations, was difficult due to the excellent techniques of concealment practiced by the North Vietnamese. To help overcome this problem in finding the site, the approximate position of an SA-2 could be revealed through a combination of radar direction-finding equipment and triangulation. Direction-finding equipment installed on an aircraft could provide the relative bearing of the emitting radar to the aircraft, the latter always at a known location. Figure IX shows typical airborne electronic intelligence equipment and a route of flight. The derived positions, no matter how carefully taken by the operator, were limited in accuracy because of limitations in the detection equipment. Also, if alerted in time by the other elements of the air defenses, the Fan Song crews could shut down their radars when an EB-66C passed nearby on such a reconnaissance mission. Despite these difficulties, the actual process to derive the approximate location a site was relatively simple in nature.

At three different times along the route of flight, the relative bearing of the desired radar signal to the aircraft were recorded, provided that the radar was transmitting in the first place. This information can be used to derive three lines of position, or LOP's, as seen in Figure X. Ideally, all the LOP's would intersect at a common point. This point represented the position of the radar site. If the lines did not intersect in the same place, the result would be a triangle, with the radar located somewhere within the boundaries of that triangle. In any event, the derived location was approximate, and there still remained the



Typical Airborne ELINT Equipment



Peripheral Reconnaissance Route.

FIGURE IX

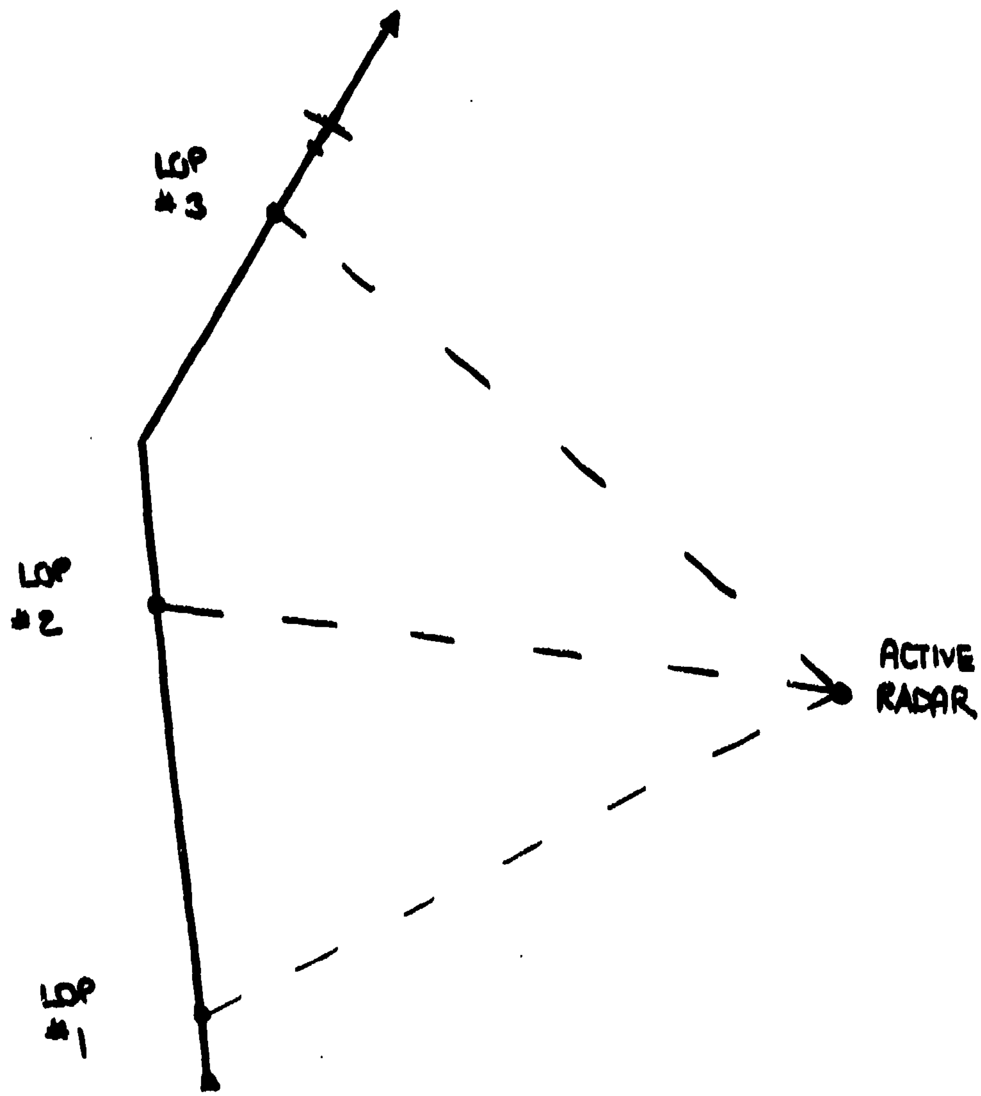


FIGURE X DETERMINING A RADAR'S LOCATION WITH LINES OF POSITION problem actually finding it. Even then, these missile sites were well-endowed with supporting batteries of anti-aircraft artillery, making aircraft attacks a risky proposition.

As the above analysis indicates, the Air Force was faced with a problem which had no simple solution. Further compounding the problem was the complete lack of electronic warfare expertise among the ranks of both the Tactical Air Command and the Pacific Air Forces decision-makers. They would come to learn that an implicit first step in the countering of such a lethal, radar-based system was having a firm program of electronic warfare already established. In 1965, however, this was not the situation at either the Tactical Air Command or PACAF, where electronic warfare operations in each had long been relegated to the backburner of daily operations. According to a contemporary Air Force report, "the SAM (missile) threat triggered a flurry of activity at PACAF...a 'wait and see attitude' had been rudely confronted with a 'what do we do now' attitude."(25)

The Commander-in-Chief of the Pacific Air Forces lamented the state of his command's electronic warfare in 1965 as "practically devoid of electronic warfare equipments (sic) and personnel." The tactical air units were faced with implementing a late, costly effort in the electronic warfare arena. He thought it was a situation "fostered by lack of emphasis on electronic warfare equipment, manpower and organization." When PACAF finally got its anti-SA-2 act in gear, efforts at countermeasures were hindered by "lack of proper manning and organization throughout the entire Tactical Air Forces."(26) As was written in a contemporary Air Force report, this was a "rerun of an old movie based on a Korean war script."(27) Old lessons in electronic warfare were going to have to be relearned, and the Air Force was finding out the hard way. More than two weeks after the downing of Leopard 04, the decision to counter the SA-2 came straight from the top of the Air Force command structure.

A task force to study the situation was officially created on 13 August, 1965 by the USAF Chief of Staff, General John McConnell.(28) This came a day after the Joint Chiefs of Staff created a similar committee under the code-name of "Prong Tong" to study the same problem.(29) The independent Air Force committee, headed by Brigadier General K.C. Dempster, was directed to study the SA-2 and determine possible ways to counter it. It was comprised of representatives from the Air Staff, major air commands, industry, and the scientific community. One of the members of the task force, who had been associated with Air Force research and development for many years, described it as "ten or twelve guys who sat in smoke-filled rooms and brought contractors in to figure out what to do."(30) In a very short time the task force had come up with several recommendations, and Dempster went over these proposals with everyone up the chain of command, starting with the Commander of the Pacific Air Forces and ending with the Secretary of Defense.(31) Ironically, Dempster's task force only echoed earlier cries for an airborne tactical electronic warfare program long since buried in a massive avalanche of military documents.

As early as 1952 Tactical Air Command had convened an Electronic Countermeasures board modeled after that of the Strategic Air Command.(32) Furthermore, Tactical Air Command had also published a document entitled "Doctrine Governing Mission and Command functions of Electronic Countermeasures in Tactical Air Operations" in November of that same year. Both the board and the doctrine pointed to a pressing need to integrate this capability with the current tactical air operations, including the means to locate and destroy threatening enemy radars.(33). Visionary statements aside, the fact remained that TAC had at this time but a handful of personnel familiar with electronic warfare. The organizational structure to implement any electronic warfare program simply could not come into being without the properly qualified people to support it. Whether this small-scale effort was the result of decisions by only a few influential officers or more of a general feeling of animosity toward such a secret program, or both, remains to be fully investigated. However, the contrast with the Strategic Air Command is rather striking.

Historians Alfred Price and Daniel Kuehl to some extent have contrasted the electronic warfare policies of Strategic Air Command (SAC) and Tactical Air Command (TAC), but the subject is open for a much more detailed examination.(34) This is especially true for the time period between the Korean and Vietnam Wars. However, it is obvious that SAC placed a much greater emphasis on electronic countermeasures. General Curtis Le May, the long-time Commander-in-Chief of SAC, held up the production of the new B-52 Stratofortress bombers in the early 1950's until Boeing redesigned the crew compartment to include space for an electronic warfare officer, not to mention an extensive electronic countermeasures suite.(35) Kuehl noted that for large exercises, SAC regularly showed up with dozens of electronic combat-capable bombers and dedicated electronic countermeasures support aircraft. On the other hand, TAC only scraped up a few such aircraft, and these were relatively obsolete bomber airframes with out-moded countermeasures equipment. The tactical fighters, too, had a paucity of jamming equipment, most of which was in storage on a Pacific Island. Suffice to say that throughout the 1950's and most of the 1960's SAC possessed the personnel and infrastructure to quickly expand any electronic warfare program while TAC did not.

Despite its lack of a sizeable electronic warfare program, TAC's immediate task was the installation of radar detection equipment onto Air Force combat aircraft. This was called Radar Homing and Warning, or RHAW gear. According to author Larry Davis, the Bendix Corporation had made this very same proposal to the USAF earlier in 1965, about the same time the first SA-2 sites was discovered in North Vietnam.(36) Bendix wanted to install RHAW gear in the F-100 fighter, but the proposal was rejected. The Air Force officers making the decision at the time perceived no need for such equipment in fighter aircraft. A second example contrasting what the tactical air forces perceived as threats before and after the July 1965 missile firing was the development of the F-105. The manufacturers of the Thud had in the original contract a modest array of electronic countermeasures to include a radar warning receiver, chaff dispenser and jammer. This was also rejected in the name of $105,000 in cost savings per aircraft.(37) On 14 October, 1965, however, the Headquarters, United States Air Force ordered its Air Force Logistics command to install RHAW equipment on the F-100 in ten days. The installation and initial equipment testing took place at the Sacramento Air Materiel Area, McClellan Air Force Base, California.(38)

Radar homing and warning gear would allow the air crews to continuously receive information as to the approximate location and intentions of active SA-2 sites and other threat radars. A missile launch warning light, accompanied by an ear-piercing tone would be triggered when the RHAW gear detected the radio guidance commands from the SA-2 fire control battery to the missile. Clear visibility to the actual launch site would no longer be the only means for a pilot to be aware of an approaching missile. This was an important consideration while operating in the variable weather conditions over the heavily defended North Vietnamese targets.

Another recommendation was that jamming equipment designed to confuse the SA-2 system be developed for mounting onto fighter aircraft. These were called pods, long, hollow aerodynamic containers with jamming equipment installed inside. Prior to take-off, the pod was attached underneath the fighter and the jammers were tuned to the frequencies of the radars which threatened the aircraft, like fire control radars for anti-aircraft artillery and the Fan Song. Pods also had their limitations. As the aircraft's speed increased, the pod would induce greater drag. The pods also took up space under the aircraft that would otherwise be used for ordnance.

The jamming pod was not a new idea to the tactical community. In the late 1950's Tactical Air command bought a few ALQ-31 pods from North American Aviation for use of the F-100 and F-105. These huge, 12-foot, twenty-eight inch diameter pods caused so much drag that the fuel consumption on these fighters was substantially increased. The fuel burn rate was so high, in fact, that the fighters would not have enough fuel to return from striking their assigned wartime nuclear targets.(39) A couple years later, Tactical Air

Command procured a large number of smaller QRC-160 jamming pods for fighter aircraft under the Quick Reaction Capability program, or QRC.(40) General Electric produced these pods, with the first arriving at operational USAF units in the wake of the Cuban Missile crisis in 1963. Many of these pods wound up within PACAF where they went into storage at Kadena Air Base. Few commanders at the time were inclined to attach the pods underneath their fighters. Neither the length of time in storage nor the humid conditions on Okinawa were favorable for these pods when they were brought out for later use in Southeast Asia.

These QRC-160 pods were sent to Southeast Asia's hostile skies by 1965, but only for a short time. RF-101 "Voodoo" reconnaissance aircraft based out of Tan Son Nhut AB, Vietnam, carried these pods on their missions. Qualified technicians and spare parts for the QRC-160, however, were in short supply. That wasn't half the problem. Not designed to withstand sustained in-flight vibrations, many of the internal parts of the pod came loose, rendering the jammers useless. An Air Force report said that the pods "also seemed to cause the RF-101 wing tips to tuck and some thought this could be (very unsafe)." These pods, viewed with a "shadow of suspicion" were sent back to the States.(41) The pods recommended by Dempster's task force needed to overcome the QRC-160's deficiencies, and the first improved models would not arrive in theater until late 1966.

A third recommendation was to build and employ a missile capable of homing in on the Fan Song's radar emissions and destroying the radar itself. Such a missile was designated an anti-radiation missile (ARM) and its origins trace back to World War II, where scientific hotbeds like the Radiation Laboratory and Radio Research Laboratory in Massachusetts produced a plethora of technologies, many of which were "reborn" for use in Southeast Asia.(42) One example of the several ancestors to modern ARM's was the Moth, originally conceived as a radio-controlled, radar-homing glide bomb. Designed to knock out German radar warning stations along the northern French coast, the Moth program was eased out of the US 8th Bomber Command's Radio and Radar Countermeasures program in November of 1943 on the grounds that the Moth tests in the United States were not proceeding at a satisfactory pace. The Army Air Forces opted instead for low-level attacks over the water by medium bombers.(43) The Moth, like so many scientific programs of that era, vanished after V-J Day.

Years later, the US Navy developed an ARM that was based on the Sparrow air-to-air missile. (44) This particular missile, known as a Shrike, was tested as early as 1958 at the Naval Ordnance Test Station, China Lake, Nevada.(45) By 1962 the Cuban missile crisis accentuated the perceived need for an ARM and so the Navy accelerated the Shrike's development. The first operational shrikes arrived for use over North Vietnam by April, 1966.

The most significant recommendation by Dempster's task force was that it called for the development of a fighter aircraft designed specifically to locate SA-2 sites and mark them for immediate attacks by accompanying flights of fighter-bombers. The equipment used for this mission was to be off-the-shelf equipment installed into an existing fighter. Moreover, the fighter had to be a two-seat aircraft allowing for both a pilot and an electronic warfare officer, the latter's job being to operate the radar direction- finding equipment.

This idea, ironically, came from a former SAC electronic warfare officer who was now out of the service and working for North American Aviation.(46) This proposal for a modification to North American's F-100F fighter aircraft was outlined on the back of an envelope on his flight over to where the task force was meeting at the Pentagon. Dempster was quite impressed with the plan but was not too confident about pushing the program through the standard Air Force acquisition routine that seemed to require, according to one member of the task force, "a development plan thirty-five feet thick that had been (outlined and coordinated with) the whole world." Convinced by the task force to bypass the cumbersome process due to the desperate nature of the situation, Dempster left the room and "fifteen minutes later he was back with two million dollars," which was sufficient to begin a program called "Wild Weasel I." The program was given the highest priority possible to ensure its fast completion.(47)

Unfortunately for the airmen flying combat missions in Southeast Asia, the manifestations of the task force's recommendations were still months away when the remnants of Leopard flight touched down on the airstrip at Ubon Air Base, Thailand in July of 1965. Until the new assets to counter the SA-2 arrived, the aviators would have to quickly come up with some ideas to deal with the SA-2 and the North Vietnamese air defense system.

Chapter Six

Desperation: The SA-2 Denies The Medium Altitudes

The SA-2 missile system dominated North Vietnam's aerial arena throughout the fall and winter of 1965 and throughout most of 1966. This weapon helped to allow the North Vietnamese defenses to effect a situation that historian Earl Tilford termed air denial.(1) This meant that the air defenses, at a time and place of their own choosing and within certain altitude regimes, could often prevent the American aircraft from operating freely. For example, F-105 pilots preferred to approach their targets from medium altitudes between 12,000 to 15,000 feet (2). If the target was defended by SA-2 battalions then the F-105's would be forced to change their plans. Often this meant approaching at a much lower altitude or even bombing another target entirely. It has been previously argued that the SA-2 was well integrated into the North Vietnamese air defenses and that this same defensive system was relatively inflexible, yet the SA-2 appears to have been an extremely effective wea[illegible] during this time.

This weapon should be considered by historians as one of the most significant weapons ever introduced into air combat. The SA-2 transformed tactical air warfare much like the rifle or machine gun changed land warfare. It brought a sense of desperation and a major shift in tactical doctrine in the forces that opposed it over North Vietnam in 1965. The SA-2 dominated the skies but a short time in a long war. It exacted a relatively small human toll and only a small number of launched missiles managed to down a target. These facts, combined with its subsequently poor performance in the Sinai has led some writers to question the effectiveness of the SA-2.(3)

In the 1967 Six-Day War, Soviet built SA-2's were used by the Arab ground defenses, but were rarely fired at Israeli Air Force aircraft. The Israelis did not use Wild Weasel-type aircraft, nor were they forced out of their preferred operating altitudes. A closer look at the combat effectiveness of an single weapon or element in a large military system might shed light on how the Israelis dominated the air in 1967 and the US Air Force was denied its operational freedom in 1965, even though both air attack systems faced the SA-2 missile system. Historian Martin Van Creveld offered a possible explanation in his aforementioned chapter on modern, integrated war.

To illustrate the relationship between an individual weapon and a highly integrated system, Van Creveld used the case of a fighter-bomber type aircraft. He called this airplane "a self-contained platform" which made it autonomous in nature with respect to the greater system. Such a weapon was therefore capable of inflicting tremendous damage to opposing forces as evidenced by the German Blitzkrieg early in World War II and in Allied tactical aircraft operations a few years later. Van Creveld asserts that this was also true in the Israeli Air Force as late as the 1967 Six-Day War. "A single pilot, " wrote Van Creveld, "requiring comparatively little outside assistance, was able to loiter above a battlefield, conduct reconnaissance, acquire a target, and hit it with the aid of weapons carried aboard."(4)

As anti-aircraft defenses became more formidable with the passage of time, the fighter-bomber became "increasingly dependent" on other technologies. The aircraft grew less effective as it became part of this growing system of integrated technologies.(5) In Van Creveld's view, integration contributed to the demise of this aircraft's effectiveness just as much as the threat posed by the modernization of anti-aircraft defenses. Furthermore, the growing system of which the aircraft was a part became less flexible as the former grew in size and degree of integration. Modern aerial warfare subsequently evolved into two huge systems engaged in a slow war of attrition with the individual elements hampered in their use and effectiveness because of the systems' growing rigidity.

However, the application of his model to the 1967 Israeli air war example seems to paint an incomplete picture. True, this 1967 air battle was a clash of two large systems -- the Israeli Air Force (IAF) on one hand and the Arab air defenses on the other. It is also true that the Israeli Air Forces facilitated the tasks of the Israeli armored and infantry units in the Sinai by pummeling the Arab ground units. If these two systems slugged it out toe-to-toe in the skies above the Sinai we are to further infer that the nimble Israeli fighter-bomber wrought havoc upon the Arab ground forces because it was independent from its own encumbering system and therefore free from this greater war of aerial attrition. Using the word "autonomy" as an explanation for the effectiveness of the Israeli fighter-bombers appears to fall short.

The 1967 Israeli pilots roaming the sky at will in search of targets could do so because the Arab air forces-- a key component of the integrated Arab air defenses-- had been smashed by the Israeli Air Force on the first day of the war. Surprise was complete, and the Arab defenses were completely shattered in a matter of minutes. Many of the same Israeli fighter bombers roaming the skies above the Sinai had been the same ones over the Arab airfields on that opening strike. After that day, nothing short of a nuclear detonation in the sky could have stopped the Israelis from loitering above the battlefield and commencing their long, diving bomb runs once a target had been located. Most of the Arab anti-aircraft artillery pieces positioned in the Sinai could not accurately reach the operating altitudes of the Israeli aircraft in order to effectively harass the pilots. Arab surface-to-air missiles, SA-2's in particular, were not even a factor to consider on the battlefield; they were too far away to stop these Israeli close air support missions.(6)

The Arab air defense network had been torn asunder, allowing the Israeli pilots to choose the time and place of their attacks. Although this appears to have been the main reason for the success of the Israeli fighter-bombers, there were other reasons. It should be kept in mind, for example, that man-made machines like tanks, trucks, vans and radars are relatively easy to spot in flat, open desert from great distances. This is especially true when they are in motion, since much dust is kicked up behind them. Factors such as a neutralized air defense system and open desert warfare, not necessarily a high degree of independence from an inflexible system made the Israeli fighter-bombers so effective. The 1967 conflict was a case of Israeli air superiority, which allowed it to spend most of its time doing what they pleased at medium altitudes often far above the small arms fire, automatic cannon, and other antiaircraft artillery pieces situated with the beleaguered ground forces.

Despite this relative freedom, about three-quarters of the approximately forty-five Israeli aircraft were downed by Arab ground fire. The rest were shot down in air-to-air combat: none were lost to missiles.(7) This should come as no surprise. Anti-aircraft artillery (AAA), consisting of everything from automatic weapons to heavy cannon, has usually out-performed guided missiles in exacting tolls from modern combat aircraft. This was as true in the Sinai as it was over Vietnam. Over 80 percent of the USAF aircraft combat losses in Southeast Asia during the course of the war were due to AAA fire and not guided missiles.(8) Most aircraft, in fact, escaped the wrath of surface-to-air missiles in the sorties flown during the course of the Southeast Asian conflict. Of over 9000 SA-2s fired between 1965 and 1972, only about 1.5% of the missiles actually brought down aircraft.(9) To use a more specific example during the 1972 Linebacker II operations, the so-called "Eleven-Day War" in which US aircraft mounted a devastating precision air bombardment of Hanoi and Haiphong in December, over one-thousand SA-2s were fired. This cost the US Air Force fifteen B-52 bombers and no fighters.(10) How much damage, then, is "enough" to make a weapon "successful?"

For the traditional measure of achievement in the form of body counts, one only need to review the employment of the rifle in the American Civil War or artillery and machine guns in the First World War. The tremendous loss of life caused by the rifle in the Civil War eventually led to the abandonment of tactics originally conceived around the inaccurate smoothbore musket. Fifty years later, the machine gun mowed attacking infantrymen down by the thousands and brought trench warfare to World War I, while artillery accounted for about sixty percent of that conflict's casualties.(11) These weapons were frightfully effective killing machines. The thousands upon thousands of dead were silent, yet powerful testimony to this fact. In 1862, over 24,000 men fell at Antietam in one day. Well over one million fell during the agonizingly long Battle of the Somme during the latter half of 1916.(12)

As long as opposing commanders had not adjusted their way of thinking to the threat posed by advances in destructive technology, these weapons would continue to wreak havoc with men-at-arms. Until changes occurred in tactical doctrine, the particular weapon in question would dominate the field. For many reasons, large military organizations are very resistant and thus notoriously slow in radically changing their doctrines to accommodate new weapons. To be sure, the fact that the aforementioned weapons were the direct cause of so many casualties greatly magnifies their impact on warfare. However, this also serves to obscure the major doctrinal changes that other less destructive weapons or technologies may have caused, simply because these other weapons failed to sweep the battlefields clean of human lives.(13) In light of this, one indication of a weapon's impact in warfare might simply be whether or not it induces a significant change in the combat doctrine of the opposition.

The Soviet-built SA-2 is an example of such a weapon that produced a major doctrinal change. The SA-2, shown previously to play a key role among the response elements of the North Vietnamese integrated air defense system, also wreaked havoc with the Pacific Air Force's aerial combat system in a number of ways. The initial response to the SA-2 was desperate and short-sighted. As was noted in the previous chapter, it was also severely hampered by a lack of tactical flexibility. This reaction came on 27 July, 1965. Fifty-four F-105s flew a poorly-planned mission against the suspected location of the SA-2 sites (known as SAM sites 6 and 7) that had fired on Leopard flight.

This mission came directly as a result of orders from the White House under the code name "Spring High." (14) Although the sites were demolished, aerial reconnaissance photographs taken after the strike showed that both sites were fakes. The real equipment had been pulled out by the North Vietnamese and fake SA-2 equipment set up, along with multitudes of anti-aircraft guns in anticipation of the American strike. This was a "flak trap" which had used the dummy SA-2 sites as bait. Making matters worse was that the attacking aircraft were directed by higher Air Force authorities to follow each other using the same low-level ingress routes to their target. This all but negated any element of surprise and practically handed the strike formation's trailing aircraft on a silver platter to the North Vietnamese gunners.(15)

"The mission was just stupid," recalled Charles Horner, who was a captain and F-105 pilot at the time. "(It was) like a North Vietnamese firepower display. We were flying right into a barrage of anti-aircraft fire."(16) The flak was so intense that the last flight of four F-105s dropped down to fifty feet off the ground at almost the speed of sound in an attempt to fly under the shell bursts. "I've never seen a sky like that," observed Captain Marty Case in that last flight, "and I never want to see another one." Six F-105 aircraft and one RF-101 "Voodoo reconnaissance aircraft were shot down, and only one of the pilots was rescued. (17)

All those aircraft were lost for an imaginary SA-2 site. It was clear that better plans for attacking the sites had to be devised, not to mention finding the real ones in the first place. Regardless of the faults of the approach used in that first retaliatory strike, it was clear that the mobility of the SA-2 was an important planning consideration. Once an SA-2 site had been located, it was important to attack it as quickly as possible, lest the missile battalion pack up its gear and drive away elsewhere.

Special flights were created to go after SA-2 sites, but the methods employed to hit the sites were quite unwieldy. It wasn't until 3 August, 1965 that the Pacific Air Forces received permission to send out photo-reconnaissance flights at low altitude over North Vietnam to take pictures of suspected SA-2 locations. "Suspected" because, electronic intercepts of the Fan Song radars alone were not deemed accurate enough to launch a strike in that location. A site discovered by interceptions of Fan Song radar transmissions, like intercepts made from an EB-66C, had to be further confirmed through photographs. This was a lengthy process, because reconnaissance aircraft had to first obtain the necessary target information by launching and then performing the mission. Once the pilot landed, his photographs had to be developed and interpreted by intelligence experts. Only after this process was finished were evaluations sent "up the line." Once in possession of positive identification, Second Air Division or Headquarters, Pacific Air Forces could order a strike. For example, on the 9th of August, the first strike was made on an SA-2 site (SAM site #9) through these methods, a full 25 hours after the initial ELINT reports. (18) There had been more than enough time for the SA-2 battalion to move away by the time strike aircraft showed up to bomb it. Remaining behind were anti-aircraft guns, which according to post-mission reports put up "intense ground fire."(19)

In August, both the Air Force and Navy established what were known as "Iron Hand" missions. These were missions planned specifically to attack SA-2 sites, and they soon became a significant portion of Rolling Thunder sorties (20) On 12 August, the Navy lost an A-4E to an SA-2 missile. On that day and the next, numerous Navy aircraft were launched on Iron Hand missions in an effort to find and destroy any SA-2 sites in the area of the downed aircraft. They found no sites and lost five aircraft for their efforts. In the case of the Air Force, Iron Hand fell to the Thuds.

Initially, Iron Hand F-105s were directed to wait on the ground in an alert status until an SA-2 site was detected by some source. Upon notification of an active SA-2 site, the Thuds would take off and try to find it. Lacking any electronic gear and hampered by excellent North Vietnamese camouflage techniques for hiding the missile sites, the F-105s were not very successful. This particular technique of ground alert was abandoned after only a week, because the Air force planners in Hawaii preferred to see the ground alert sorties in the air on a strike mission rather than idle. Ground alert sorties for Iron Hand on 12, 14 and 15 August, for example, were never launched.(21) To avoid losing sorties on paper, these ground alert sorties were flown as armed reconnaissance sorties, searching for North Vietnamese targets along suspected lines of communication, like roads. The efforts to seek out and destroy SA-2 sites became a part of daily Rolling Thunder operations.

One example of an effort organized to flush out these North Vietnamese SA-2 predators was operation "Left Hook." The plan behind this was to launch an unmanned target drone aircraft high over the air defenses to provoke the latter into directing a missile launch. Waiting near the drone -- but safe from the NV defenses -- would be electronic reconnaissance aircraft. These aircraft, upon detecting Fan Song emissions, would relay the relative bearings to an airborne command post. From these bearings the command post would plot the sites' location and direct strike aircraft into the area. Additional aircraft would be on patrol in the vicinity of suspected SAM sites, waiting for the launch of the Guidelines to give away the site's location. Left Hook I took place on 21 August, 1965, but no missile radars were turned on by the North Vietnamese. Ten days later, Left Hook II flushed out a Fan Song but the strike aircraft were unable to spot the SA-2 battalion. An F-105 was lost to AAA on an attack on an alternate target. (22)

Thereafter, the Thuds flew armed reconnaissance over North Vietnam in search of active SA-2 battalions. Certain geographical areas in North Vietnam were cleared by President Johnson and his advisors for strikes against these missile sites no matter how they were located. Sites found outside these cleared areas still had to be seen on reconnaissance photos before a strike could be authorized.(23) Although clearing out strike zones for the purpose of hunting SA-2 battalions decreased the time lag between initial site location and the launch of strike aircraft, the problem of pinpointing the sites had yet to be solved. Air Force aircraft continued to be traded for attack opportunities on suspected sites. For example, on 16 September, six F-105's attempted to seek out and strike three suspected missile sites, only to be met with fierce anti-aircraft fire from waiting guns. One F-105 was lost before it reached a suspected site, and another went down somewhere near that same site, but the SA-2 itself was never located. The remaining four aircraft found an unoccupied site and bombed it.(24) Fourteen days later another F-105 went down, this one victim to a Guideline. The pilot, a squadron commander, had been warned of SA-2 activity, but was occupied in directing his squadron's attack and could not see the rising

SA-2 due to clouds. Eight prepared SA-2 sites, some not yet occupied by SA-2 battalions, were found and destroyed between July and November by Iron Hand Missions, but the cost to the Air Force in downed aircraft was unacceptable.(25) The North Vietnamese seemed to be building sites faster than the attacking aircraft could destroy them, shuttling their battalions around from site to site in a deadly shell game.

On 31 October, 1965 the USAF borrowed the services of a Navy "Hunter-Killer" A-4E, an aircraft which could detect and pinpoint the SA-2s radar emissions. The Navy was far better prepared than the tactical Air Force in regards to the SA-2. Their "Project Shoehorn" literally crammed RHAW gear and other appropriate electronic equipment into any available nook and cranny in certain attack aircraft, like the A-4E Skyhawk. One of these jets, from the aircraft carrier USS Oriskany, landed at Takhli Air Base on 30 October so that the Navy pilot could discuss the upcoming mission with the F-105 strike pilots. This mission was a Navy strike on a highway Northwest of Hanoi, with the F-105's assigned Iron Hand duties in support of the operation. (26)

Eight F-105's accompanied the A-4 on this mission, and the Navy pilot quickly located two active SA-2 sites. In the wild attack that followed, six Guidelines were fired, two radar sites were confirmed destroyed, and the A-4 was lost. It had dropped it's bombs on an SA-2 site from an altitude of fifty feet and was caught in a barrage of ground fire as the pilot desperately climbed to a safe altitude. Since the A-4E was a rare and valuable Navy asset, the Navy husbanded the rest for their own air strike operations.(27) A promising prospect of inter-service cooperation thus went down with the Navy fighter. Still, this mission was an indication of what was to be brought to bear against the North Vietnamese air defense system.

Weapons, too, had to be developed to counter the SA-2 sites. During this time period in late 1965, air crews were instructed to use weapons designed to cover a large area when detonated. Their advantage lay in the ability to devastate a wide area and increase the chances of hitting an SA-2 battalion even if the pilot had problems pinpointing the hidden, dispersed site. The weapons initially chosen were napalm and cluster bombs, both deadly weapons against "soft" targets such as exposed personnel and unarmored vehicles. Both types of ordnance necessitated level, low-altitude deliveries -- rather than dive-bombing from a higher altitude -- which left the aircraft exposed to ground fire for long periods of time.(28) Iron Hand missions were dangerous propositions for the air crews involved, but there were other means for countering the missile systems.

The only Air Force aircraft capable of taking on the SA-2 in the electromagnetic spectrum were the relatively few available EB-66's. At the time of the loss of Leopard 02, there were a total of nine EB-66C's available for operations in this theater.(29) This aircraft became the workhorse of the electronic warfare campaign against the North Vietnamese air defenses despite being plagued by electronic equipment maintenance problems and high operating costs. (30) Fighter pilots, according to the 355th unit historian, were "high in their praise of the EB-66C's and their crews for the protection they provided," even dubbing the EB-66C unit "The Second Best Fighter Squadron in Southeast Asia."(31)

The success of the SA-2 forced a change in EB-66 operating procedures. The EB-66 jamming could no longer significantly degrade major portions of the North Vietnamese air defenses because the aircraft were thrust into a role of directly defeating the SA-2 battalions. EB-66 jamming targets became the radars which most immediately threatened the attackers -- SA-2 radars and AAA fire control radars. Receiving less emphasis than before were the other warning radars of the North Vietnamese air defense network, which meant that much of the information that the EB-66's were trying to deny the SA-2's through jamming was being supplied by other, non-jammed radars in the defense system. The high degree of North Vietnamese integration prevented the American countermeasures from being effective. This unhappy fact, added to the predictable routes and timing of the Rolling Thunder attacks made tough going for the strike forces. (32) In 1965 the USAF fought an air war of desperation, a condition brought on largely by the introduction of SA-2 battalions.

The first and most obvious impact of the SA-2 was that it forced the USAF aircraft into flying back down into the very low altitude regime -- often only a few hundred feet in the air-- to avoid the missiles. These tactics served two purposes. First, the low altitude approach greatly decreased the range at which the attackers could be detected by radar, thus cutting down the North Vietnamese reaction time. Second, and most important, the SA-2 performed very poorly at these low altitudes so this tactic practically negated the SAM threat. Unfortunately the low-altitude approach brought the pilots into the lethal range of a myriad of anti-aircraft guns.

This was also far from an optimum bombing situation. Flying at high speeds while at low altitude increased the pilot's chance of survival, but it was quite a difficult task to find his target from this viewpoint. Prominent terrain features like mountains, hills and trees served to block a pilot's view from the aircraft to the target. To compensate, pilots performed a "pop-up" maneuver prior to the target area at some specific time or place after passing the "initial point."

The last navigation timing point on a bombing mission is called the initial point, or IP. The IP was usually some significant or recognizable landmark, and from this point the aircraft would be flown at a constant heading -- provided the pilot wasn't busy dodging flak --until the target was attacked by releasing the weapons. Long before the IP the aircraft had descended to an extremely low altitude, perhaps only a few hundred feet above the ground. Shortly after passing the IP, at a pre-determined location called the "pop-up" point, the pilot climbed to an optimum attack altitude.(33)

This maneuver caused the aircraft to climb rapidly to at least a few thousand feet in altitude (sometimes higher) which gave the pilot greater visibility needed to find his target. Once the target was found, the pilot would immediately dive upon it and release his weapons. Unfortunately, it was not easy to find a target in such a short time period, and the rapid climb served also to reduce the aircraft's speed, thereby making it more vulnerable to AAA fire. Bombing accuracy was significantly affected, also. According to one F-105 wing commander's end-of-tour report, "numerous targets have not been hit because the strike force could not go to the target at the desired altitude and (aircrews) were forced to use 'pop-up' tactics which allow only a few seconds to acquire the target and (this) decreases bombing accuracy."(34) Not only were the strike aircraft forced to fly at lower altitudes, the support aircraft were driven farther away.

The increased number of SA-2 sites also drove the slow, less maneuverable EB-66 electronic warfare support aircraft farther from the aerial battlefield to escape the missile threat. The farther away the EB-66s were, the less effective their jamming was on SA-2 radars or any other North Vietnamese radars. Although the jamming efforts of these aircraft only marginally degraded the SA-2s radar at best -- the effect of an EB-66C's jamming was reportedly overcome by relatively simple and easily acquired radar operator techniques -- it was at least better than no help at all.(35) Even a few seconds' worth of confusion among the operators in the SA-2s fire control battery could mean the difference between a missile hit or miss. Therefore, the once closely-integrated support elements for American air strikes were stretched out and the overall system weakened. This made the individual aircraft elements more vulnerable.

If fighter-bombers, like the F-105 "Thud," pressed home their attack from higher altitude such as 15,000 feet to avoid the AAA, they still ran the risk of encountering the SA-2s. In these cases a medium altitude was chosen for F-105 operations. The SA-2 was slower and less maneuverable at these altitudes and flight above 10,000 feet was beyond the reach of most AAA pieces. For most of the F-105's, the recommended altitude for air strikes against fixed targets was usually between 12,000 and15,000 feet. This altitude range would vary depending upon the heights of the cloud layers. Air crews preferred to fly at least 7000 feet above the undercast, which allowed at least some opportunity to see and react to an SA-2 coming up through the clouds. Lacking any protective electronic gear, the only hope for a Thud pilot who faced a climbing SA-2 was to perform a drastic maneuver. Often this involved heading straight for the missile, and waiting until the last possible instant to pull down (or up) into a new direction perpendicular to the missile's flight path. (36)

These evasive maneuvers often generated forces of at least four times that of gravity, or 4"G's" to be thrust upon aircraft and crew. This force and the resultant stress on the airframe was complicated by the weight of additional ordnance of the aircraft's wings and fuselage. Fighters could out-maneuver the missiles faster and in a much safer fashion if they weren't laden with their heavy bomb load. Also, such a maneuver with full ordnance loads caused losses in speed and maneuverability after the it was completed. By dumping ordnance, a fighter would significantly reduce its drag and weight and be better able to maintain its precious speed throughout the evasive maneuver. According to a post-war report, "the USAF aircrews (regularly) avoided oncoming SAMs by jettisoning ordinance immediately and using a high 'G' turning maneuver to make the missile overshoot." (37)

The SA-2, despite its radar guidance and maneuverability, was not physically capable of making drastic changes of direction to compensate for significant evasive maneuvers made by its intended target. There was about a 5-second delay between the time the Fan Song's computer recognized a need to alter the missile's course and when the missile actually responded to the new guidance command.(38) This missile, it will be recalled, was designed to down large bombers, like the B-52. The unsuspecting, non-maneuvering F-4C's of Leopard flight made relatively easy prey for the first of those three SAMs. The subsequent violent turns of the remaining Phantoms were too great for the other SA-2s to follow so these missiles missed their targets.

In fact, the SA-2s became known for their lack of maneuverability against the agile fighter aircraft, but this knowledge came out of combat experience. Former F-105 pilot Jack Broughton wrote in that "If you can see Sam (sic), you can usually escape. It has little, stubby wings and it is going like hell, so it can't turn very well. You can take it on just like another aircraft and if you force it into a commit position and out-turn it, it will stall out and auger in. If its radar guidance can't stick with you, it will just explode in the empty sky..."(39) However, If one couldn't see the SAM because of intervening cloud layers or simply by not looking in the right direction, then one had a problem.

Broughton relayed one episode that occurred while looking for his target on a bombing mission. "(We) came spitting out of the clouds," he recalled, "and we met three Sams in formation coming up. I never saw them until the first two roared between John (Broughton's wingman) and myself...between our wingtips. The first sensation was the most god-awful noise I have ever heard. It ripped me way down in the bottom of my stomach someplace, like an old steam engine bursting out of a tunnel. The white hot light of two rocket engines, passing vertically only feet away, was bizarre and momentarily tumbled my emotional and physical gyros." (40) The two pilots were lucky that the SAMs failed to detonate. Evasive maneuvers helped to minimize the need for luck.

Although these violent maneuvers made the aircraft safe from the missile attack, at this point pilots often found themselves down at a much lower altitude, back into the teeth of the anti-aircraft artillery. This was not a very positive experience for those flying the harassed aircraft. Moreover, the aircraft usually had no bombs left to drop, either, so there was no point in continuing their mission. Whether or not the aircraft made it back safely was not a concern to the SA-2 battalion, for they achieved their original goal of preventing an aerial attack upon the target that they were defending. The Thuds would return another day, but today the SA-2 and the air defenses could claim victory.

These maneuvers also tended to disrupt the integrity of a particular flight by scattering it across a large volume of airspace. Most American aviators had long since discarded the "lone wolf" approach to air combat and based their tactics on mutual support. (41) Key to this concept was situational awareness, part of which entailed knowing where your own flight was at all times. Scattering a flight of aircraft in response to a SA-2 launch only added to the confusion inherently present in combat, and made temporarily isolated aircraft vulnerable to waiting North Vietnamese fighters. Even if not forced to perform a violent maneuver, the appearance of a SA-2 battery somewhere in the countryside ahead would force a change in the planned route of attacking aircraft. (42) In common jargon that meant not flying a mission "as briefed."

As previously argued, the missions were planned for aircraft to adhere to specific routes, altitude and airspeeds. This allowed for timely coordination and support from a variety of aircraft operating from different air bases. Changing one's plans in such a highly dynamic environment -- aircraft cannot "stop" to allow for careful contemplation -- greatly adds to the already daunting tasks facing the aviator in combat. Flying as briefed was especially critical regarding the low-level tactics which the SA-2 forced on tactical combat aircraft in 1965.

Since chances were good that the pilots wouldn't even see his target until about the time he popped up, it was crucial to at least anticipate where one should look. Changing tactics and approaches after take-off greatly complicated the problem of finding the target. All the key visual reference points would either be approached from a different direction or be completely different points altogether. The margin for error, already low, greatly decreased in an environment where aircraft flew a mile every eight or nine seconds. A few seconds' worth of confusion was all it took for a target to be missed entirely.

Another effect of the SA-2 was that it either diverted a large number of aircraft and resources into specific support roles in SAM suppression or diverted many air strikes from SA-2 defended areas. More aircraft were lost to AAA fire while attacking SA-2 sites than were downed by the SA-2's themselves.(43) Without the SA-2 around, many of these aircraft could otherwise have been used to strike other targets. For example, during each two-week "period" of authorized Rolling Thunder strikes, the Navy and Air Force would be authorized about 600 sorties -- one mission by one aircraft -- each for "armed reconnaissance" in addition to their specific list of Presidentially-approved targets. Armed reconnaissance sorties flew along suspected lines of communication, such as roads, in search of truck convoys or other targets of opportunity. From 29 October to 11 November approximately twenty-percent of these "armed recce" sorties were originally planned to be Iron Hand sorties. Also, one of the six specifically authorized targets was a support facility for surface-to-air missiles.(44)

All told, over 200 Iron Hand strikes were flown between August and December of 1965,(45) but the number originally planned to be Iron Hand far exceeded that number. Poor weather over North Vietnam, for example, cancelled many sorties during the winter months and if there were no known SA-2 battalions operating or possible sites discovered then those Iron Hand sorties would instead be flown as armed reconnaissance. Headquarters, Pacific Air Forces noted at the time that a large number of armed reconnaissance missions were devoted instead to Iron Hand duties throughout the fall (46) Research analyst Mike Fossier called this diversion of aircraft to other roles as "virtual attrition."(47)

Virtual attrition could take out an entire strike force. As shown earlier, the downing of just one aircraft by an SA-2 could call a halt to the air strike in progress and all efforts would be made instead to locate and rescue the downed air crew.(48) Not only would a large number of aircraft be stopped from striking a target, but the rescue operation was dangerous for the aircraft involved. In November, after an F-105 was shot down by an SA-2, two helicopters and two close air support aircraft were shot down in attempts to rescue the pilot. That the air above North Vietnam was often denied to the Americans was not in doubt, but this was not the most important result of the SA-2 launches.

Probably the most significant impact of the SA-2 was that it changed the way the Air Force fought tactical operations. Electronic combat was exhumed from the tactical graveyard and given new life as a prominent player in tactical combat planning.(49) Air Force tactical planners learned not to ignore the threat of surface-to-air missiles and other developments of air defense systems. Tactical Air Command, once practically devoid of anybody familiar with electronic warfare, now made a concerted effort to develop and test new technology for the electronic warfare arena. This was partially shown in the last chapter by the actions of Dempster's task force. The remainder of this study is concerned with some of these developments in tactical electronic warfare.

Therefore, the SAM did not have to destroy many aircraft -- 194 known missiles fired in 1965, for example. resulted in eleven downed US aircraft -- to make its mark on air combat. The SA-2 greatly contributed to the overall North Vietnamese air defense system, and that same system made the SA-2 a highly lethal threat to US aircraft. This happened despite an apparent lack of autonomy in a system that showed a relatively high degree of integration. The SA-2 was seen to be formidable threat by the aviators who faced it. "While actual kills by SAMs were not excessive," cautioned an Pacific Air Forces report, "the effectiveness of the SAM transcended this criterion because the threat was real enough to trigger other side effects."(50)

The SA-2, in fact, dominated Vietnam's aerial arena in late 1965. The above evidence suggests that the SA-2 would have been far less effective had it not been highly integrated into the air defense system. This episode provides some insight into the immediate, often desperate changes induced in one system by the weapon of another. The days of the SA-2's dominance became numbered when a new technology appeared in Southeast Asia, the Wild Weasel.

Chapter Seven

Adaptation: The Wild Weasel I Program

Eglin Phase

The story of technological change within a military system is usually told from the "top-down" and thus the predominant viewpoint is that of the decision-makers. Missing from these stories is an complete explanation as to how and why a technology changes once it is introduced into the system. Detailed examinations of technological change that considered the operators' perspectives -- "bottom up" approaches -- can fill in many of these missing pieces. For example, a previous chapter discussed the problems of cracking bomb fins and the need for new bomb design. Operators were not mentioned (except to illustrate the detrimental effects of the inadequate bombs) and the decisions to implement the changes were implicitly assumed to come from higher headquarters such as PACAF. The story about the technological response to the SA-2 was seen from the perspective of Dempster's task force but that had little impact on how the airmen dealt with the threat until the new technology arrived. The air combat system had already begun to change on its own before the new technology was even built. If the story of the Wild Weasel I program was told only from the perspective of the high-level decision-makers then it, too, would paint an incomplete picture.

Shortly after Dempster's recommendations were made known, Headquarters, US Air Force directed that four F-100F's be modified with off-the-shelf radar warning and homing (RHAW) gear built by Applied Technology, Incorporated. The Wild Weasel I program received its modified aircraft in October. Volunteer crews were quickly trained and were sent to Southeast Asia at the end of November. The Wild Weasel I "test period" lasted 60 days, from 28 November, 1965 until 26 January, 1966. In those sixty days, 135 sorties were scheduled for the four Wild Weasel aircraft, of which 112 were flown.(1) In these sorties SA-2 homing tactics were refined under combat conditions. Although the

Weasels located only a few SA-2 sites, on 22 December one Wild Weasel aircraft managed to mark a site for escorting F-105 aircraft which subsequently destroyed it. The program was seen as successful, and in January Dempster ordered the Weasel aircraft to be changed to the F-105. This version, called Wild Weasel III, appeared by the spring of 1966.

Unfortunately, this brief account leaves out specific answers to an important question: who held the power to implement major changes in tactics, training and technological design? This account, like many studies of military technological change, implicitly assumes that the system's major decision-makers, like PACAF or Dempster's task force, held that power. Likewise the operators are assumed to have successfully figured out how to use the new technology in battle because the test program produced a tangible result -- the destruction of an SA-2 site. However, a bottom-up look at the Wild Weasel I test program will show the inadequacies of these assumptions.

The idea of using specially-equipped aircraft to seek out radar sites did not originate with Dempster's commission. In 1944, the Royal Air Force equipped some Typhoon fighter-bombers, under a program called "Abdullah," with radar detection gear to find German radars. These typhoons were accompanied with other typhoons who would attack the site once the Abdullah aircraft marked it with smoke. The program, however, was not very successful.(2) In the US Army Air Forces, specially configured bombers like the B-17, B-24 and B-29, all called "Ferret" aircraft, monitored German and Japanese radars and gave approximate locations through triangulation of the intercepted signals. Other aircraft were later sent out to bomb the sites.(3)

In the Pacific especially, some B-25 Mitchell bombers were converted into "radar-busters." Radar detection equipment was installed into these aircraft. This technology, combined with the B-25's already lethal nose armament and internally carried bombs, made them deadly threats to Japanese radar operators. These aircraft attacked and destroyed approximately fifty Japanese radar sites.(4) During the subsequent conflict in Korea, a similar Air Force effort was undertaken to seek out and destroy North Korean ground control intercept radars. Only a few specially modified aircraft were produced, and as historian Daniel Kuehl has shown, the program was not very successful.(5) In each of these cases the idea of "radar-busters" appeared to have died with the end of hostilities. A renewal of conflict led to the resurfacing of these methods and the earlier pattern was repeated for Southeast Asia when the representative from North American outlined the Wild Weasel on the back of an envelope. A radar homing effort again began from scratch.

As in previous programs, the aircraft chosen to pursue the Wild Weasel mission already existed in the active Air Force inventory. A two-seat aircraft was necessary to accommodate both a pilot and electronic warfare officer, or EWO. Obviously the pilot was needed to fly the aircraft but the aviator in the back was needed to operate and interpret the displays of the radar detection equipment. The aircraft chosen was a two-seat version of the North American F-100 Super-Sabre.

The F-100, the first of the "Century-Series" aircraft, was a fighter design that emerged out of the Air Force's lessons from the Korean War. The cry for better aircraft performance was answered by the single-seat F-100, the first aircraft to achieve supersonic speed in level flight. The "Hun", as it was called, was harder for the pilot to control at lower speeds than it was flying faster, so a two-seat trainer version, designated the "F" model, was built. This allowed experienced instructors to pair up with less experienced pilots in the same F-100F. The two-seat version was longer, heavier and slower than the single-seat version. It was not originally intended to fly in combat. The commander of the Wild Weasel I program, a veteran of many hours in the F-100, summed up his feelings on the matter by saying "I sure as hell never thought I'd be going into combat in a 'Hun' two-holer!" (6) Much less probable was the thought of this aircraft sporting radar detection equipment and a non-pilot occupant in the rear cockpit.

This technology included off-the-shelf equipment from a small-sized defense contractor called Applied Technologies, Incorporated (ATI) based in Palo Alto, California. The Vector Homing and Warning System, the WR-300 Receiver, and the IR-133

Panoramic Scan Receiver were the names given to the newly installed gear.(7) This radar homing and warning equipment also necessitated the installation of multiple small receiving antennas onto the nose, fuselage, wingtips and tail of the aircraft. Each piece of equipment had a specific function.(8)

The Vector was a 3-inch diameter circular cathode ray tube (CRT) that was installed in both the front and rear cockpit.(9) Radar energy received in the its antennas would be processed and be made to cause a strobe to shoot out from the Vector scope's center toward its edge. The size of the strobe varied directly with the strength of the received signal. A radar that was tracking the aircraft would produce a much bigger strobe than a radar that was not. Additionally, the strobe itself varied in its appearance depending upon the type of threat detected, because the logic circuitry of the Vector was designed to distinguish between various types of radar types. (10) By interpreting the scope the EWO could discern an approximate bearing of the site's position relative to the jet.(11) Below the screen was a panel of lights which indicated to him whether the signal was from an SA-2 site, a anti-aircraft artillery fire control radar, or some other kind of radar. Many radars transmitting simultaneously could pose problems for the EWO, because it was quite a difficult task to continuously match multiple strobes with their associated radars.(12)

The WR-300, unlike the Vector, did not detect a wide array of signals but instead focused solely on the SA-2's missile command guidance signal. The WR-300's designers at Applied Technology were led to believe by an Air Force intelligence report that the SA-2's radio guidance signal suddenly became much stronger when a missile launch was imminent so they built their device to detect a three-decibel shift in signal power within one second. As it turned out, the guidance signal did change its characteristics prior to a launch but not due to a power increase. Nevertheless, the signal change triggered the WR-300 anyway, for the wrong theoretical reasons.(13) The WR-300 had three lights colored green, amber and red. If the green light was illuminated, then a Fan Song Radar had been detected.

Amber meant that a missile launch was imminent. If it detected a launch, the WR-300 illuminated a bright red "launch" light.(14)

The most sensitive and also most complicated piece of equipment to master was the IR-133. It was a panoramic receiver, which meant not only that it received signals though a wide band of frequencies, but it also could be tuned to a specific radar frequency and allow individual radar signals to be analyzed. This was of tremendous value when many radar signals had to be distinguished from one another. It was assessed to be superior to other available radar detection equipment, even those on EB-66C's.(15) The IR-133 was sensitive enough to pick up radars at greater distances than the Vector, and one of its operating modes allowed for very accurate radar homing.(16)

Some Wild Weasel test personnel initially thought it was possible to determine the range to a particular radar based on the indications of the IR-133 and Vector. (17) By using the IR-133 to point the aircraft directly at the radar and rolling the F-100F into ninety degrees of bank -- one wing pointed straight down to the ground and the other straight up -- the Weasel crew, through a quick trigonometric calculation attempted to determine the range. For example, if the aircraft was flying at one-thousand feet over perfectly flat terrain, a bearing indication of one degree to the left meant, in theory, that the radar site was ten miles away. However, at one-half a degree the site would be at a range of twenty miles, and at one-quarter degree the range turned out to be forty miles.(18) The test personnel gave up on the idea, since flying at ninety degrees of bank at extremely low altitudes was dangerous, and at higher altitudes combat conditions would not allow for the delicate maneuvering required for precise distance calculations.

The range to the site was a very important piece of information for the tactical puzzle, and later modifications would address the problem. Wild Weasel I crews, however, would not have the technology capable of providing that information. Range calculations would have to be made based on operator judgment. In combat, range could only be determined if the Weasel crew actually saw a missile launch from a camouflaged site, but

Weasels maintained a sense of humor in light of their grim missions. When Secretary of the Air Force Harold Brown queried Weasel pilot Captain Al Lamb on how he determined range to SA-2 sites, Lamb replied, "when Jack (Captain Jack Donovan, Lamb's electronic warfare officer) breathes real heavy, we're close. When he stops breathing, we're there."(19)

Regardless of range, the Weasels were quite adept at homing in on radar sites at the Eglin Ranges. Both the Vector and IR-133 could be used for this activity, although each operator tended to use different techniques in using his equipment. For example, the Vector could be used initially to provide the relative bearing of the site to the air crew. The Weasel's electronic warfare officer (EWO), once having determined the bearing of the site, directed the pilot to fly toward that initial bearing. Once the aircraft was pointed roughly at the site, the IR-133 could be used to further refine the direction for a more accurate homing run. Other EWO's used the IR-133 from start to finish. By selecting "Direction Finding Mode" on the IR-133, the electronic warfare officer would see two vertical lines on the IR-133 display. Each line represented the relative strength of the signal being received in the left and right antennas, respectively. A taller line on the left meant that the left side of the aircraft and its corresponding antenna was receiving more radar energy than the right side.(20) This was interpreted by the aircrew to mean that the aircraft was heading toward the right of the site and needed to turn left slightly. The best indications of proper homing were a Vector strobe that pointed straight up to the "twelve o'clock position" and two equal amplitude lines on the IR-133. The trick, however, was to realize just when one actually passed over the radar site, called "station passage."

Station passage is more commonly associated with radio navigation devices. In a typical radio direction-finding device, when tuned to the "station" one wishes to locate, a needle points to the relative bearing of the destination. Assuming the station is straight ahead and that the needle is pointing to the "12-o'clock" position, if the aircraft passes over the station and leaves it directly behind, the needle will point to the "6-o'clock" position.

However, as it flies directly over the station, the needle will often swing back and forth between 12 o'clock and 6 o'clock before finally staying put at the 6 o'clock position. These needle fluctuations indicate station passage.

On the Vector, as the Weasel flew along the radar beam toward the site, the strobe grew in length as the aircraft got closer to the radar and ultimately extended from the center to the edge of the CRT. At station passage, the strobe "curled" at the edge of the CRT, forming a hook. After passing over the radar site, a short strobe appeared at the 6 o'clock position.(21) That a short strobe appeared at 6 o'clock and not a long one had to do with the radiation pattern of most radars used at that time.

A radar transmits most of its energy in the direction that its antenna is pointing. This is commonly called the main radar beam, or "lobe," but there are also other beams called "side lobes" and "back lobes." In other words, a radar that is transmitting toward the east with its main beam is usually transmitting to the north, west, and south with weaker beams as well. The IR-133 was sensitive enough to pick up these weaker side and back lobes at relatively long distances. Homing in on these lobes rather than the main lobe offered the prospect of safety and surprise because the Weasel could not be tracked by the SA-2 radar operators. Therefore, as soon as its Fan Song radar was turned on, an SA-2 battalion might attract a Wild Weasel from any direction, no matter where its radar was pointed. (22)

The case in which back lobes, side lobes and main lobes of different radars could be sorted out by a Wild Weasel crew depended upon the radar signal knowledge of the operator in the back seat and how well he knew his equipment. In very dense signal environments -- occasions when many different radars are simultaneously received -- the Vector could have problems in discerning SA-2 radar from fire control radar and even friend from foe.(23) If the Vector displayed several signals simultaneously at various azimuths, the operator would often have to tune the IR-133 to specific signals, checking to see if the IR-133 indicated a particular signal left or right of the airplane. He would have to further correlate the noises pulsating through his headsets with similar visual indications on the displays in front of him. Adding to this were a number of distractions such as communicating with the pilot, busy radio traffic and the WR-300 flashing in his face, not to mention taking time out to see what was outside the cockpit. It took a large measure of skill not only to overcome for the equipment deficiencies but also to maintain the required level of concentration.

The Wild Weasel pilots and electronic warfare officers were highly experienced in their respective specialties. A total of eight F-100 instructor pilots and five B-52 electronic warfare officers became part of the Wild Weasel I program. Five of the eight pilots had previous combat experience, but none of the EWO's had seen any combat time, let alone any time in an F-100. None of the aviators, however, had less than 1000 total flying hours, and the average flight time for all the fliers was well over 2000 hours.(24) Although Tactical Air Command produced the pilots, the message had to reach Strategic Air Command before prospective electronic warfare officers could be tapped.

Messages had been sent out by US Air Force Headquarters to both Tactical Air Command (TAC) and Strategic Air Command (SAC) as soon as Wild Weasel I began to take shape.(25) Few had any idea what exactly it was they were volunteering for, since the nature of the Wild Weasel program was closely held. The mission was only described as an "F-100 Command Post" and as being highly classified in nature. "Fortunately," said a subsequent Air Force study on the Wild Weasel program, "the US Air Force has never been short of highly skilled volunteers in search of a new challenge."(26) This is an antiseptic and rather inaccurate way of describing the volunteer process for one of the most dangerous missions ever envisioned for combat aircraft. The truth was, at least as far as the SAC electronic warfare officers were concerned, the Air Force did much of the "volunteering." Former B-52 electronic warfare officer Captain Jack Donovan was surprised with his orders sending him to Eglin Air Force Base, Florida for temporary duty in an "F-100 Command Post." He and his fellow SAC aircrew members were hand-picked by higher headquarters for the Wild Weasel I test program.(27)

The "volunteer" aviators arrived in Florida at different times, but were all in place by early October. Donovan and another electronic warfare officer, Captain Walt Lifsey, were the first to arrive at Eglin AFB for Wild Weasel I in late September. They were immediately flown to Los Angeles, California, and then driven to some dilapidated, but well-guarded, hangars at Long Beach airport. According to Donovan, inside one of these buildings was an F-100F "with all its guts hanging out."(28) In other words, engineers from North American had already begun the process of modifying the aircraft for its mission. The next day the airmen were driven to Palo Alto, California and met with a representative from Demptser's task force and engineers from Applied Technology Incorporated (ATI). The design engineers of North American and ATI eagerly accepted inputs from the Air Force captains. Donovan and Lifsey determined how ATI's equipment was arranged inside the rear cockpit as well as gave suggestions for its operation. "We'd tell them we'd want a knob to do this and a switch to do that," said Donovan.(29) In this fashion the procured equipment was initially adapted to the tactical combat system.

The process of adaptation in this program involved more than learning the operation of new knobs, dials and switches. While the some of the pilots were learning for the first time that the position of electronic warfare officer actually existed in their own air force, some electronic warfare officers "were reluctant to bounce all over North Vietnam in a single-engine fighter with a wild-eyed, hot dog pilot at the controls."(30) The early encounters between the two groups were uneasy. "We had never seen a fighter pilot up close before," said a Weasel EWO. "They were trained to be aggressive and obnoxious and they didn't disappoint us." (31)

Fighter pilots from tactical air command, generally speaking, were used to being the sole person in the cockpit of their aircraft. Initially, "we weren't happy about the team concept," recalled Weasel pilot Captain Al Lamb.(32) Having another pilot sit behind them was one thing, but these electronic warfare officers -- initially referred to derisively as "trained bears" -- were another matter entirely. "(Pilots) were proud of the fact that they were perfectly capable of steering themselves from place to place in the world," wrote Jack Broughton " and the thought of having a bomber navigator sitting behind them was completely foreign...I hated listening to someone ' breathe into my ears on the hot mike for hours."(33) Initially, the control stick in the rear cockpit was taken out when the new equipment and its operator arrived, lest he try to fly the aircraft! Objections from the EWO's brought the stick back, but no throttle controls.(34)

Both pilots and EWO's set aside their reservations as each teamed up to form a combat partnership. Pilots and their back-seaters ate together, roomed together, flew together and soon became able to anticipate each other's actions while flying. Still, old habits died hard. Jack Donovan recalled that on his initial training mission with pilot Al Lamb, he identified himself on the intercom with "Pilot this is EWO" before commencing with his request. This was common procedure in B-52's because up to ten airmen used the same intercom system on that airplane. Lamb's reply: "well I hope to God that's you back there" indicated the different style of communication that was required in this situation. Cockpit communications needed to be brief; sometimes a grunt would suffice to convey a message. (35)

Since the back-seat aviators came from B-52's, the view from the rear canopy of the F-100F was probably the first time since navigator training that these electronic warfare officers could actually see where the aircraft was going.(36) Additionally, no relatively slow, lumbering B-52 could hope to match the maneuvering characteristics of a fast, agile F-100. These new, highly maneuverable fighters also brought with them a correspondingly high potential for airsickness in queasy back-seat aircrew members accustomed to less gut-wrenching rides in heavy aircraft! Such physical feelings could severely hinder an airman from performing his duties, but once adjusted to the fighter's characteristics, the electronic warfare officers could then concentrate on their primary task of identifying threat radars with the equipment and working with the pilot to find those radars on the ground.(37)

Project Wild Weasel I was officially underway at the Tactical Air Warfare Center at Eglin Air Force Base (AFB), Florida by 4 Oct 1965, but the official reports give little indication of what role the operators played in conducting training.(38) The detail in which many Wild Weasel I training activities are shown in these reports can easily lead a historian to assume that the airmen simply assumed their position within a pre-established formal test program at Eglin AFB. This was not entirely the case. The tests for the new detection equipment had been established beforehand, but there was hardly any time originally planned for the development of combat tactics.

Although a later chapter will outline the eight specific objectives established by TAC and the Air Force's Tactical Air Warfare Center for Wild Weasel I it is important to note here that only one specifically referred to the development of procedures to locate, attack and neutralize the SA-2 battalions. The air crews would have to develop tactics on their own time once the flying began. There were no classrooms, no periodic intelligence briefings on American and Vietnamese air tactics used over North Vietnam, and no training flights geared toward finding camouflaged, well-protected sites. What little time could be found between training flights to discuss the employment of this aircraft was supplemented by time used in the dorm rooms and at the bar. Discussions ensued wherever possible about subjects such as optimum size of formations, spacing between attacking aircraft, altitudes at which one could expect to acquire targets, suggested attack profiles, and munitions loads. One of the most important issues among these was how the Wild Weasel crew might be best able to provoke an SA-2 battalion into turning on its Fan Song radar. The lack of formal training for combat was corrected in subsequent Wild Weasel training classes.(39)

Flight training took place on the ranges at Eglin in four newly-modified F-100F's. Before the crews set foot in their new aircraft, the Air Force had required that the newly modified Wild Weasel aircraft were ready for them. Once the specialized equipment was installed onto the F-100's, North American had first to test each aircraft at their Long Beach facility and then fly them to Eglin AFB, where they were put through further testing on Eglin's flying ranges. Only after the contractor's flight test were complete were these aircraft to be turned over to the Air Force crews, but the staggered arrival of the selected Wild Weasel pilots led some of the electronic warfare officers to begin their flight orientation with North American Aviation test pilots.(40)

The test flights explored the ability of ATI's equipment to detect and locate simulated Fan Song radar signals. The Air Force possessed Soviet Air Defense Simulators, or SADS, which imitated SA-2 radar signals based on the latest electronic intelligence information. The SADS had its own operators, and for all practical purposes the system acted like a normal radar. It was paired with another radar for the purpose of tracking and recording the test aircrafts' routes of flight to reconstruct missions. (41) The crews would fly about in the Eglin ranges waiting for the SADS signals to be detected on the receivers. Once the latter occurred, the electronic warfare officer in the back would direct the pilot toward the SADS site until either the pilot or back-seater could see the site from the aircraft. (42)

Twenty sorties were flown at various altitudes between 100ft and 10,000 feet to specifically assess the operation of the radar homing and warning capability of the Weasels.(43) All told, approximately three-hundred practice runs were made against the SADS site during the Wild Weasel testing. Four times during the mission the SADS site would transmit its synthetic SA-2 signal, and the EWO would notify the ground radar operators as soon as he picked up the SADS signal. After carefully noting the angle between the aircraft heading and the relative bearing to the SADS signal, the EWO would direct the pilot to the site with the object of overflying and locating the SADS visually. By comparing what the EWO saw on his scopes and what actually was the case, the equipment's accuracy could be determined. At Eglin, 235 runs gave an average 77 foot miss distance for overflights.(44) Similarly, ten sorties at similar altitudes were flown without the benefit of homing. Once the back-seater detected the SADS signal and its relative bearing, the SADS site would shut off its transmitter and the crew would have to find the site with only that initial information. Another concern was the use of on-board jamming pods and their possible effect on the detection equipment. Five sorties were flown where the F-100 carried a jamming pod. Although the resultant jamming interfered with the radar detection equipment, the electronic warfare officer still had to guide the pilot to the SADS site.(45)

An overlooked aspect of this program, but one no less important, was that this stateside phase had to result in some sort of Wild Weasel organization. It was, in fact, a system all to itself that had to be built from the ground up. Air crews had to be selected, certainly, but so did maintenance specialists, intelligence experts and other support personnel.(46) For example, each aircraft had its own pair of crew chiefs, who were responsible for the overall condition of the aircraft. There were also included individual specialists in areas like the repair of flight instruments, navigation equipment, and electronic components. There were two jet engine specialists, weapons specialists, a parachute rigger, and two fuel system specialists. Three representatives from Applied Technology deployed with the team to provide their expertise. All told, about 53 people comprised the Wild Weasel I test team, as seen in Figure XI.(47)

An interesting feature of this team was that it also included a body to evaluate the project at each phase and continually make improvements while establishing some set of standards for the Wild Weasel program.(48) The process by which this was to take place was officially established about a week before the F-100F's departed for Korat Air Base. The key to this evaluation was an accurate reconstruction of the mission. A major input to this process was a debriefing by the pilot and electronic warfare officer after each F-100 mission. Wherever possible, details were not spared. Pilots, for example, were asked about the enemy air defenses that were encountered and what kinds of evasive maneuvers they

Wild Weasel I Test Team Composition

Positions (officer/enlisted)	Positions (enlisted only)
Commander (officer)	Instrument Repairman
Administrative Supervisor (enlisted)	Aircraft Pneudraulic Repairman
2 Administrative Specialists (enlisted)	Inventory Management Supervisor
Air Operations Officer (officer)	Aircraft Ground Equipment Repairman
Operations Analyst (civilian)	2 Electronic Warfare Repairmen
Operations Staff Officer (officer)	2 Jet Engine Mechanics
Air Operations Supervisor (enlisted)	Mechanical Access Repairman
5 Tactical Fighter Pilots (officer)	Aircraft Radio Repairman
5 Electronic Warfare Officers (officer)	2 Flight Control System Mechanics
Aircraft Maintenance Officer (officer)	Weapons Maintenance Supervisor
3 Weapons Mechanics (enlisted)	Parachute Rigger
4 Aircraft Crew Chiefs (enlisted)	Egress System Repairman
4 Aircraft Assistant Crew Chiefs (enlisted)	Aircraft Fuel Systems Mechanic
Airframe Repairman (enlisted)	Personal Equipment Specialist
Parachute Rigger (enlisted)	
Aircraft Electrical Navigational Equipment Repairman (enlisted)	
Flight Control Systems Specialist (enlisted)	
Aircraft Maintenance Superintendent (enlisted)	

FIGURE XI

used. The electronic warfare officers were asked to detail what they saw on their equipment. Both were asked to address a variety of problems and suggest solutions. What was the communication like between the crew? How should the equipment be repositioned or what else needs to be added? This, however, was just one part of a larger process.

Each aircraft carried an airborne tape recorder in the rear cockpit and one carried a seventy millimeter KA-60 camera in the nose.(49) The taped conversations of the crew could clarify further the pilot and electronic warfare officer reports. The camera could help identify overflown SA-2 sites, and, if these sites were attacked, give some indication of damage. Photographs from subsequent reconnaissance flights would provide better bomb damage assessment in these instances. Information from other sources, such as intelligence and electronic reconnaissance aircraft was gathered. When all this was combined, a more complete picture of the mission emerged. Having painstakingly reconstructed the mission, there now came the task of evaluating the mission. What went wrong? What went right?(50) By late November, their training had been completed and the four Wild Weasel crews flew their F-100F's to Korat AB in Thailand.

The process through which this took place however, was not as simple as it otherwise might appear. Each F-100 carried only two aviators. That left over forty-five others without transportation, not to mention the support equipment. Many organizations had their hand in the movement of the Weasel team from Florida to Thailand. The Tactical Air Command Headquarters in Virginia monitored the overall conduct of the program and was responsible for acquiring contractors to assist the Wild Weasel maintenance personnel. The Tactical Air Warfare Center at Eglin Air Force Base arranged for the deployment of the Wild Weasels and also remained ultimately responsible for supporting and evaluating the program during its tour in Southeast Asia. Other Air Force commands had to be notified of the deployment so that they could provide support. The Pacific Air Forces, for example, were given operational control of the Wild Weasel force once the latter flew west of 140 degrees longitude. They also had to provide facilities for the Weasels at their final forward base in Thailand as well as logistical support. The Military Air Transport Service airlifted most of the Weasel force from Florida to Thailand. Strategic Air Command provided the tanker aircraft that enabled the both F-100's and the transport aircraft to make the Transpacific flight, as well as providing a staging base (Anderson AFB Guam) for this redeployment. Further coordination for various reasons was required with the stateside Air Defense command, The western area US Coast Guard, Air Force Logistics Command, The Air Force Communications Service and the US Navy.(51) This deployment was not a simple process for the people of the Wild Weasel team, either.

The personnel involved had relatively short notice as regards their future destination. This was, after all, a highly classified project and most knew only that experienced personnel were needed. Each individual was "processed," as it were, through what was known as a mobility line. Every thirty minutes, fifteen people were processed through this line in a large aircraft hangar.(52) By the time an individual completed his time in the line, practically every personal and professional need was addressed. Suitcases and bags were checked and re-checked to make sure everyone had what was needed for several months of duty in Thailand. Uniforms or pieces of equipment that were either misplaced or not deemed serviceable were immediately replaced. Each person received a special copy of their personnel records to take with them, and was also required to fill out a form indicating who was to be contacted in case of emergency. For those with families, decisions had to be made with respect to care of children, payment of bills and other personal concerns. Chaplains and legal representatives were available in the line for counseling and legal matters such as the formation of wills. Also on hand for the test team's departure to Southeast Asia were the Secretary of the Air Force, the Air Force's Vice Chief of Staff, and the Commander of Tactical Air Command. The absence of the Air Force Chief of Staff was noted by one Weasel, who deduced that he was in church praying for the success of the mission.(53)

The rather complex process of sending personnel through a mobility line and moving the test team from Florida served as a reminder that the small test team was part of a greater entity. The rather fluid, almost haphazard nature of the Wild Weasel I program contrasted sharply with the larger, rather inflexible Air Force system. Precise records of technical changes were not always kept properly, and even ATI's initial contract with the Air Force for procurement of parts was a photograph of a signed blackboard, since there was no time for an official contract to be drawn up.(54) While much of the ad hoc nature of Wild Weasel I can be attributed to the wartime needs of a military system in a desperate situation, the growing ability of the operators to almost independently guide this program is not so easily explained. The Wild Weasel had been adapted by its operators to fit the tactical combat system, but the process of adaptation was far from complete. The true testing ground for this new technology would be over North Vietnam.

Chapter Eight:

Adaptation: The Wild Weasel I Program

Southeast Asia Phase

The Weasel crews were not thrown into direct combat immediately upon arrival in Southeast Asia, despite the desperate situation facing the Air Force. The initial sorties for each crew were orientation flights for testing their equipment and getting adjusted to the signal environment. More importantly, it was a check to see just how the friendly and enemy radar emissions were displayed on the receivers. The SADS at Eglin did not necessarily produce a signal which exactly matched those which the North Vietnamese radars employed, and the electronic warfare officers had to rely upon their own experience to sort out the various enemy and friendly signals. Eight of these types of sorties were flown from the 28 to 30 November.(1)

During most of these initial missions, a pair of Wild Weasels teamed up with EB-66C's flying outside SA-2 range to observe and record North Vietnamese and Chinese radar signals. Usually these flights would be along the western border of North Vietnam or over the Gulf of Tonkin. Where possible, the electronic warfare officers on each aircraft would track identical signals at the same time, and after landing the accuracy of the Wild Weasel receivers could be compared with that of the EB-66C's. The sets of data from each aircraft tended to compare favorably for most radar signals; both the Weasel crews and EB-66 crews usually identified the same signals at nearly the same radar frequencies.(2)

The most prevalent Wild Weasel missions were not of this nature. In December the Wild Weasels assumed their primary roles of leading the Iron Hand missions, which were flown directly into the teeth of North Vietnam's air defense. Initially, these were conceived as search-and-destroy missions where the F-100F would be assigned a specific geographical area in which to look for SA-2's. For these missions a Weasel was mated with a flight of three or four F-105s, forming a "hunter-killer" flight. The F-100F acted as the hunter and the escorting Thuds were the killers.(3)

The problem with the mix of F-100's and F-105s was that the Weasels flew about 100 knots slower than the typical speed for the F-105. This often forced either the F-105 pilots to fly at a slower speed than which they were accustomed or the F-100 to use its fuel-gulping afterburner just to keep up with the Thuds. Rather than spend the entire mission trying to keep track of the slower F-100F, the F-105s would often lead the hunter-killer flight until SA-2 signals were picked up by the Weasel's receivers. At that time, the Weasel crew would take the lead and hunt down the SA-2. There were three different types of combat formations used by the hunter-killer flight, as seen in Figures XII, XIII, and XIV. The weaving pattern of the F-105 aircraft was devised by the Weasel EWO's as a countermeasure to direct threat radars, like the Fan Song or anti-aircraft fire control radars. The formation would appear on the Fan Song operator's scope as varying between a single and target and multiple targets, possibly hindering his ability to continuously track a single aircraft.(4)

For the Wild Weasel to home in on an SA-2 site, the back-seater would first have to discern the Fan Song radar emissions from all the other active radars in a large radius. This tended to be more of a problem at the higher altitudes than at the lower altitudes. The path of radar waves from a ground site to an aircraft at 10,000 feet was rarely blocked by intervening terrain such as mountains. For example, there were many cases of Weasel crews finding their scopes "cluttered" with radar signals from the Hanoi area while the aircraft were still well within Laotian airspace.(5) Conversely, flight at lower altitudes resulted in many distant radar signals being blocked by intervening hills and mountains which made the task of sorting out radar signals much easier for the back-seater. Once the electronic warfare officer found a Fan Song and determined where it was in relation to his aircraft, he would direct the pilot toward the site. Just prior to beginning the homing run, the Weasel pilot would transmit "contact" over the radio to the escorting F-105's.(6) The

FOUR-SHIP FORMATION

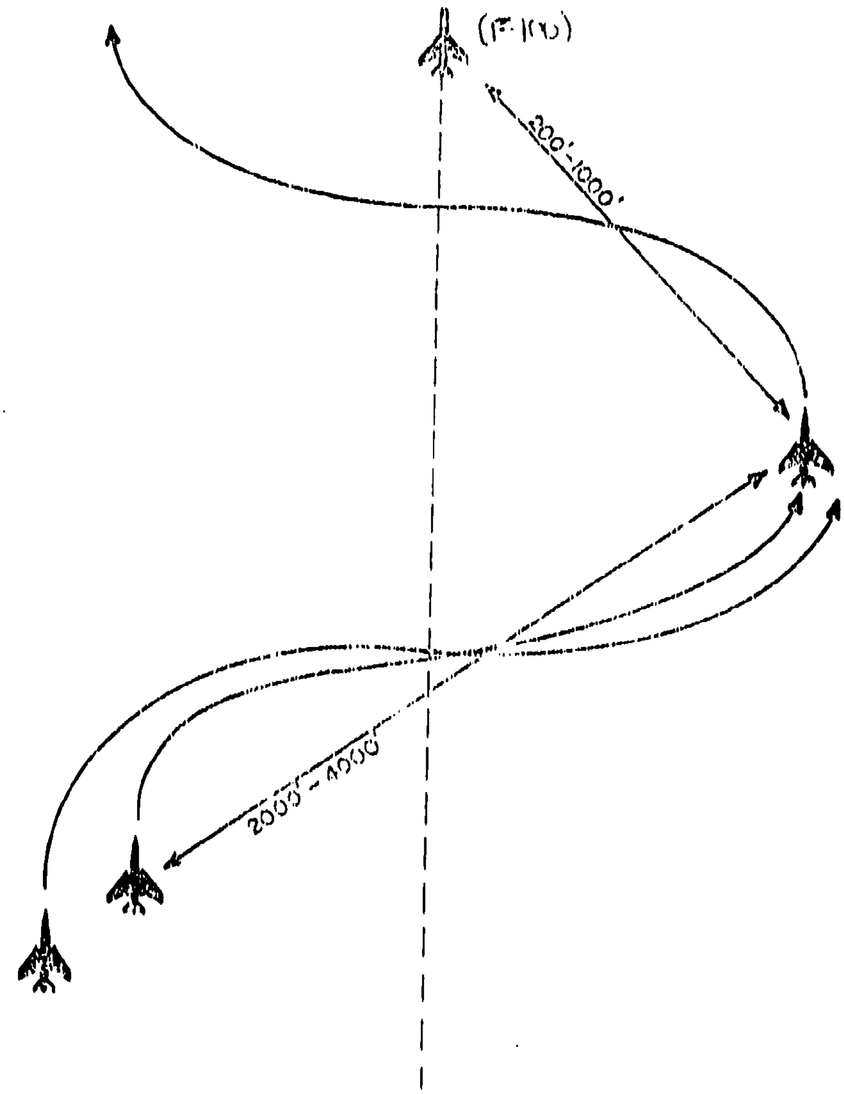


FIGURE XII

FIVE-SHIP FORMATION

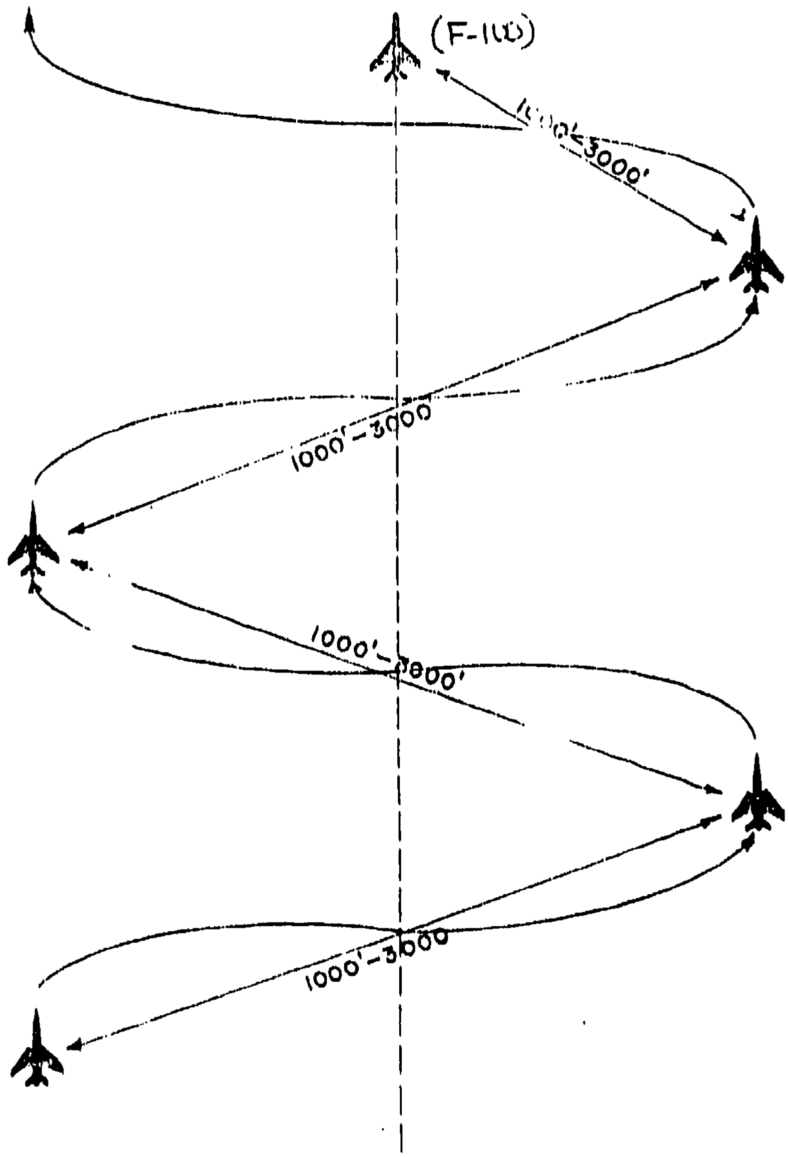


FIGURE XIII

FIVE – SHIP FORMATION

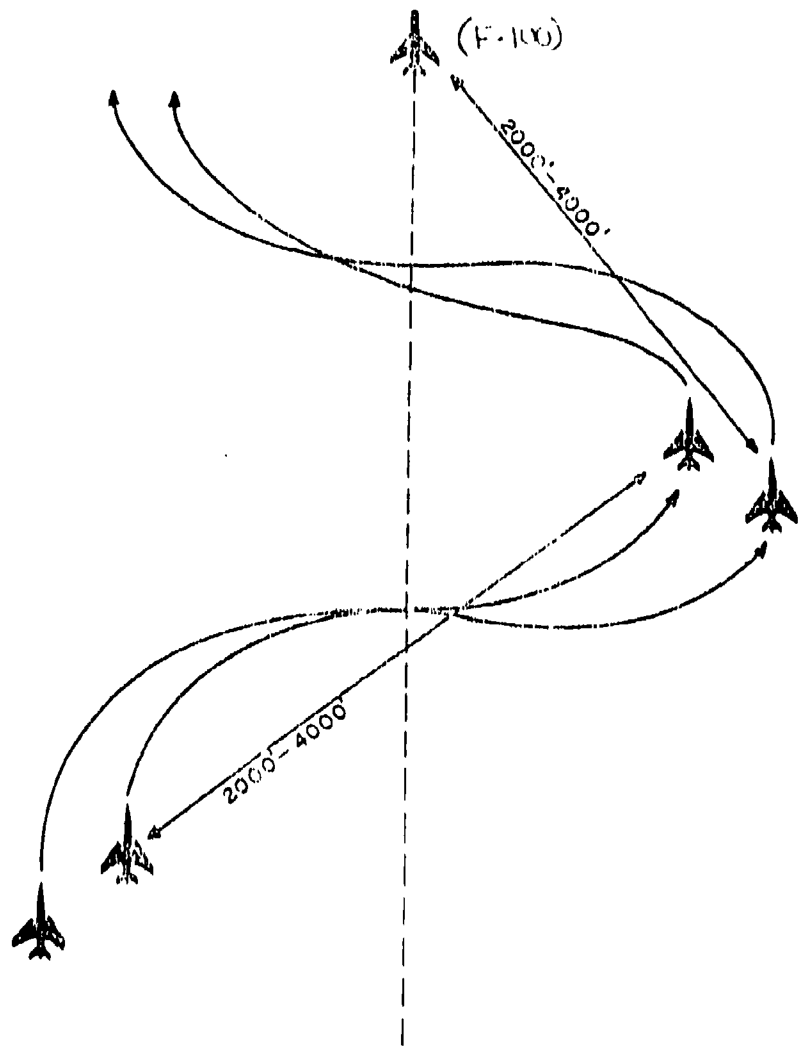


FIGURE XIV

sites were well camouflaged, so it was necessary to fly right over the site's location in order to find it and mark it for the follow-up F-105 attack.

There were two ways in which homing runs were accomplished, direct homing and terrain masking. The direct approach called for cooperative weather conditions, with an eye to the height of the lowest cloud layer. North Vietnamese gunners often set their shell fuses to explode right at the base of the cloud layer, providing a nasty surprise for aircraft descending through the clouds. This tactic also greatly constricted the flexibility of aircraft flying below the clouds by trapping them between anti-aircraft barrages. Direct homing flights preferred to operate between 4500 and 8000 feet, altitude ranges that gave some measure of safety from small arms fire and the prolific North Vietnamese 37mm AAA guns.(7) The advantage of the direct approach was also its disadvantage. These flight profiles provoked the air defenses into reacting against the Iron Hand flight, and there was nowhere to hide from resultant missile launches, except through evasive maneuvers.

The evasion of missile launches on Iron Hand missions brought the Weasels and Thuds down to the lowest altitudes and the necessary hard maneuvers to get them there caused losses in airspeed. Like any other aircraft in such a position, the Weasels were vulnerable to anti-aircraft fire. Even without SA-2 launches, Weasels working radar signals were still subject to attack. On 20 December 1965, the first Wild Weasel aircraft was shot down by AAA fire shortly after the crew picked up a Fan Song on the receivers. Many more Weasels were to go down in this deadly game of cat and mouse.

The terrain masking approach offered some measure of protection, but also at a price. The primary problem for terrain making flights was not the North Vietnamese defenses, but avoiding slamming into a mountainside. Although most airmen knew that radars had difficulties tracking low-flying aircraft, it was not necessarily common knowledge at the time that putting a mountain between one's aircraft and a ground radar prevented active radar detection.(8) These were extremely tricky flights with the crews subject to frequent, often constant, high-G maneuvers. The F-100 would climb over a mountain only long enough to have the Fan Song register on its receivers so that an azimuth could be read and then dip back down into the valleys and behind the hills to avoid radar detection. This method required an absence of low altitude clouds and excellent visibility (9) but offered the advantage of surprise. Although the Weasel could detect the Fan Song it was not necessarily true that the latter's operators knew about it, especially if the Weasel was homing on the side lobes or back lobes. Further, such a method could also take the anti-aircraft gunners off-guard as well. It was such an approach that enabled the first Wild Weasel kill in December, an event discussed later. Whether using the direct or indirect approach, there remained the problem of finding the site.

Overflight procedures were relatively easy over the Eglin ranges but much more difficult in combat conditions. Unlike the Eglin SADS sites, North Vietnamese SA-2's were ringed with multitudes of gun positions. Despite trying to stay above 4500 feet, Weasels were still subject to massive anti-aircraft fire, not to mention the chance of an angry reply from the SA-2 fire control battery. In dry conditions a missile launch kicked up tremendous clouds of dust which lingered in the air after the missile was airborne. Even if the hunter-killer flight did not see the missile until after its launch, they often could pick out the dust which gave away the location of the hidden site.(10) Once the SA-2 missiles were avoided by the flight, the search for the site would continue in earnest. Even overflying the site's position was no guarantee that one could positively identify it.

Sometimes, the Weasel crew would intentionally fly left or right of the suspected location, called an offset approach, to prevent the aircraft itself from blocking the view of the site. Having determined the approximate location of the radar, the Wild Weasel would have to come back to where station passage occurred and the crew would then search for the site. If they found it, the Weasels could immediately attack the radar van and missile launchers with cannon and rockets, the latter also serving to mark the area with for the F-105s.(11) The Weasel crews found that measuring homing accuracy was not easy in a combat zone. Adding to their trouble was the fact that the SA-2's were expertly hidden.

There were two cases in December, 1965 where the Weasels received electronic indications that an SA-2 radar had been overflown. As seen below, these particular sites were too well-camouflaged, however, and could not be pinpointed.

On 19 December, an F-100F flew in support of a Joint Chiefs-directed strike north of Hanoi, with the task of silencing any Fan Song radars that threatened the strike force.(12) Still sixty miles from the Vietnam border, the aircraft's receivers picked up numerous fire control radars while flying just under 10000 feet. Upon reaching the border, these radars so inundated the electronic warfare officer's Vector and IR-133 displays that he found it difficult to sort them out. When a Fan Song finally appeared, the Weasel led the flight toward it, descending in the process to 3000 feet. The low altitude of the F-100F allowed the terrain to block any distant fire control radars, so the scope became less cluttered. The Weasel flew right over the transmitting Fan Song and the crew determined there was definitely a cleared area in the vicinity, but neither the Weasels nor the accompanying F-105 pilots saw any signs of hostile activity.(13) No weapons were fired or dropped.

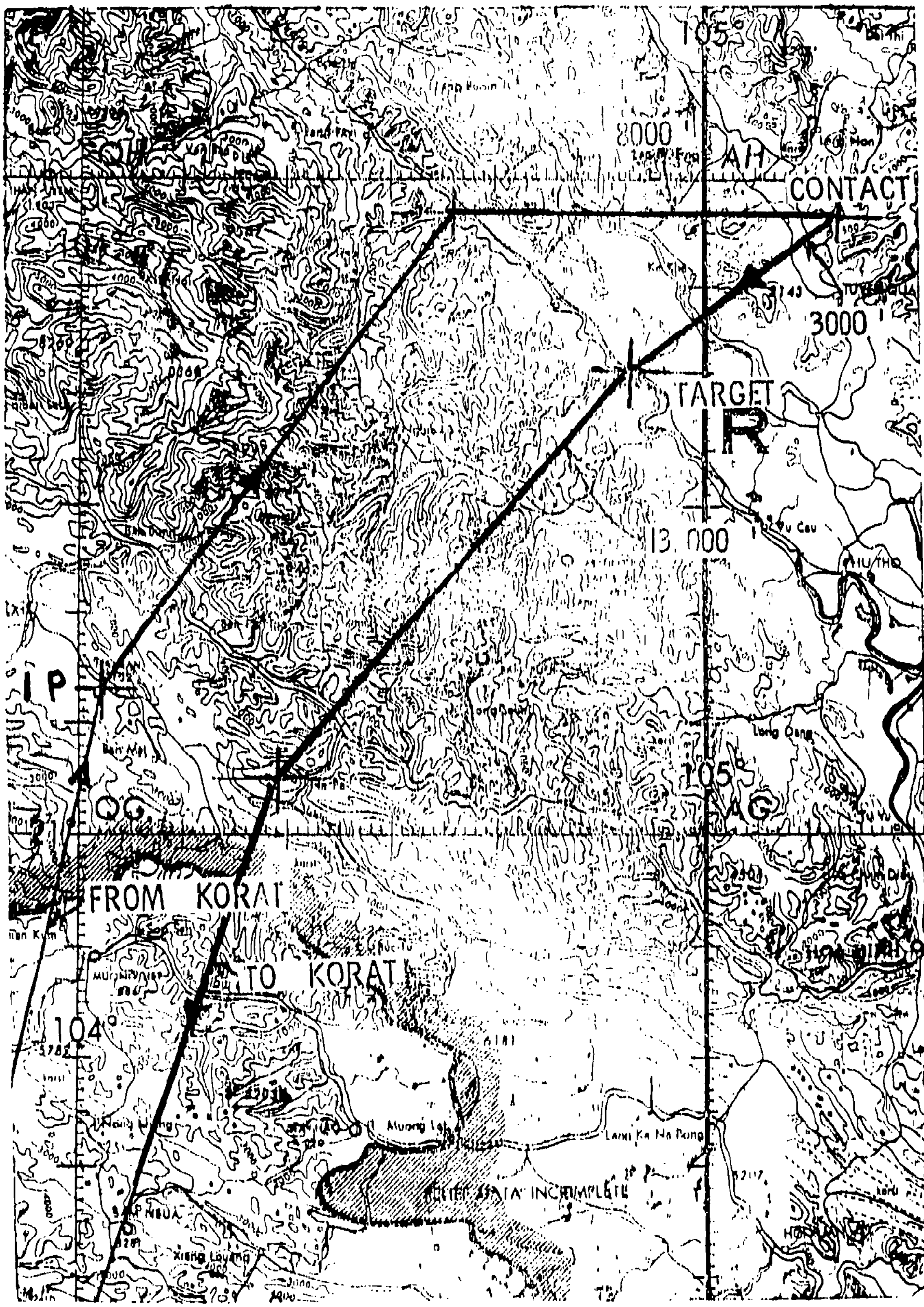
This particular combat experience emphasized the importance of proper planning for Wild Weasel missions. The direction from which a Weasel would approach a suspected target area had to be carefully studied. Not only were the anti-aircraft artillery defenses an important consideration in planning the route, but so was the signal environment. A well-planned mission could avoid having the electronic warfare officer try to sort out a mass of radar signals in order to pinpoint a Fan Song.(14) For example, assuming that there was a suspected Fan Song Location south of Hanoi, an east-west search route might mask the southern signal within the mass of radars near Hanoi. A southern route, however, effectively isolates this area from Hanoi. Site locations were not always known beforehand, but where possible, crews took advantage of advanced planning

It should be noted that the flight path of this 19 December Iron Hand mission should have left little doubt to the North Vietnamese defenders that the Air Force was using an aircraft with homing capabilities. The flight had been well within the envelope of the SA-2 system for about five minutes. The SA-2 battalion did not turn on their Fan Song until the flight was well on its way away from the site. As seen in Figure XV, the Iron Hand flight had to turn right almost 150 degrees in order to home in on the site. This abrupt change of course coinciding with the Fan Song transmission had to have been obvious to the defenses. This point was probably further driven home to the North Vietnamese by the experiences of a second Wild Weasel on the same day.

Not only did this other Wild Weasel crew also home on a Fan Song but this particular homing run led them to a small village as well as a cleared area. This mission showed how the process of adaptation is continuous. Here it was confirmed that the way in which the homing runs at Eglin were flown was inadequate for combat missions. Unlike typical stateside missions, the electronic warfare officer found it difficult to use the IR-133 in the "direction finding" mode by comparing signal amplitudes left and right of the aircraft. The Fan Song signal on this mission was so strong that "both strobes went off (the) scope." (15) It was impossible for the back-seater to compare their respective amplitudes for refined steering as was commonly done on the Eglin runs. The Vector, on the other hand, provided all the necessary information for the final phase of homing.(16)

Even though the IR-133 had been successfully tested and introduced by ATI and North American into the Wild Weasel program, and the electronic warfare officers had established individual procedures that seemed to work with the IR-133 in a flying environment, combat necessitated further changes. When the aircraft travels at least six miles every minute and only a few seconds' of time is often critical, seemingly minor changes in equipment operating procedures may make huge differences. Here, it was confirmed that despite the accuracy and sensitivity of the IR-133, it was best employed prior to the final homing run, for its sensitivity allowed radar signals, especially side and back lobes, to be detected at great distances.(17) The Vector, though slightly less accurate than the IR-133, was less sensitive and best used during the final phases where hard

IRON HAND ROUTE 19 DECEMBER 1965 ACFT #227



NOTE THE LARGE RIGHT TURN AFTER "CONTACT"

FIGURE XV

maneuvering and fast action required a simpler display and azimuth. Some back-seaters were therefore obliged to modify their habit patterns formed at Eglin.

The process of adaptation, though continuous, was not going fast enough for the Air Force's decision-makers (18) Almost three weeks had passed since the Weasels' arrival and there had been no tangible results. No sites had been destroyed, and of those subject to homing none were precisely located. The heretofore loose control by PACAF on Wild Weasel I tightened somewhat when the order came down for most of the hunter-killer flights to fly in the same formation with the strike forces. They were to lead the strike into the target area and take care of any SA-2's that challenged the bomb-laden F-105's. This proved to be an unwise decision, because tying the Weasels to the strike force greatly constricted their actions and weakened their potential effectiveness against the SA-2 battalions. It also led to the first Wild Weasel casualties.

On 20 December, an F-100F flown by pilot John Pitchford and electronic warfare officer Robert Trier, both Captains, led a flight of four F-105's supporting a strike against the Vu Chua railroad bridge, forty miles northeast of Hanoi.(19) The Wild Weasels led the entire strike formation as they headed north from the Gulf of Tonkin. Unfortunately, low clouds in the area forced the formation into flying less than 4000 feet above the ground just to see the ground. While about five miles from the heavily defended North Vietnamese airfield at Kep, the Weasel crew transmitted "contact" to the F-105 flight but was hit by anti-aircraft gunfire shortly afterwards.(20) Although the pilot fired marking rockets in the general direction of the SA-2 site, he was more concerned with keeping his aircraft in the air. His efforts could not prevent the aircraft from becoming uncontrollable, and both crew members were forced to eject. The pilot became a prisoner of war until 1973. The electronic warfare officer was killed by North Vietnamese ground forces.

During this mission, the low cloud base had provided the North Vietnamese gunners with an definite altitude at which to set their fuses. This sandwiched the American aircraft between two zones of fire with little room for error. The upper zone consisted of timed shell bursts while the lower zone was dominated by small arms fire. The aircraft had to fly below the clouds in order to see their target, but spent most of their time trying to dodge the intense ground fire. The bridge was not destroyed and three of the approximately thirty aircraft in the strike were shot down.(21) The Wild Weasel team quickly established guidelines for further Iron Hand missions. In suspected SA-2 locations, target locations, and in the approach and exit routes to these areas, the lowest cloud ceiling had to be at least 8000 feet above ground level accompanied with a five mile visibility. (22)

The weather was not the only problem. Radio frequencies provided the source for yet another change. Flying directly among the strike force forced the hunter-killer fight to use the same radio frequency as the other strike aircraft. Complicating matters was the fact that the Wild Weasel flight had its own need for inter-flight communications that were independent of the needs of the strike force.(23) This resulted in a problem on a radio net already cluttered with voices even before the shooting started. During the high-pitched moments of actual combat, the confusion on the radios often rose exponentially. All US Air Force aircraft radios could receive transmissions on the emergency frequency known as "Guard", while simultaneously operating on their normal strike frequencies. SA-2 warnings were transmitted on this guard frequency as standard procedure, so the message would reach all aircraft simultaneously. Rather than be tied to the same radio channel as the other aircraft, hunter-killer flights were directed to use a separate radio frequency within their flight during most of the mission. The Weasels changed over to strike frequencies when necessary and always broadcast their SA-2 warnings on the common Guard frequency.

Even the Weasel formation itself presented unforeseen problems. The use of five aircraft in one Iron Hand flight greatly reduced the time the hunter-killer teams could remain in the target areas to search for SA-2's. On the 20 December mission, the hunter-killer flight had to leave the target area and not seek out the active SA-2 site because the aircraft were running low on fuel. Refueling with five aircraft on one KC-135 tanker took anywhere from fifteen to thirty minutes, with an average just over twenty minutes' duration.(24) This assumed that the hunter-killer flight flawlessly rendezvoused with the tankers in the first place, a task that was not always as easy as it would otherwise seem. By the time the last aircraft were fueled the first aircraft had expended precious gas that could otherwise allow more time in the target area. Thereafter, two tankers were used for long flights where these fuel considerations were important. The hunter-killer flight's basic composition was also subject to close scrutiny.

The Wild Weasel team reported that the five-aircraft hunter killer formations provided an "alerting and aiming point for ground gunners" (25) The gunners could use the F-100F as an aiming point for the entire formation because the Thuds weaved back and forth across the straight path of the F-100F. Flight using this formation also tended to lose integrity during combat. On the 20 December mission, for example, two of the five aircraft in Pitchford's flight got separated from the main formation.(26) Although the five-ship formation continued to be used in addition to the four-ship, the Weasel team looked at the pros and cons of each more closely. Tactics continued to change as the system adjusted to these new aircraft.

Most important of these changes was the eventual decision to separate the hunter-killer flight from the main strike force, yet allow for the latter's support. The initial Wild Weasel recommendation was that the strike force arrive in the target area prior to the Wild Weasel force so that the strike mission commander could evaluate the weather in the target area for Weasel operations.(27) The Wild Weasels would then plan to arrive somewhere between the time the first and last bombs were dropped. The rationale behind this was to allow the Weasels to loiter in the target area after the strike force left because the SA-2 battalions tended to shoot as the force egressed. Although this particular suggestion was not followed, many hunter-killer teams soon were freed from the strike formation, but not during Wild Weasel I. In these subsequent cases the Weasels became the first into the target area on large strike missions, "stirring up" the enemy defenses in the hopes of finding an SA-2 battalion.(28) The first time a hunter-killer flight first succeeded in doing what the

Weasels set out to do, however, did not occur as part of a larger mission. It was a pre-planned strike against a suspected location of an SA-2 site.

On 22 December, 1965, an F-100F crewed by Captains Al Lamb and Jack Donovan, found and successfully attacked an SA-2 battalion near Yen Bai, North Vietnam. Spruce Flight, consisting of four F-105s with Lamb and Donovan's F-100, crossed the North Vietnamese border at 16,000 feet altitude only to be greeted with a searching Fan Song. After quickly lowering their altitude to put hills and ridges between their flight and the SA-2, the Weasel -- Spruce Zero-One -- would occasionally "pop-up" so that Donovan's equipment could get a "fix" on the SA-2. In this manner Lamb would climb over a ridge, level the wings long enough for Donovan to get a reading, and then execute a half-barrel roll into the next valley. Each succeeding valley ran perpendicular to the site, so the flight followed the leader up and down each valley.(29) The flight profile is shown in Figure XVI.

Each pop-up exposed the Vector's sensitive antennas to bursts of Fan Song radar energy from a slightly different relative bearing than the bearing noted after the previous pop-up. The hard maneuvers caused a force varying from four to six times that of gravity to be almost continually exerted upon aircraft and crew. (30) Under these kinds of conditions it would have been extremely difficult, if not impossible, for Donovan to make fine tuning adjustments to his IR-133. The Vector scope was the most practical to use during these maneuvers. Donovan kept track of these changes by looking at the Vector's scope display and kept Lamb constantly updated on the situation.(31)

This particular mission showed the role crew judgment played in determining range. The Vector did not receive a noticeable "burst" from the Fan Song until its antennas had an unobstructed path to the radar. Each successive pass through a mountain valley saw the signal grow larger on the vector as the range diminished, but an educated guess as to the approximate location to the site could be made based on how high the Weasel had to fly above the intervening terrain in order for the Vector to register the Fan Song.(32)

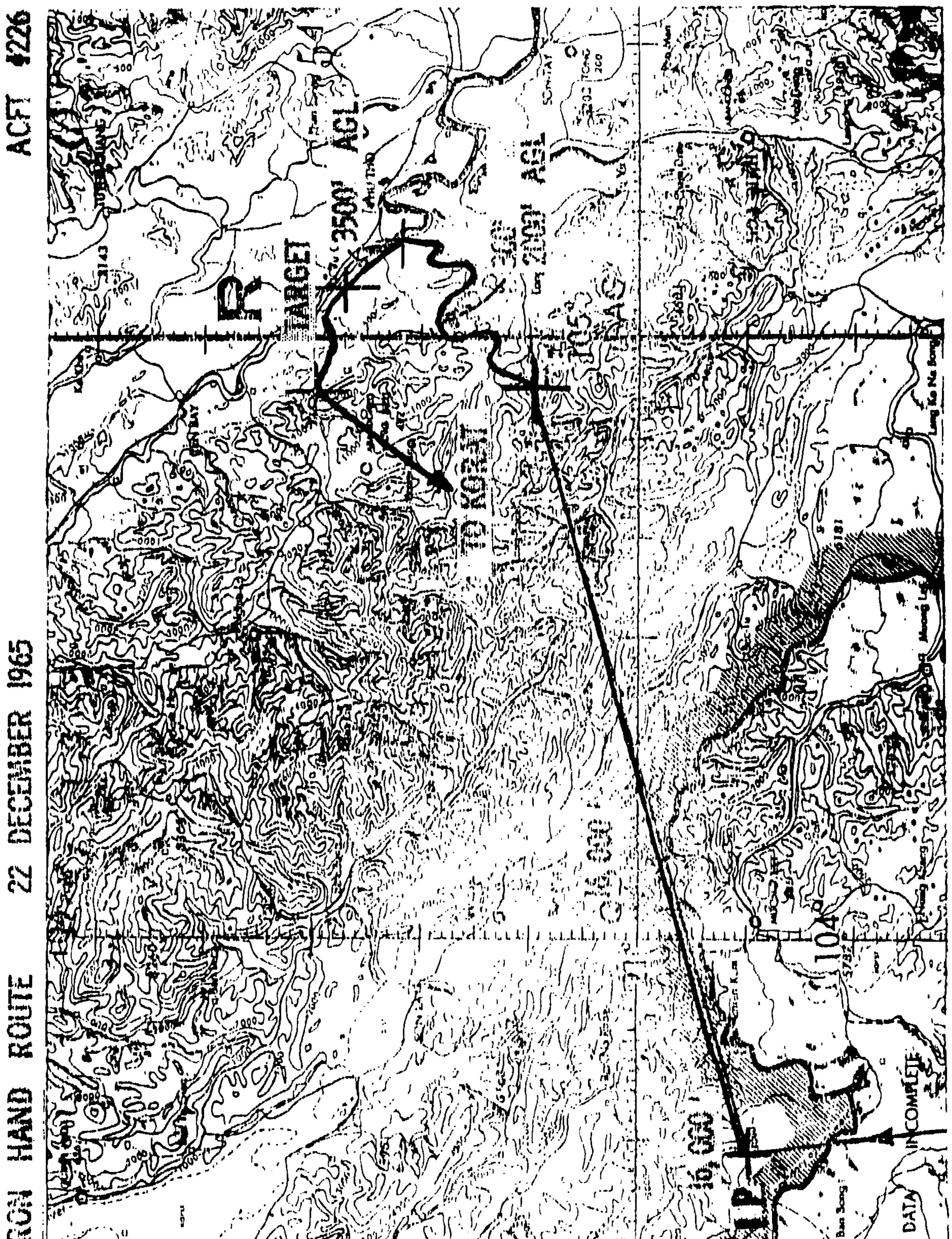

IRON HAND ROUTE 22 DECEMBER 1965 ACFT #226
TARGET
3500' AGL
2000' AGL
TO KORAT
IP
DATA INCOMPLETE

FIGURE XVI

Soon, the Weasel had no more hills for hiding, and it emerged over a wide, flat plain, quite vulnerable to any radar. "Bang!" Recalled Donovan. "The Vector scope had a two and one-half ring strobe."(33) There were three concentric circles, or "rings" on the Vector Scope. Two-and-one-half rings meant that the strobe was so long it nearly reached the edge of the scope. By this time, the Fan Song switched to a high pulse repetition frequency that enabled faster updates of target information. The higher octave tone in the electronic warfare officer's ears associated with this switch indicated that the SA-2 crew was refining the target data in preparation for launch. Although the Weasel had managed for a time to sneak in "behind" the main lobe, the element of surprise was no longer in the Americans' favor. Continuing their maneuvers, the Weasel attracted the attention of the other nearby SA-2 site as well as some anti-aircraft fire control radars. Donovan's Vector "started looking like a Christmas tree" as it tried to sort out all the radar signals. Still, there was no SA-2 site to be seen, only "some fields, a tiny village, and some rice paddies." (34)

The Vector strobe jumped to three rings as Lamb popped up to 3500 feet to get a better look at the village. The site was then spotted. It had been expertly hidden in the middle of the village with the missiles under thatched huts on the village periphery. The radar sat alongside a long "hootch," and the white missile tips were barley visible as they protruded from underneath thatched roofs.(35) Lamb dove on the position, firing all his 2.75 inch diameter high-explosive marking rockets and following that up with 20mm cannon fire. The four F-105s followed Lamb and Donovan and demolished the site, although only the lead F-105 pilot actually saw where Lamb fired his rockets. Each succeeding F-105 pilot, busy trying to keep tabs on the aircraft in front of him while avoiding the ground, did not pick up the site until the very last minute, either.(36) The mission, however, was a success. The Wild Weasel I commander sent a message to the Air Force Chief of Staff: "Wild Weasel sighted SAM, destroyed same."(37) A White House-directed bombing halt implemented a few days later suspended all further combat flights over North Vietnam until well after the New Year. The combat test of Wild Weasel I came to an end about one month later.

Chapter Nine

Transformation: Tactical Electronic Combat Is Reborn

A new element, the Wild Weasel, had been added to the US Air Force tactical combat system, and as was seen in the prior chapter, the process of integration for this aircraft was rather complex. As both element and system were adapted to each other, the system itself began to change. The Wild Weasel, however, had yet to be fully integrated into the larger system for two main reasons. One, the process of adaptation was far from finished by the Spring of 1966 because the F-100F's were to be replaced with faster and more compatible F-105F's. Two, the elements which could best provide mutual support for the Weasels, technologies such as anti-radiation missiles and jamming pods had yet to arrive in Southeast Asia.

Consequently, the Weasels remained extremely vulnerable to the air defenses, and attrition rates for Weasel crews were high. Shortly after the bombing pause ended, two more Weasel F-100F's went down, bringing the total losses to three out of the four original F-100F's by February, 1966. Follow-on Weasel training programs, originally designed to build up the reserve of Weasel crews, merely served at this time to replace the combat losses. Three new F-100's quickly appeared and brought the total available back up to four.(1) These aircraft, the harbingers of tactical electronic combat in the age of missiles, would soon be joined by other technologies in a continuous process of integration.

Some of the new additions to the American combat system in 1966 were the cornerstones of tactical electronic combat. New versions of Weasel aircraft, EF-105F's of the Wild Weasel III program soon made their appearance, with the F-100's being phased out by July.(2) The Navy's AGM-45 Shrike missile was modified to be carried by both the F-100 and F-105 aircraft. Improved versions of the QRC-160 pod were introduced by the fall. Special teams were deployed throughout the command structure to analyze Air Force electronic warfare efforts. In short, the system whose foundations were laid out by Dempster's task force in 1965 emerged in nascent form by the end of 1966.

Dempster's task force had a pretty good grasp of what was needed to defeat an air defense system featuring weapons like an SA-2. The Wild Weasel program was the first step in a deliberate attempt at system-building, not solely a knee-jerk response to a new threatening technology. New elements of tactical electronic warfare were constructed in the hopes of adapting them to the existing system of aerial combat. The mixture of these new elements with the existing system was intended to produce a new tactical system to bring the American aircraft back into its familiar realm of medium-altitude operations. The Wild Weasel I program was a test program, and when it concluded in January of 1966, there were eight distinct objectives against which it was measured. These objectives were as follows:

1) To determine the warning capability of RHAW equipment installed in the Wild Weasel F-100F aircraft.

2) To investigate the effect of jamming by friendly aircraft on Vector and IR-133 equipment

3) To determine the homing accuracy of the RHAW equipment and the capability of the crew to place the aircraft within visual range of the target.

4) To develop tactics for employing the Wild Weasel aircraft against SAM defense systems.

5) To determine maintenance requirements and reliability of RHAW equipment

6) To determine the organizational and manning requirements for Wild Weasel operations.

7) To determine training requirements for flight crews and RHAW maintenance personnel

8) To test any additional equipment which may be made available for this system during the period of operational test and evaluation.(3)

Only one of the eight objectives specifically referred to development of combat tactics to defeat the SA-2. To the airmen flying over North Vietnam, the whole point of the Wild Weasel I program was to see if the F-100F could suppress the SA-2, but in creating a program of electronic warfare there were other factors to be considered.

Objectives one, three, five, and seven, each pertaining to the radar homing and warning (RHAW) devices, show that the scope of the test went beyond a single type of aircraft. Although fighter RHAW gear was peculiar only to the Weasel and certain Navy aircraft in 1965, Dempster's task force intended to equip all F-105 fighter aircraft with this RHAW technology. The Air Force had ordered over five-hundred of Applied Technology Incorporated's (ATI) radar homing sets by awarding ATI a contract for them on 19 November 1965.(4) Lessons and recommendations from the Weasel program could save time and money in an Air Force-wide RHAW gear installation and maintenance program.

Wild Weasel crews also recommended changes and modifications for follow-on programs. There were also recommendations for the maintenance program as well. These planned changes were all included in the final report of this test, printed in March of 1966 and distributed to all the major Air Force commands, research centers and tactical fighter wings. (5) The recommended classroom and flight simulator training for new volunteer crews totaled a minimum of forty-three hours of instruction. Half of these hours consisted of "flight" time in an F-100F simulator, approximately twelve hours were focused on the operation and employment of the radar homing equipment, and eight hours were set aside for classroom instruction on the North Vietnamese air defenses.(6) Figure XVII shows an overview of the recommended training classes, while figure XVIII shows an example of a specific class. Recommendations also covered the training flights in Wild Weasel aircraft.

Nine training flights were recommended, the first of which was designed solely to familiarize the electronic warfare officer with the F-100F and the second to practice basic techniques of flight crew coordination. Each of the succeeding missions was planned to be of increasing difficulty and incorporated combat tactics learned from experiences in

TRAINING

1. GROUND TRAINING. Air Crews

LESSON NUMBER	SUBJECT	TIME REQUIRED
1 P,O	General Orientation & Overview	1:00
2 P	Radar Primer for Pilots)	
2 O	Aircraft Familiarization for) RHAW Operators)	2:00
3 P,O	RHAW Equipment Familiarization	4:00
4 P,O	RHAW Performance & Operation	4:00
5 P,O	Simulator (10:00) & Simulator Critique (10:00)	20:00
6 P,O	Intelligence Enemy Defense System	8:00
7 P,O	RHAW System Employment (Tactics)	4:00
8 P,O	Survival Training	As Rqd
	TOTAL	43:00

P - For Pilots

O For RHAW Operator

FIGURE XVII WILD-WEASEL I: RECOMMENDED GROUND TRAINING

GROUND TRAINING (Cont'd)

LESSON NO: 7 P,O

SUBJECT: RHAW System Employment (Tactics)

TIME REQUIRED: 4 Hours

OBJECTIVE: To give the crew an understanding of tactics used to employ the Wild Weasel aircraft.

OUTLINE: I. Iron Hand Tactics

A. Formation

1. Composition

2. Procedures

B. Search Phase

1. Flight Profile - Altitude, Maneuvers

2. Detection Techniques

C. Homing Phase

1. Terrain Masking

2. Offset Tactics

3. Crew Coordination

4. IR-133

5. Vector

D. Attack Phase

1. Target Acquisition

2. Station Passage Indications

3. Marking Techniques

E. Escape Phase

1. Flight Profile

2. Tactics

FIGURE XVIII: RECOMMENDED LESSON PLAN

Southeast Asia. For example, mission number seven was planned to make the crew understand "problems related to attacking a camouflaged target, " with the hopes of forcing airmen to anticipate the North Vietnamese camouflage techniques.(7) An example of a recommended flight training sortie is seen in Figure XIX. Wild Weasel I training flights back in October, 1965 did not include practice on finding hidden sites. Not only were many of these training modifications put into effect, but most of the original Weasels returned to the states to form a cadre of Wild Weasel instructors. The 4537th Fighter Weapons School, nicknamed "Wild Weasel College," was established at Nellis Air Force Base, Nevada in February, 1966.(8)

Wild Weasel III had its origins on 8 January1966 when General Dempster officially decided to change the Weasel airframe to a two-seat F-105F and add new electronic equipment. Switching to a Thud eliminated the problem with F-100/F-105 speed differences, but all versions of the F-105 had already gone out of production. High losses would be difficult to replace.(9) Equipment changes in Wild Weasel III were slight, but an "AZ-EL" system, referring to "azimuth-elevation" gave the crews improved capability in locating SA-2 sites. If the electronic warfare officer maintained adequate AZ-EL equipment settings during the final phase of a homing run, a green dot would be projected onto the pilot's windscreen. The position of this dot on the glass was intended to correspond with the location of the missile site relative to the aircraft, thus helping out in finding hidden sites.(10)

By Spring, 1966, the F-100F Weasels, and subsequently the F-105 Weasels, were mated with what became their weapon of choice, the AGM-45 Shrike anti-radiation missile. This particular ARM was designed to home in on radar transmissions not only from Fan songs, but also "Fire Can" fire control radars for anti-aircraft artillery. The Shrike enabled the Wild Weasels to take on SA-2 sites without being forced to enter the lethal small arms fire at the lower altitudes, and could prevent the dangerous tactic of flying over SA-2 sites in order to pinpoint the location. It carried a fifty-one pound warhead that

MISSION NO: 2

SUBJECT: Equipment Operation, Crew Coordination

TIME REQUIRED: 1:30

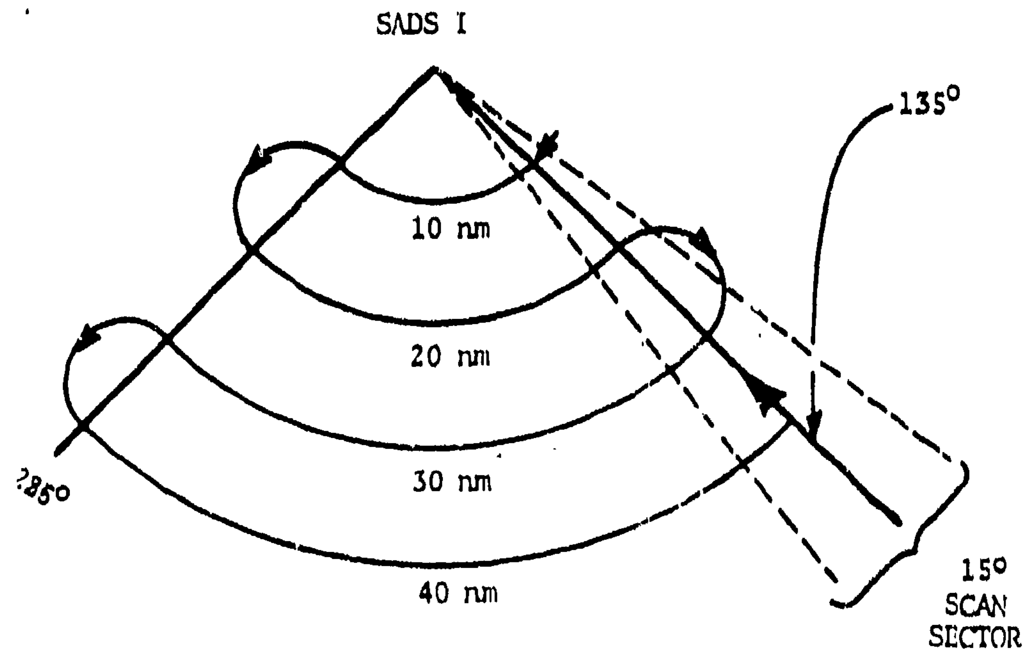
OBJECTIVE: To familiarize the crew with equipment operation, signal presentation, and crew coordination procedures.

OUTLINE: I. Signal Presentation and Familiarization.

A. Mission Profile.

1. Altitude, 4000 to 8000 feet AGL.

2. Approximate arc, aircraft positioned by radar control, as indicated below.



3. Repeat as fuel and range time allow.

B. Signal Presentation, Bearing & Strength Variation.

1. Range Effect.

2. Main Beam - Side Lobe Effect.

FIGURE XIX

FLYING TRAINING - Cont'd

C. Equipment Operation

1. IR-133 - Start each leg in sweep mode, check amplitude in both low and high sensitivity, then go to manual and repeat.

2. Vector - determine strobe characteristics and relative bearing changes.

II. Crew Coordination

A. Threat location - RHAW Operator reports threat bearing changes using clock position, to pilot.

B. Homing - RHAW Operator reports approximate degrees off nose or clock position.

III. Aerial Demonstration (off range)

A. Jinking maneuvers.

B. Pop-up simulated ordnance delivery.

IV. Mission Debriefing

FIGURE XIX

sprayed small steel balls after detonation.(11) This was enough to destroy or at least seriously damage a radar, but would not destroy the entire site. Therefore, a number of Shrikes also carried white phosphorus that served as excellent marking tools for hidden sites. Over four-hundred Shrikes were fired in 1966, three times that many in 1967, and when Rolling Thunder was halted in March of 1968 the firing rate would have put the yearly total over two-thousand.(12) For all the promise offered by this weapon, it too needed to be adapted.

In order for the ARM to hit a radar, the latter had to be radiating up until the time of impact. Sensitive receivers in the Shrike's nose were tuned to specific radar frequencies on the ground prior to the mission. The missile was designed to home in on the strongest source of electromagnetic radiation in this specific frequency band, the radar antenna itself. Should the radar be turned off for any reason, the Shrike would have no source for homing and would "go stupid," missing the intended target. In evaluating the initial uses of the Shrike, airmen sometimes mistakenly thought when a radar went "off the air" it was destroyed.(13) This was not necessarily so, for the North Vietnamese quickly realized what kind of weapon was being used and either limited their transmission time or shut the radars off entirely.

The early Shrike attacks were conducted in the "lower" Route Packages because the air defenses there were less dense than those around Hanoi and correspondingly less capable of providing mutual support. Wild Weasel crews could then practice against isolated sites. Also, with less radars around, the possibility was lessened that the Shrike receivers would get confused from multiple radar emissions coming from various directions.(14)

The first Shrike attack occurred on 18 April 1966.(15) An Iron Hand flight of three single-seat F-105D's and a two-seat F-105F Weasel encountered a single fire control radar about six miles northwest of Dong Hoi, North Vietnam. The missile was fired at the site, even though the latter could not be seen due to intervening clouds. The missile disappeared into these clouds, but the radar went off the air shortly thereafter. The remainder of the defenses soon reacted and severely limited the transmission time of their radars, which, according to an Air Force report on the Shrike missile, became "intermittent and sporadic in nature." Thus the Wild Weasel could neutralize a site not only by destroying it but also by intimidating the operators, although this was not the first time the Weasels forced Fan Song radars off the air.(16)

Launching Shrikes also brought dangers. The Shrike, though an important weapon, often required flying into the heart of the SA-2's lethal envelope. The range at which the Shrike could be effectively employed was no more than twelve miles from the Fan Song radar, which was only about one-half the SA-2's maximum effective range at the typical Wild Weasel flight altitude. Also, the maximum speed of the Shrike was Mach 2.0, a little more than half the SA-2s maximum speed of mach 3.5.(17) Because of these characteristics, the aircrew intentionally had to make a target out of themselves, trying to keep the Fan Song radar on the air long enough for the anti-radiation missile to hit its target. If the SA-2 site fired upon the Weasel, the aircrew could only hope that they had fired soon enough for the slower Shrike to hit the Fan Song before the accelerating Guideline hit their own aircraft. At best, the Weasel would be forced into a violent evasive maneuver to avoid the oncoming missile.

The effective ranges of the Shrike and Guideline had forced the Weasels to develop new tactics based on the limitations of their ARM. Prior to launch, a Weasels began to "loft" the missile, which meant the aircraft had to pull up into a climb just prior to firing.(18) This started the missile out on a higher trajectory which increased its effective range almost to that of the Guideline's. This tactic also had its drawbacks. As it was, Iron Hand flights, due to their peculiar flight paths, were the focus of special attention from the North Vietnamese defenses and this method of "lofting" the missile invited additional trouble. The climb would slow the aircraft down, making it relatively more vulnerable to any nearby threats. Each side in this deadly game of cat and mouse could monitor the other's actions. SA-2 radar operators attempting to shoot down Weasels could also track an incoming Shrike on the Fan Song's radar scopes. Of course, the very act of tracking the Shrike led the ARM to its prey, so the radar would have to be shut off to prevent homing. The fire-control battery could no longer direct the Guideline if the radar stopped transmitting. For the American airmen this meant that if the SA-2 radar was shut down, that particular SA-2 system ceased to be a threat to the strike force. Any Guidelines already airborne were reduced to flying like oversized bullets with large warheads.

The Shrike appeared to have a definite impact on North Vietnamese air defense operations as seen in Figure XX. Data for Shrike use between October 1967 and March 1968 are instructive, even though they pertain to a period beyond the focus of this study. In comparing Shrikes fired and not fired against SA-2s within fifteen miles of potential targets, there is a clear correlation between Shrikes fired and the potential effect on SA-2 operations. When SA-2's engaged a target by radiating their Fan Songs and no Shrikes were fired, 250 missile launches (of at least one missile each) were observed out of 560 radar engagements. During this same time period, 309 radar engagements were met with Shrikes. Of these, only 16 launches were observed.(19)

As 1966 progressed, newly integrated munitions freed the Iron Hand flights from having to overfly the site directly in level flight to drop area weapons. Improved cluster-bombs like the CBU-24 and CBU-29 did not require a level, low-altitude release like their predecessor, the CBU-2A. This allowed for relatively safer dive-bombing runs to be used against the sites.(20) Once the bomblets had dispersed and exploded over the area to suppress the site defenders, the rest of the Iron Hand Flight could then destroy the site and its equipment with heavier ordnance. The Wild Weasels and their Iron Hand missions in 1966 were markedly different than what originally was done in 1965.

To summarize the Wild Weasel program in 1966, the most significant change occurred when the EF-105F was introduced to the force and then mated with the Shrike. The speed difference between the F-100's and F-105's were no longer a factor in the Iron

INFLUENCE OF SHRIKE ON SAM REACTION
(Oct 1967-Mar 1968)

Reactions (missile launch) were compared when Shrikes were launched/not launched and a potential target was within 15NM of an occupied site. The following chart shows results:

	NOT SHRIKED OPPORTUNITIES	REACTED	SHRIKED OPPORTUNITIES	REACTED
Oct	174	59	58	3
Nov (17 18 19 20)*	43	36	38	5
Nov (1-16 21-30)	60	21	30	0
Dec	80	42	34	0
Jan	49	30	69	1
Feb	90	37	35	2
Mar	64	25	45	5
TOTALS	560	250	309	16

* These four days are presented separate from the remainder of November, because of the unusually high number of SAM reactions noted. On these days, strikes involving unusually large number of aircraft, were conducted against well defended targets in the high SAM threat area which resulted in the launching of approximately 130 SAMs.

FIGURE XX

Hand flights and strike formations. With the F-100F being phased out and the EF-105F assuming its place, American hunter-killer flights became rather formidable weapons. Now, all strike aircraft flew at similar airspeeds. Although shrike employment was discussed earlier, it is important to point out that when a Weasel fired a Shrike the radar site was immediately put on the defensive, allowing the Iron Hand flight quickly to close the range to the site. Also, even though a Shrike did not knock out the radar, if a white phosphorus version was used, its warhead would detonate and leave a clearly identified column of white smoke in the site's vicinity. (21) New elements continued to be added to the tactical air combat system.

Another USAF element began its process of adaptation to the aerial combat system on 26 September, 1966. Twenty-five redesigned QRC-160-1 pods began their "combat evaluation" over hostile skies, and were soon supplemented by almost identical ALQ-71 pods (22) The 355th Tactical Fighter Wing was chosen to conduct a combat evaluation of the QRC pod over the skies of North Vietnam.(23) The jammers in the pods were tuned to the known frequencies of radars which directly threatened the aircraft, like the Fan Song or the Fire Can. Initially, these evaluation missions were flown in low-threat areas, but pod-equipped aircraft were soon facing the heaviest North Vietnamese air defenses.

Pods were relatively simple for the F-105 pilots to use. There would be one control box for each pod attached to the aircraft, up to a maximum of two. Immediately after take-off, the pilot turned the selector switch on the control box to the "standby" position. This allowed the pod to "warm-up" prior to actual use. The pilot would then see a white "number one" light illuminate if the pod warmed up. If this occurred he subsequently turned the selector knob to the "transmit" position for use in combat.(24) There were a total of four color-coded lights on the control panel pertaining to the pod's operation, and a relatively simple "troubleshooting" checklist was provided in case the proper lights were not illuminated.(25) That the above technology was easily operated by the pilots was an important part of the process of adaptation. The introduction of more complex equipment that required a pilot to keep his attention inside the cockpit rather than outside would have invited trouble, because the pilot would either spend too much time trying to operate the device at the expense of performing his mission or give up on the device altogether in order to fly the mission properly. Therefore, the process of adaptation has its subtleties.

Less subtle was the challenging task of adjusting combat tactics to allow for the use of these pods. While carrying pods, it was important for the fighters to fly what was called a "pod formation." One pod acting alone was often insufficient to counter the Fan Song radars. It was the combined radiation patterns of all the flight's pods which produced the desired results. This pod formation was much more compact than what was preferred to be flown by pilots. It placed the flight's aircraft much closer together than was considered practical for flying into an area threatened by enemy fighter aircraft, reducing the overall field of view for the flight. Pilots entering enemy airspace preferred to be flying farther apart than what the pod formation would allow, so the actual pod formations flown in combat were a compromise. Consequently, they were different than the "optimum formation." recommended by stateside testing, as seen in Figures XXI, XXII, and XXIII.(26)

The pods also forced changes in tactics when SA-2 launches occurred. Usually, a pod-equipped flight would continue along the same flight path at medium altitude without maneuvering when an SA-2 was launched at them. The flight leader would initiate evasive maneuvers if he determined that the SA-2 was undeterred by the jamming. Even then, the maneuvers would often be in the vertical plane (usually a dive) at a relatively shallow angle so as to not interfere with the pod's radiation patterns. Horizontal plane maneuvers that entailed large bank angles were avoided when possible since a banked aircraft would direct radiation away from the site and leave the Fan song unjammed.(27) Each flight strived to maintain its tight formation despite these conditions in order to prevent the loss of flight integrity.

OPTIMUM POD FORMATION

(VARIATIONS USED IN PRACTICE)

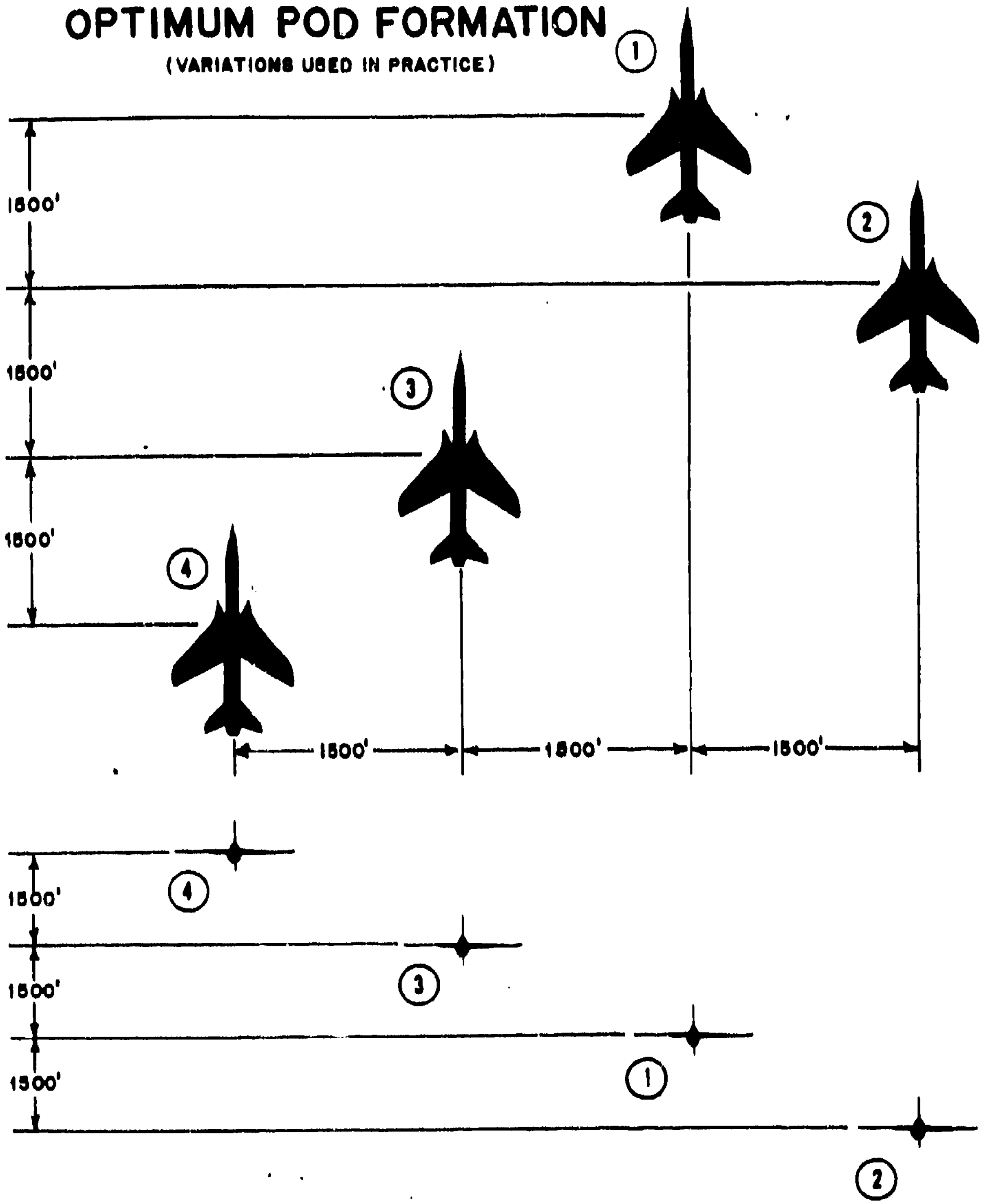


FIGURE XXI

355th TFW
POD FORMATION

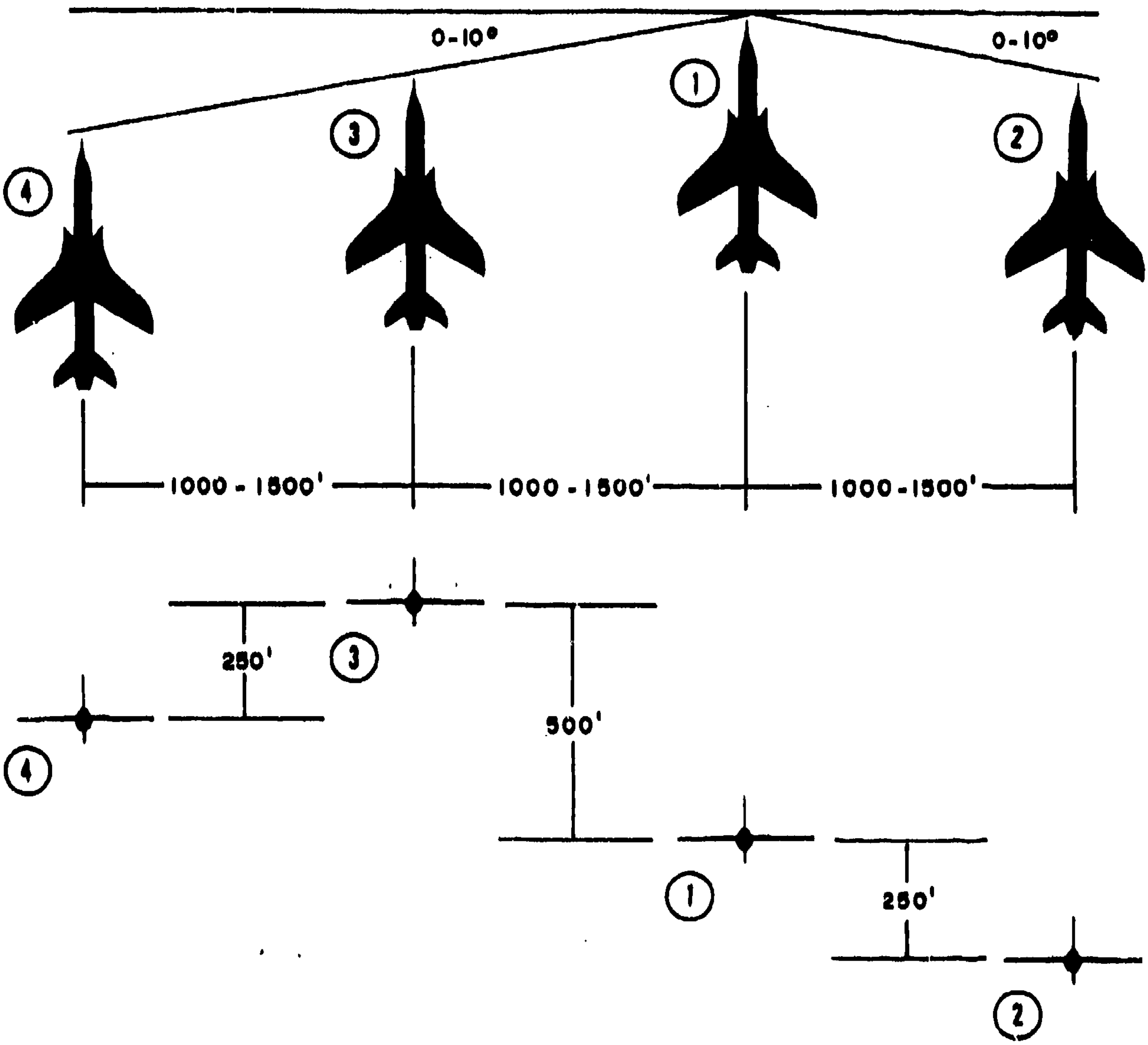


FIGURE XXII

388th TFW
POD FORMATION

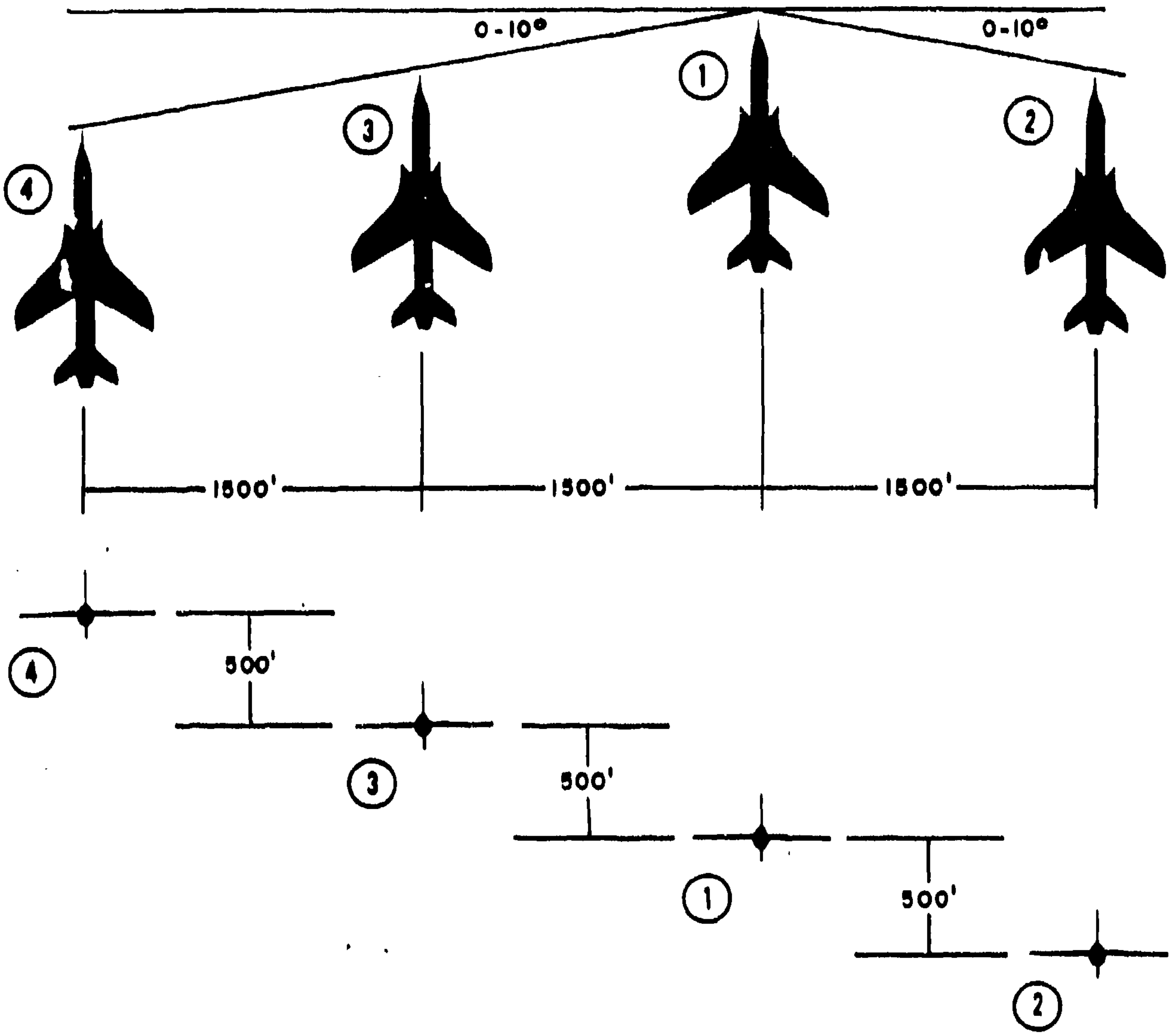


FIGURE XXIII

According to reports written just after the September-October pod flights, despite presenting themselves "as a straight and level non-evasive target at 85mm and SA-2 point-blank altitude, " no fire was directed at the pod-equipped aircraft. (28) If any fire at all was directed at these targets, it was nowhere near the mark. The "fighters were able to go relatively unmolested into the target area at altitudes between 10,000 and 17,000 feet." Some aircraft even flew "racetrack" patterns in target areas, orbiting at altitudes once dominated by the SA-2. Only a year prior, such tactics would have proved disastrous in SA-2 defended regions. The North Vietnamese were not just taking the day off. Some aircraft did not have pods, and were rudely awakened by anti-aircraft fire. In one flight of four F-105s, two did not carry pods. "They received 37mm, 57mm, and 85mm fire, and one SAM (SA-2) passed nearby," according to the post-mission report. This evidence reflected the perils of incomplete pod formations. (29)

The Pacific Air Forces conducted a study of these pods' effectiveness from September through December of 1966. (30) The report's authors were hesitant to point to any single conclusive finding as evidence of the pods' unequivocal success, but noted that a combination of factors were quite telling. The loss rate for pod-equipped F-105's flying missions in "Route Pack Six" in November and December was less than one-third of the loss rates sustained in the same area for F-105's prior to the pods' arrival.(31) Evasive maneuvers by F-105 formations became less frequent after the pods were introduced. Between July and September, over 50 percent of F-105 flights performed evasive action during SA-2 launches. From October to December that number was reduced to less than 10 percent.(32) Finally, the SA-2 missiles were reported to be having problems in tracking their prey and were missing their targets by greater distances after the pods were used than before they were introduced. Between July and September, of the almost sixty "miss-distances" (i.e. SA-2's launched at their flight resulting in a miss) reported by F-105 flights, about thirty misses were by less than 1000 feet and the rest were greater than 1000 feet (The SA-2 needed to get within 200 feet to cause damage). After the pods were used, twenty-two of the twenty nine reported miss-distances were greater than 1000 feet.(33) Also, the number of sorties jettisoning ordnance due to SA-2 launches declined steadily from August until the end of the year.(34)

The medium altitudes, once denied to the American airmen, were again open for grabs in 1966. The door had opened a crack, and the US Air Force was trying to pry it wide open. With the pods now appearing to confuse the ground threats, bombing missions were immediately restored to the medium altitudes. The EB-66's were freed from their SA-2-jamming role and allowed to concentrate on a greater segment of the North Vietnamese air defenses. Iron Hand flights gained a measure of self-protection and were better able to carry out their mission. If fired upon by SA-2 sites, the Iron Hand flights, rather than immediately descending into the waiting anti-aircraft fire, could instead assume a pod formation. Wild Weasel crews had to be careful when choosing to use this formation because the pods' jamming would wreak havoc with their own sensitive radar warning gear.(35) The successful integration of these new electronic combat technologies was an ominous sign for the defenses.

The North Vietnamese did not back down so easily. The value of successfully integrated weapons in air defense was obvious to the air defense system because the new Vietnamese MIG-21 interceptors picked up where the SA-2s were slipping. The new MIG-21's, out in force since April of 1966, contested the American attempts to control the skies. For example, the numbers of American sorties jettisoning their bombs to fend off MIG attacks were significantly higher in the fall of 1966 than comparable figures for SA-2's and ground fire.(36) All things considered, the US Air Force made successful changes in the ways it went about it business of flying tactical combat missions.

Some changes were less obvious. Along with these new technologies came two organized efforts to understand the new technologies' impacts on the USAF system. These were called Anti-SAM Combat Assistance Teams and Comfy Coat.(37) Anti-SAM Combat Assistance Teams (ASCAT) arrived in theater with the first Wild Weasels in 1965, and were also farmed out to most Air Force wings. Each ASCAT team, consisting of a pilot and electronic warfare officer, quickly became an integral part of a wing commander's staff. The focus of the Anti-SAM effort was narrowed to the electronic combat equipment and its associated tactics. These teams also monitored the equipment's performance and recommended improvements. Comfy Coat and ASCAT were two examples of a rapidly expanding command network handling all electronic warfare operations in Southeast Asia.

Headquarters US Air Force initiated the "Comfy Coat" program in October 1966 "to develop the capability for comprehensive evaluation of US Air Force electronic warfare effectiveness in Southeast Asia combat operations (pertaining to) electronic warfare support, self-protection, Wild Weasel, anti-radiation missile operations, and RHAW" equipment.(38) This evaluation program was conducted under the guidance of the US Air Force Security Service, then based in San Antonio, Texas. The Comfy Coat team did not physically arrive in Southeast Asia until July 1967. Representatives from Comfy Coat made their way to most major American air bases and worked directly with the wings.

Although most of the Comfy Coat activity falls outside the scope of this study, it is useful in terms of system-building. The Comfy Coat reports usually came in two varieties: immediate reaction reports (IRR) and monthly summaries (MSR) The first IRR came out on 9 March 1967 and the first MSR at the end of that same month. The IRR's analyzed specific events in detail, with "every element pertaining to the mission exhaustively scrutinized and reconstructed for evaluation." (39) Data from the missions, characteristics of the electronic warfare equipment, American air tactics, and North Vietnamese tactics were just some of the areas investigated. Monthly reports were constructed in a similar way. In its final report for Rolling Thunder, Comfy Coat showed that the probabilities for the Air Force's weapons to actually destroy an SA-2 site was quite low -- less than 20 percent -- even with later improvements of anti-radiation missiles. What the final report did show was the rather timid North Vietnamese actions when faced with aggressive American electronic combat methods (40) show was the rather timid North Vietnamese actions when faced with aggressive American electronic combat methods (40)

One set of data helps to illustrate the effects of the integrated electronic combat elements. The ratio of SA-2 missiles fired to aircraft lost was 12 to 1 in 1965. This ratio jumped to 30 to 1 during 1966. April through October 1967 saw an 83 to 1 ratio.(41) Although the number of missiles fired per aircraft lost is not by itself crucial in determining the SA-2's effectiveness, the trend is important. Certainly, other factors must be considered when examining the performance of the American tactical air combat system, but it is clear that tactical electronic warfare had emerged in nascent form by the end of 1966. A little over a year after Leopard 02 was downed by an SA-2, the US Air Force system had evolved into a new form. It was to keep this basic structure throughout the rest of the Rolling Thunder operations. As each new electronic combat technology was integrated into the this system, as each element was adapted, the air attack system recovered an extra degree of freedom of operations over the North Vietnamese skies.

Conclusion

The air combat operations during Rolling Thunder in 1965 and 1966 resembled Van Creveld's generalization of two large systems slugging it out in the skies in a slow war of attrition. That it took well over a year for the US Air Force to regain their freedom of operations and that the ground-based air defenses would rarely deny the use of these altitudes after 1966 suggest that both the North Vietnamese air defense system and the US Air Force tactical air combat system might have been relatively inflexible. With these systems, the high ground in combat was taken by the side possessing a technological edge, and that advantage remained as long as the technological gap remained.

This "edge" was provided by self-contained platforms like the SA-2 and Wild Weasel. Each platform was capable of acquiring and attracting targets on its own. The effectiveness of these weapons stemmed both from their newness what seemed to be their ability to stand apart from the larger, inflexible combat systems of which they were a part. While the former factor is rather obvious, the latter requires a closer look at the relation between an individual weapon and its system, specifically the process of integration.

The SA-2, while a threat in its own right, depended upon integration into the air defense system not only for its own success as a weapon but also for its very survival. The system's detection elements, for example, continuously fed information to an SA-2 battalion. First, this allowed the latter to remain off the air and not reveal the site's location until the last possible moment. Second, the radar operators would already know where to look for their target, thus allowing for a faster launch. Meanwhile, the anti-aircraft artillery covered the low altitudes which American fighters used to avoid the SA-2, and shot down many aircraft as a result. North Vietnamese fighters could track the progress of American strike formations and could also attack in an attempt to scatter the American formations. It was the combined actions of all these elements which contributed to the SA-2's effectiveness, and it has already been shown what the North Vietnamese air defense system did to the US Air Force in 1965 and 1966.

The integration of new American technologies neutralized the threat posed by the North Vietnamese air defenses and restored freedom in US Air Force medium and high altitude operations. A single technology like the Weasel or even several technologies weren't by themselves responsible for overcoming the defenses. Were Guidelines not fired because a Weasel was feared to be nearby? Or, was it because the SA-2 operators gave up trying to overcome the jamming from pods? Was a Shrike effective after it was launched on its way to a specific radar? Or, while it was still carried aboard an Iron Hand flight prowling within range of several radars? The answer to each of these questions is "yes." Many Weasel crews forced an SA-2 battalion to shut off its Fan Song radar merely by heading directly for the site or feigning a Shrike launch. Those radars that remained on the air were potential beacons for Shrike missiles. North Vietnamese radar operators who could not handle the jamming from a pod formation either did not fire their missiles or fired blindly. In short, the blows of the SA-2 battalions were parried by jamming pods while the thrusts of the hunter-killer teams forced the battalions on the defensive. Although the air defenses continued to grow and remained a lethal threat during the rest of Rolling Thunder, the SA-2 would no longer dominate the air as it had in 1965 and 1966.

The North Vietnamese air defenses were highly integrated and highly coordinated, but the nature of the system played an important role in its combat employment. In this system most every tactical decision came out of Hanoi. Soviet air defense doctrine did not leave much autonomy in the hands of the lower levels of command. As long as the lines of communication from the control center to the various elements remained unobstructed and the Americans remained fairly predictable, this system worked quite effectively. Given that flexibility is governed by the nature of the system and that this system was highly ordered, we can conclude that the North Vietnamese air defense system was to a large degree inflexible as long as strong Soviet influences remained. Furthermore, this condition does not seem to be influenced more by the process of integration than it was by social and cultural factors. The same holds true for the US Air Force system.

The inflexibility in the US Air Force tactical combat system seems also to have been caused by a similar situation of centralized control. That US planes could not bomb most targets without President Johnson's specific permission is an indicator of the lack of autonomy present in the American air combat system. The US Air Force leadership at the highest levels also shared this centralized control with the Johnson Administration. The Headquarters, Pacific Air Forces, thousands of miles from its nearest subordinates, tried to maintain tight control of daily air operations over North Vietnam. This was not always the case, however. For example, each Air Force strike mission, although planned at the highest levels, was thoroughly reviewed by those who were to do the flying. Once launched, tactical decisions were usually left in the hands of the American force commander in the lead flight of Thuds. He was well aware of what to do in case the primary target could not be struck or if some other unforeseen problem arose, and could still execute decisions in the absence of radio contact with the Second Air Division or even PACAF Headquarters.

By the same token, he might also be leading his flight down the same route that was used the day before or even minutes before. Some of his aircraft may not have been carrying full loads of bombs due to ordnance loading problems or because of higher headquarters' demands for increased sortie rates, bombs or no bombs. His target might have been one of dubious tactical value even though his superiors might have been well aware that a convoy carrying Guideline missile reloads was intentionally left untouched that day. Whatever the source of control, whatever the political restrictions in force at the time, and regardless of whether or not airpower could do what either the Johnson Administration or the Air Force leadership though it could do, the constraints placed on air operations greatly exacerbated the immediate tactical problem posed by the SA-2 and the North Vietnamese air defenses in 1965. Fully a year elapsed after the first SA-2 launch before the US Air Force combat system came to terms with its foe.

In retrospect, the limitations imposed on the Air Force system accidentally may have turned out to be of long-term benefit to tactical electronic warfare. Had the missile sites and the reserve supply of North Vietnamese SA-2's been targeted and struck, perhaps the impact of the surface to air missile would have been less felt in the tactical air community. This may or may not have lessened the urgency -- or perhaps might have even delayed the creation of -- Dempster's task force. The Air Force's tactical electronic warfare program may well have remained dormant or only partially developed.

With regard to the nature of technological change, the focus of this study is too narrow for any sweeping generalizations to be made. However, historians of technology would be well-served to consider the role that the operators play when technological change occurs within a system. In this specific case of using Wild Weasels to combat air defenses, the operators helped to bring about changes in training, tactics, the design of new technologies and even Air Force doctrine because in this case the system allowed for a high degree of operator input. This seemed unusual in an organization which otherwise appeared to prefer distant, centralized control of the planning and execution of air operations. Most historians of technology would probably assume that a huge, hierarchical system like that of the US Air Force would not allow for operators to have such decision-making power, but unless a view from "the bottom up" had been taken, a case like this will most likely go unnoticed. Each system, however, has its own unique dynamics and the people using the technology in question will play different roles within different systems.

To be sure, the advent of a new technology by one side does not necessarily produce a natural technological response by the other side. Other studies of response patterns in military systems -- and even in non-military systems -- will shed more light on O'Connell's promising concept of counter-responses. The transformed North Vietnamese air defense system, and not just a surface-to-air missile, elicited a US Air Force response in electronic warfare technologies and concepts, which, when combined to the existing air combat system produced a powerful new system of tactical air combat. The process by which this new Air Force combat system emerged was part evolution and part system building. If the rifle forced an abandonment of musket-based Napoleonic tactics the SA-2 forced the Air Force to discard the doctrine dictating tactical air operations up until July of 1965.

This study shows additional factors, such as a system's nature and the process of adaptation, that historians might consider when they examine military systems and technological change within them. What does it mean exactly to have an "integrated" system? There are many possible interpretations. For example during the Wild Weasel I test program, the decision to tie the hunter-killer flights to the strike force could be seen as a process of integration where a heretofore autonomous element -- the hunter-killer flight -- lost its effectiveness because it was denied freedom of operation. However, it could also be seen as poor employment of a new weapon. Hunter-killer flights were no less integrated in 1966 when they preceded the strike force into the target area and stayed there after the strikers left, but here the Weasels' employment better matched their capabilities. Does integration in modern warfare simply mean that the elements can communicate and coordinate with each other or, more ominously, that some central force has taken control by forcing intermediate-level humans out of the decision-making loop? This latter definition, in fact, seems to be what Van Creveld was trying to emphasize. Yet the operators, the humans, seem to be alive and well in the age of computers, electronics, and integrated warfare. It can only be concluded that the relation between systems integration and modern warfare needs further study.

The strobe on a Weasel's Vector or the blip on the Fan Song's radar represented to the operator more than an electronic display. Ultimately, it represented another human trying to kill him. The struggle that is modern air warfare is more than a clash of technologies. It is a struggle between people. Combat tactics used by one side not only took into account the capabilities of the individual operators and their weapons, but also the perceived abilities of the opponents. The SA-2s denied the medium altitudes because airmen were afraid of it. Similarly, the SA-2s lost their dominant position because their operators were intimidated by Wild Weasels. As in any conflict, it was as much a challenge to control the actions of one's own forces in combat as it was to predict the response of the opponent. Ultimately, either one side would win, the other would lose, or both would retreat to lick their wounds. To these ends, warfare has not changed.

NOTES AND REFERENCES

NOTES, REFERENCES FOR INTRODUCTION

1. This study strives to remain within the realm of USAF tactical air operations directed against North Vietnam in 1965-1966. Very little mention will be made in this essay of either US Navy or Marine Corps air operations. This in no way intends to detract from the others' roles; I had to narrow the scope of this paper in order to make it manageable for a master's thesis.

2. See Mark Clodfelter, The Limits of Airpower: The American Bombing of North Vietnam (New York: Free Press, 1989) and Earl Tilford, Jr. Crosswinds: The Air Force's Setup in Vietnam (College Station: Texas A&M University, 1993).

3. As will be seen later, the Navy configured its own aircraft for a similar purpose but did not continue operations with a dedicated "Wild Weasel" type aircraft after the Vietnam conflict. On the other hand, the Air Force continues to maintain a Wild Weasel force until the time of this writing. Wild Weasels are but one part of a multifaceted approach to electronic combat. Current US Air Force doctrine, as explicitly stated in Air Force Manual 1-1: "Basic Aerospace Doctrine of the United States Air Force," (Vol II page 191) calls electronic combat "a sine qua non of modern warfare, particularly for airmen." One would be hard-pressed to find such a claim in Air Force doctrine in 1965.

4. Alex Roland's "Technology and War: The Historiographical Revolution of the 1980's," (Technology and Culture Jan 93.) reviewed many major works of the last decade. See also John Ellis, Social History of the Machine Gun London, 1976 ; IB Holley, Ideas and Weapons, Yale University Press, 1953; Alex Roland, "Secrecy, Technology and War: Greek Fire and the Defense of Byzantium" Technology & Culture (Oct 1992); Kemp, Pfaltzgraft and Ra'anan The Other Arms Race: New Technologies and Non-Nuclear Conflict , Toronto: Lexington Books, 1975; K.Perkins. Weapons and Warfare: Conventional Weapons and Their Roles in Battle, New York: Brasseys, 1987; Trevor Dupuy The Evolution of Weapons and Warfare, New York: The Bobbs-Merill Co., 1980. The Journal of Military History has featured several articles involving military technology since 1989. Some include: George Raudzens "War-winning weapons: The Measurement of Technological Determinism in Military History" 54(Oct 1990); Daniel Kuehl "Refighting the Last War: Electronic Warfare and USAF B-29 Operations in the Korean War," 56(Jan 1992); Roland, "Technology, Ground Warfare and Strategy: The Paradox of American Experience." 55(Oct 1991); Kenneth Werrell "The Weapon the Military Did Not Want: The Modern Strategic Cruise Missile," 53 (Oct 1989).

5. Martin Van Creveld Technology and War, New York: The Free Press, 1989, p279. Specifically, I refer to his chapter called "Integrated War."

6. Van Creveld Technology and War p280

7. By using the term "weapon", I refer here not only to an actual weapon but also to related military technology which can improve the effectiveness of these weapons. Thus, for the purposes of this essay, the terms "weapon" and "technology" will be used interchangeably. For example, with reference to a modern electronic battlefield, weapons refer to new cannon as well as new fire control system enabling the cannon to be fired with unsurpassed accuracy. Other examples would be an improved version of a jet fighter or an electronic jamming pod which disrupts air defense radars and can be attached to any fighter aircraft.

8. The users of the technology in combat and the decision-makers who first introduced the technology into the system are generally two separate entities. I define "operators" as the individuals -- the troops, airmen, sailors, marines -- who use the technology in daily combat operations. "Decision-makers" refer to those who have the authority or ability -- commanders, procurement officers, government contractors -- to introduce or deny the introduction of a new technology to a particular military system. The degree of ease in communication between these two groups generally determines how quickly and effectively a new weapon becomes integrated into the overall system.

9. One wonders, for example, what might have happened if the Germans were better prepared to react quickly to the gas-induced gaping hole in the French lines at Ypres in 1915. In 1940, British and French tanks were far superior to the German panzers in numbers, armor thickness and firepower. Yet in the Blitzkrieg across France the Allied armor was usually out-fought by their German counterparts.

NOTES, REFERENCES FOR CHAPTER ONE

1. "SAMs Down F-4C, Damage Three Others," Aviation Week and Space Technology, 2 August 1965,p27.

2. USAF strategic air warfare, directed by Strategic Air Command (SAC), had by this time already reacted to the missile threat. The B-70 bomber program, expensive electronic countermeasures equipment for the existing B-47 and B-52 bombers, and change of penetration tactics to low-level in an effort to fly underneath Soviet radar coverage are three examples. See Price Electronic Warfare.

3. Outgoing Message: Commander-in-Chief, Pacific Air Forces (CINCPACAF); Subject: Rolling Thunder Basic Operations Order, 5 May, 1965. (AFHRA)

4. For Bell Labs work regarding radar and air defense systems see: Fagen, M.D., ed. A History of Engineering and Science in the Bell System. Vol II National Service in War and Peace (1925-1975). New Jersey: Bell Telephone Laboratories, Inc., 1978.

5. See Alfred Price, History of US Electronic Warfare Volume II, Alexandria: Association of Old Crows, 1989. Also, Kenneth Werrell's Archie, Flak, AAA and SAM (Washington DC: US Government Printing Office, 1988)traces some aspects of guided missile history.

6. The SA-1 had a limited field of fire and was permanently revetted. It's radar, the "Yo-Yo", used a then unheard-of radar antenna scan pattern called a "track-while-scan." This allowed the radar to track a target (i.e. provide a firing solution to for the fire-control system) while simultaneously monitoring a number of other potential targets within a "sector" of airspace. A new scan pattern complicates the task of creating effective countermeasures for the radar. See Alfred Price, History of US Electronic Warfare Volume II .

7. Gary Powers' own account is in his Operation Overflight (New York: Holt, Rinehart, and Winston,1970). Werrell, Archie,Flak, AAA and SAM p.130 and Larry Davis, Wild Weasel: The SAM Suppression Story, (Carrollton, Texas: Squadron/Signal Publications, 1986) both cover earlier SA-2 firings.

8. See Werrell, Archie, Flak, AAA and SAM

9. Letter to the author from historian Alfred Price, dated 21 December, 1993.

10. "Wild Weasel I: Response to a Challenge." USAF Southeast Asia Monograph Series, Maxwell Air Force Base, Alabama: Air War College, 1977, p.9. The post mission report is contained in "Bluebells Ringing," USAF Project CHECO (Contemporary Historical Evaluation of Combat Operations) Report 65-1, but there are no surviving copies of this report at the USAFHRA or in the records of the PACAF Historian (Hickam AFB, Hawaii). The written accounts conflict with a 1985 video interview (see below) with one of the pilots in Leopard flight. They refer to "02" being hit while the pilot says it was "04." I chose to use the pilot's account

A hard-to-find but informative video on the Wild Weasel program includes an account of this July mission: see Patti King, prod. First In, Last Out (The BDM Corporation, 1985) hereafter referred to as "First In, Last Out."

11. John Morocco, Thunder From Above, Boston, Boston Publishing Company, 1984 p 106. For fighter operations over Vietnam see also R. Frank Futrell, ed. Aces and Aerial Victories, (Washington DC: Headquarters, USAF, 1976).

12. William A.Hewitt. "Planting the Seeds of SEAD," Maxwell AFB, Alabama: School of Advanced Airpower Studies Thesis, 1993 p 1. For a description of Airborne control and MIG warning see Berger, ed. The United States Air Force in Southeast Asia. Washington DC: Office of Air Force History, 1977

13. Morocco, Thunder From Above, p.106

14. "Wild Weasel I: Response to a Challenge," p.11

15. Ibid, p.9

16. For one account of Lyndon Johnson's rationale behind the prosecution of the Rolling Thunder campaign, see Doris Kearns, Lyndon Johnson and The American Dream, New York: Harper and Row, 1976.

The micro-management of the Vietnam air war by the Johnson Administration is an important factor for any historian to consider when analyzing US aerial operations in Southeast Asia through 1968. It is not, however, the only reason Rolling Thunder turned out to be just a rumble as has been shown in the studies by Earl Tilford, Jr. and Mark Clodfelter, Air Force historians critical of the way the US Air Force fought the Vietnam war. See Tilford, Crosswinds: The Air Force's Setup in Vietnam and Clodfelter, The Limits of Airpower.

17. Air Force General-Major Mikhail Ilyich Fesenko, "The Vietnam Syndrome:Uneven Play," Aviation and Cosmonautics no 7 (July, 1992). (Translated by Peter Vorobeiff, Lehigh University).

18. For a look at the former Soviet Union's air defenses see David Isbey, Weapons and Tactics of the Soviet Army London. Jane's Publishing company. 1988. Many Russian veterans of Vietnam were SA-2 advisors/operators, and only recently have they been

allowed to organize open veteran's groups. The Vietnam Veterans of America and Veterans for Peace have established contact with many Russian veterans, especially those from the conflict in Afghanistan, who suffer from post-traumatic stress syndrome. These Russian operators represent an untapped, valuable source for studies covering air operations in Southeast Asia.

19. For a historical treatment of US electronic reconnaissance operations, see John T. Farquhar "A Need to Know: The Role of Air Force Reconnaissance in War Planning, 1945-1953 " Ohio State University: PhD dissertation, 1991 and Volumes I and II of Alfied Price, History of US Electronic Warfare. One RB-66B strayed 100 miles off course and into East German airspace in 1964. It was shot down by Soviet fighters. The crew survived and returned to the West a few weeks later.

At this time, the aircraft were referred to as "RB-66's." The nomenclature "EB-66" came about after 1965, but I have chosen to use this designation throughout the essay. See Rene Francillon and Mick Roth, Douglas B-66 Destroyer ("Aerofax Minigraph 19,"Arlington, Texas: Aerofax, Inc, 1988.) for a detailed examination of the B-66 aircraft and all its variants.

20. Some radars can be "heard" no matter what their operating frequency. Even though radar waves are far beyond the human hearing range, the rate at which radar pulses are sent out of the radar transmitter -- called the "Pulse Repetition Frequency, PRF -- usually falls within the range of audible frequencies for a human. These tones can be heard given the proper radar detection equipment. Therefore, sophisticated radar receivers can produce distinct sounds for different radars. A trained ear can identify scores of different radars by sound alone.

On the EB-66C, each of the aircraft's four electronic warfare officers had specific duties. Each listened to different bands of radar frequencies, but two of the four looked specifically for Fan Song and Fire Control radars. (Source: Author's interview with former EB-66 EWO Col Bill Jahn, USAF (Ret) April, 1994.)

21. The traditional curtain of secrecy surrounding the development of military radars and radar countermeasures hindered widespread dissemination of information related to these kinds of duties even within the Air Force.

22. Jack Broughton Going Downtown: The War Against Hanoi and Washington, New York: Orion Books, 1988, p.172. Broughton is a retired Air Force Colonel and former Deputy Wing Commander of the 355th Tactical Fighter Wing in 1966-67.

23. For a short account of the employment of an SA-2 battalion as well as typical soviet-style air defenses see David Isby, Weapons and Tactics of the Soviet Army.

24. "First In, Last Out" (see note 10)

1. The concept of systems has been around at least since the writings of Adam Smith. The Department of Defense embraced the word "weapon system" in the years prior to Vietnam. Historians of technology are most familiar with systems as defined by Thomas Hughes (Networks of Power: Electrification on Western Society 1880-1930. Baltimore: Johns Hopkins University Press, 1983). John Staudenmaier, in Technology's Storytellers(Cambridge: The MIT Press, 1985) showed many ways in which historians have used systems in their works. This essay attempts to rest part of its foundation upon the concept of complexity, complex systems, and system dynamics as described in works like: M. Mitchell Waldrop, Complexity: The Emerging Science at The Edge of Order and Chaos, New York: Simon and Schuster, 1992 and John L. Casti, Searching for Certainty: What Scientists Can Know About The Future, New York: William Morrow and Company, 1992. These are just two of the hundreds of works in this field.

2. Philip Babcock Grove, ed. Webster's Third New International Dictionary of the English Language Unabridged, Springfield, Mass: Merriam Webster, Inc, 1981, p. 2322.

3. John Warden III, The Air Campaign: Planning For Combat. New York: Pergamon-Brassey's, 1989, p.31

4. Richard Hallion, Storm Over Iraq: Air Power And The Gulf War, Washington DC: Smithsonian Institution Press, 1992, p169-170.

5. See Robert O'Connell, Of Arms and Men: A History of War, Weapons and Aggression, New York: Oxford University Press, 1989, p209. See Also Ellis, Social History of The Machine Gun, and George Raudzens "War Winning Weapons: The Measurement of Technological Determinism in Military History." For a similar example see also Thomas Espers, "The Replacement of the Longbow by Firearms in the English Army," in Technology and Culture, July, 1965.

"Adapting the technology to the system" more correctly refers to lengthy process in which a system sees a need for a new technology, contractors come up with proposals and bid of the project, a selected contractor builds a weapon to the system's specifications, the initial versions are then tested by the system, modifications are recommended and implemented, and then it is finally sent out to the operational units. I have primarily focused on this final stage, where the actual operators come in contact with this technology and provide their own inputs to technological change.

6. See S.L.A. Marshall, Men Against Fire, (Morrow,1947) Reprint from Byrrd Enterprises, Inc Alexandria, VA.

7. See M. Mitchell Waldrop, Complexity: The Emerging Science at the Edge of Order and Chaos, p.311-312.

NOTES, REFERENCES FOR CHAPTER THREE

1. For classic examples of similar air defense systems in World War II-era Britain and Germany, see Sean Swords, Technical History of the Beginnings of Radar, IEE History of Technology Series. London: Peter Peregrinus, Ltd.,1986, Alfred Price, Instruments of Darkness, RV Jones, Wizard War. New York: Coward, McCann & Geoghegan, Inc. 1978, Brian Johnson The Secret War. New York: Methuen, Inc 1978, Martin Streetly, Confound and Destroy London: MacDonald and Janes, 1978. The most complete US History is Henry Guerlac, RADAR in World War II. The history of Modern Physics Series. Tomash Publishers, 1987.

2. During World War II, German air defenses often were forewarned of an impending night attack from the Royal Air Force Bomber Command by detecting emissions of the bombers' radar. British maintenance crews often tested the radar on the ground prior to a mission, and the bomber crews themselves switched on their sets shortly after takeoff.

3. Tilford, Crosswinds: The Air Force's Setup in Vietnam

4. Table of anti-aircraft artillery weapons commonly seen in North Vietnam:

Weapon	Most Lethal Range	Maximum Altitude
12.7mmQuad	1000'	5000'
14.5mmTwin	1300'	6500'
37mm	1400'	10000
57mm	1500-5000'	18000'
85mm	5000-10000'	25000
100mm	3000-20000'	30,000

From AJC Lavelle, ed. The Tale of Two Bridges and The Battle For The Skies Over North Vietnam, "USAF Southeast Asia Monograph Series Volume 1"Washington DC: US Govt. Printing Office. 1976, p. 122.

5. Directorate of Tactical Evaluation. "Contemporary Historical Evaluation of Combat Operations -- Rolling Thunder Continuing Report: July 1965-Dec 1966." (printed in July, 1967) Headquarters, Pacific Air Forces, p 21 (Hereafter referred to as "CHECO Rolling Thunder").

6. Ibid

7. Broughton, Going Downtown, p.29

8. Directorate of Tactical Evaluation, "Contemporary Historical Evaluation of Combat Operations -- Tactical Electronic Warfare Operations in Southeast Asia, 1962-1968,Headquarters, Pacific Air Forces, Figure 13. (Printed February, 1969) Hereafter referred to as "CHECO Tactical EW."

9. William Momyer, Air Power in Three Wars,(Washington, DC. US Government Printing Office, 1978) describes the tight, positive control North Vietnamese GCI controllers had over their pilots' missions.

10. One of the biggest lessons learned was that "dogfighting" skills were not made obsolete with the advent of radar-guided and infrared air-to-air missiles.

11. See: Lavelle, The Tale of Two Bridges and The Battle For The Skies Over North Vietnam (hereafter cited as A Tale of Two Bridges) and Futrell's Aces and Aerial Victories for the use of North Vietnamese interceptors.

12. The tremendous "boom" associated with the launch of a Guideline was heard by airmen forced down in the vicinity of active SA-2 battalions.

13. David Isbey, Weapons and Tactics of The Soviet Army, p.335-339.

14. "CHECO Rolling Thunder," p. 104 and "Iron Hand/Wild Weasel," Project Corona Harvest, Maxwell AFB: USAFHRA, p.10

15. Unit History, 355th Tactical Fighter Wing, July to December, 1965. (USAFHRA). There were at the time nine EB-66C's of the 9th Reconnaissance Task Force (Later the 41st Tactical Reconnaissance Squadron) supporting operations in Southeast Asia.

16. "CHECO Tactical EW Operations," p. 15.

17. Ibid, p.49

18. Fesenko, "Vietnam Syndrome: Uneven Play"Aviation and Cosmonautics 7 (Jul. 1992).

19. Fesenko, "Vietnam Syndrome: Skills to Take the Fortress," Aviation and Cosmonautics.9 (Sep 1992) (Translated by Peter Vorobeiff, Lehigh University).

20. See Futrell, Aces and Aerial Victories.

21. "Wild Weasel I, Final Report (Southeast Asia Phase), Eglin Air Force Base, Florida: Air Proving Ground Center, Air Force Systems Command and Tactical Air Warfare Center, Tactical Air Command, March 1966, p. 37.

22. "CHECO -- Tactical EW Operations" p. 26

23. Extreme forms of centralized control were true in 1972 as well, when the North Vietnamese air defenses were reeling from the US "Linebacker I" air campaign in response to the Easter Offensive. See Fesenko, "Vietnam Syndrome: Skills to Take The Fortress."

24. The most recent example of a highly centralized air defense system that got shattered was that of Iraq in January of 1991. See Hallion, Storm Over Iraq. By contrast, the US Air Force espouses centralized control of planning and decentralized execution in combat operations.See both the 1984 and 1992 version of Air Force Manual 1-1: "Basic Doctrine of the US Air Force."

1. Outgoing Message: Commander-in-Chief, Pacific Air Forces (CINCPACAF); Subject: Rolling Thunder Basic Operations Order, 5 May, 1965. (AFHRA)

2. A typical fighter wing might have at least 75 fighter aircraft. For a straightforward passage on the US tactical unit command structure see Morocco, Thunder From Above, p. 191.

3. See Futrell, Aces and Aerial Victories.

4. "Air Tactics Against NVN Air/Ground Defenses," USAF Working Paper in AFHRA, 27 Feb 1967, p. 7. (Some portions remain classified; this comes from a page that had been declassified entirely)

5. Modern US Air Force E-3A or US Navy E-2C airborne warning aircraft fly at high altitude with "look-down" radars. The EC-121 "Big Eye" has long since been out of the USAF inventory.

6. "Air Tactics Against NVN Ground Defenses," p. 7.

7. "F-105 Combat Tactics, 388th Tactical Fighter Wing," Maxwell Air Force Base, Alabama: USAF Historical Research Agency (USAFHRA), September, 1967, p. 56. Hereafter cited as "388 TFW Tactics."

8. Ibid

9. "Aerospace Rescue and Recovery in Southeast Asia," Project Corona Harvest. Maxwell Air Force Base, Alabama: Aerospace Studies Institute. April, 1969, p.15. See also, Earl Tilford, Jr. The United States Air Force Search and Rescue in Southeast Asia, Washington, DC: Center for Air Force History, 1992.

10. "388 TFW Tactics," Chapter I, p.4.

11. "Aerospace Rescue and Recovery," p. 15. See also Jack Broughton, Thud Ridge

12. "An Analysis of the F-105 Weapons System in Out-Country Counter Air Operations," Maxwell Air Force Base, AL: Air War College, April, 1968, p. 3

13. Ibid, p. 12

14. "CHECO Tactical EW Operations," Figure 13

15. "EB-66C Out-Country Electronic Reconnaissance, 1965-1967," Maxwell AFB, AL: Air War College, April 1968, p.2.

16. Ibid, p.1

17. Ibid, pp.3-4

18. Alfred Price, History of US Electronic Warfare, Volume II, p.249

19. United States Air Force Oral History Program, Interview of Mr. Peter R. Murray, AFHRA, 10-11 July, 1973. p. 34

20. "388 TFW Tactics," p.3.

21. Ibid

22. Ibid, p.4

23. Ibid, p.3

24. Jane Grubb and Don Morrow, "The Air War in Korea," Force Employment, Volume 3, Maxwell AFB: USAF Squadron Officer's School, p.65

25. "Command and Control of Southeast Asia Air Operations, 1 January 1965 - 31 March. 1968," Project Corona Harvest, Maxwell AFB: USAFHRA, p. 25 (Hereafter cited as "Command and Control.")

26. See Tilford, Crosswinds: The Air Force's Setup in Vietnam

27. Little effort was directed toward integration with neither the Army nor Marines. See "Command and Control, " p. 3

28. Ibid, pp. 53-54

29. "388 TFW Tactics," (no page given). A cluster bomb, identified by the prefix "CBU" is essentially a hollow shell containing hundreds of "bomblets," or small, baseball-sized explosives. At a preset altitude the casing separates and releases the bomblets over a wide area; the bomblets arm themselves through spinning and explode upon contact with the ground.

30. Lavelle, A Tale of Two Bridges, p. 120.

31. Tilford used the term: "on the wings of strategic bombing," to describe the thinking of the Air Force leadership at the time. See Tilford, Crosswinds: The Air Force's Setup in Vietnam.

32. The Air Force emphasized nuclear warfare in their planning, which carried over into daily training. Procedures and considerations for a conventional environment are different than that for nuclear combat.

33. "An Analysis of The F-105 Weapons System in Out-Country Counter-Air Operations," Maxwell AFB: USAFHRA , p. 3

34. Unit History, 355th Tactical Fighter Wing, USAFHRA; Telephone interview by author with General Charles Horner, Commander USAF Space Command, 5 April, 1994

35. Interview with General Charles Horner, 5 April, 1994.

36. "An Analysis of the Present Tactical Fighter Weapons Systems Capabilities in SEA Out-Country Interdiction Operations," Maxwell AFB: Air War College, April, 1968, p. 2.

37. Ibid, pp. 2-4

38. "Command and Control," p.3

39. Ibid, p. 26

40. Ibid, p. 3

41. Morocco, Thunder From Above, p. 125.

42. Ibid, p. 107

43. "An Analysis of the F-105 Weapon System in Out-Country Counter-Air Operations." p. 5

44. See Broughton's Going Downtown and Thud Ridge.

45. For example, compare Clodfelter's Limits of Airpower with Admiral US Grant Sharp'sStrategy For Defeat (Presidio Press, 1979).

46. "Command and Control," p. 2

47. Doris Kearns, Lyndon Johnson and The American Dream, p. 264

48. Ibid, p.270

49. Earl H. Tilford, Jr., "Vietnam," Force Employment (USAF Squadron Officers School Text) Vol 3, March, 1988, p.74.

50. Fesenko, "Skills To Take The Fortress." Aviation and Cosmonautics 9 (Sep 1992).

NOTES, REFERENCES FOR CHAPTER FIVE

1. Message: PACAF to 2nd Air Division, October, 1965. AFHRA.

2. Lethal envelope refers to the volume of air surrounding the missile site subject to a missile attack by the SAM. It takes both the maximum missile range and altitude into account.

3. See for example John Staudenmaier, Technology's Storytellers Cambridge: The MIT Press, 1985 and George Raudzens, "War Winning Weapons."

4. O'Connell, Of Arms and Men p. 264

5. Ibid, p.7

6. Of course this concept applies to sonar as well, but that is beyond the scope of this paper.

7. See Alfred Price Aircraft Versus Submarine (London: William Kimber, 1973) or Brian Johnson The Secret War (New York: Methuen, Inc., 1978) for treatments of technological responses and counter-responses in warfare under the North Atlantic during World War II.

8. See Paul Watzlawick, John Weakland and Richard Fisch Change: Principles of Problem Formation and Problem Resolution New York: W.W. Norton & Company, 1974 pp 111-112.

9. The options considered here are adapted from John Warden III, The Air Campaign.

10. Most historical works relating to the history of radar have come from Great Britain, and many of these written by the very scientists involved in British radar development. American treatments, especially among historians of technology, have been relatively sparse. However, the most detailed case history was written by an American, Henry Guerlac (Guerlac, Henry E. RADAR in World War II. The History of Modern Physics Series (1800-1950). Tomash Publishers for the American Institute of Physics, 1987.) See also David Kite Allison's New Eye For The Navy: The Origin of Radar at the Naval Research Laboratory (Was, DC: US Govt. Printing Office, 1981). A sample of some British works include:

Bowen, E.G. Radar Days. Bristol: Adam Hilger, 1987.

Callick, E. B. Metres to Microwaves: British Development of Active Components for Radar Systems, 1937 to 1944. IEE History of Technology Series. Exeter: Short Run Press, Ltd., 1990

Fisher, David E. A Race on the Edge of Time: Radar the Decisive Weapon of World War II. New York: McGraw Hill, 1988.

Lovell, B. Echoes of War: The Story of H2S Radar. Bristol: Adam Hilger, 1991.

Rowe, A.P. One Story of Radar. Cambridge: University Press, 1948.

Watson-Watt, Robert. The Pulse of Radar. New York: The Dial Press, 1959.

In 1985, the American IEEE had a fifty-year anniversary issue about radar, which included many recently released British wartime reports. See: Institute of Electrical and Electronics Engineers. "Historical Radar." In Proceedings of the Institute of Electrical and Electronic Engineers 132, vol. 6, part A (October 1985).

There are relatively few treatments of electronic warfare, many of these by Alfred Price. Most works tend cover electronic warfare over the course of the twentieth century. Thus there is plenty of room for more specific studies. Some examples of what has been done:

Arcangelis, Mario de. Electronic Warfare. United Kingdom: Blandford Press, 1985.

Price, Alfred. Instruments of Darkness. New York: Charles Scribner's Sons, 1978.

_____. The History of US Electronic Warfare. Vol. 1, The Years of Innovation--Beginnings to 1946. Alexandria: The Association of Old Crows, 1984.

_____. The History of US Electronic Warfare. Vol 2, The Renaissance Years, 1946 to 1964. Alexandria: The Association of Old Crows, 1989.

11. This story is told in RV Jones, Wizard War.(New York: Coward, McCann & Geoghegan, Inc, 1978).

12. Chaff continues to be an effective passive radar countermeasure. It did not figure prominently over Vietnam during the time period covered in this study, since the tactical combat aircraft were not equipped with chaff dispensers at this time. Some enterprising F-4 Phantom crews trapped chaff boxes between the speed brake and wing, allowing for a one-time use by deploying the speed brake in flight.

13. Different radars are modified with different kinds of "electronic counter-countermeasures," each giving some measure of protection against enemy active and passive jamming methods.

14. Some British military officials were hesitant to use the revolutionary H2S bombing radar in their RAF Bomber aircraft. It was argued that it one of the bombers was shot down, the Germans would have an intact radar.

15. See Farquahar "A Need To Know" and Volume I of Alfred Price, History of US Electronic Warfare.

16. An example of differences in radar operators abilities to work through jamming can be seen in Alfred Price, History of US Electronic Warfare, vol II pp 211-214

17. Ibid, pp. 183-186

18. This comes from an excellent, unclassified Air Force pamphlet on the basics of electronic combat. See "Electronic Combat Principles," Air Force Pamphlet 51-45, 15 September, 1987.

19. Price, History of US Electronic Warfare, Volume II, p. 299

20. Ibid, p. 301

21. Ibid, p.287

22. "USAF Reconnaissance Activities in Support of Operations in Southeast Asia, 1 January 1965 - 31 March 1968," Project Corona Harvest. Maxwell AFB: USAFHRA, 1968.

23. Ibid

24. Many studies in operations research have been done regarding penetration of integrated air defense systems. For example, see Michael P. Bailey "Measuring Performance of Integrated Air Defense Networks Using Stochastic Networks," in Operations Research 40(Jul-Aug 1992): 647.

25. "CHECO Tactical EW Operations," p27

26. Ibid, p. 24

27. Ibid, p. 56. An excellent study on this "Korean War script" is Daniel Kuehl's, "The Radar Eye Blinded," Duke University: PhD Dissertation, 1992.

28. "USAF Research and Development and Procurement Activities in support of Operations in Southeast Asia," Project Corona Harvest, Maxwell AFB: USAFHRA, 1968, p. 44. See also Davis, Wild Weasel, p.8

29. "DRV SAM Problem", Combat Arena Background Paper, Maxwell AFB: USAFHRA, p. 5.

30. USAF Oral History Program, Interview with Mr. Peter Murray: 10-11 July, 1973 (USAFHRA) p. 34.

31. "DRV SAM Problem," p.5

32. Kuehl, "The Radar Eye Blinded," p. 233

33. Ibid, p. 232-236

34. See Price History of US Electronic Warfare, Volume II and Kuehl, "The Radar Eye Blinded."

35. Kuehl,"The Radar Eye Blinded," p. 226-227

36. Larry Davis, Wild Weasel, p.8

37. Kuehl. "The Radar Eye Blinded," p236.

38. "USAF Research and Development and Procurement Activities in Support of Operations in Southeast Asia, 1 Jan 65 - 31 March 1968," Project Corona Harvest, Maxwell AFB: USAFHRA, p.44.

39. Price. History of US Electronic Warfare p 263

40. The QRC-160 pod was ten inches in diameter, about one-hundred inches in length, and weighed approximately 150 pounds.

The QRC program, attempting to live up to its name, bypassed normal acquisition procedures and gave a virtual monopoly in electronic countermeasures contract to one company, Hallicrafters. Other manufacturers were eventually made part of the program. Price touches on this subject in his History of US EW and Kuehl does also, but the story behind QRC is worth a detailed analysis. Historians of technology have not made many detailed case studies of the modern military-industrial complex. A recent case study is Glenn E. Bugos, "Testing the F-4 Phantom II: Engineering Practice in the Development of American Military Aircraft," University of Pennsylvania: PhD Dissertation, 1989.

41. "CHECO Tactical EW Operations," p. 18.

42. Some of the best published histories of the activities at the Radiation Laboratory are Guerlac's RADAR in World War II and Price, History of US Electronic Warfare,Volume I

43. Courtesy of Mr. Daryl Jacobs, the contents of three 8th Air Force--8th Bomber Command Army Air Force letters regarding the Moth program, dated 5 Nov. 1943, 5 Nov. 1943, and 22 Nov. 1943 were retrieved from the archives at the Association of Old Crows and relayed to me by personal letter dated 12 August, 1993.

44. The latest versions of the Sparrow are still used by USAF,USN and USMC fighters.

45. Hewitt, "Planting the Seeds of SEAD" p 15 and Price History of US Electronic Warfare Vol II p80.

46. USAF Oral History Program, Interview with Mr. Peter Murray, 10-11 July, 1973 Maxwell AFB: USAFHRA. p34

47. Ibid.

1. Tilford, Crosswinds: The Air Force's Setup in Vietnam pp 81-88

2. "388 TFW Tactics," p.2

3. Nordeen (Air Warfare in the Missile Age), for example, calls the SA-2 "somewhat of a disappointment." p40
John Dickson, in "Electronic Warfare in Vietnam: Did We Learn Our Lessons?"(Air University: Air War College Thesis. May 1987, p.11) wrote the SA-2 received "undeserved attention." by those who have observed the air war in Southeast Asia.

4. Van Creveld used this term in a generic sense; he did not identify specific types of aircraft. See Technology and War New York: The Free Press, 1989 p280

5. Ibid

6. See Werrell, Archie, Flak, AAA, and SAM p137 and Lon Nordeen Jr. Air Warfare in the Missile Age (Washington DC: Smithsonian Institution Press, pp111-123)

7. Nordeen. Air Warfare in the Missile Age, p.122.

8. Tilford, Crosswinds: The Air Force's Setup in Vietnam

9. Momyer, Airpower in Three Wars, p.136

10. Momyer. Airpower in Three Wars, p 136 and Karl Eschmann Linebacker: The Untold Story of the Air Raids Over North Vietnam New York: Ivy Books, 1989, p 203.

11. See for example, O'Connell Of Arms and Men. For a shorter treatment of the impact of weapons on battlefields see George Raudzens. "War-Winning Weapons: The Measurement of Technological Determinism in Military History."Journal of Military History.

12. See John Keegan, Face of Battle and Allan R. Millett and Peter Maslowski, For the Common Defense. New York: The Free Press, 1984.

13. I.B. Holley, in Ideas and Weapons (Yale, 1953), linked the need for doctrinal change to coincide with, if not precede, technological change.

14. "DRV SAM Problem," p.1

15. Morocco, Thunder From Above, p. 107-109

16. Quoted in Al Santoli, Leading the Way: How Vietnam Veterans Rebuilt the US Military, (New York: Ballantine Books, 1993).

17. Morocco, Thunder From Above, p108. One of the captured USAF pilots became Keirn's cellmate for a short time

18. "DRV SAM Problem," p. 2.

19. "CHECO Rolling Thunder," p. 6

20. Ibid, p.7

21. Ibid, p. 5 and "CHECO Tactical EW Operations," p.85

22. "DRV SAM Problem," p.4

23 Ibid, p.2

24. Ibid, p.3

25. Davis, Wild Weasel, p. 8 and Unit History, 355th TFW, Maxwell AFB: USAFHRA.(no page number given).

26. Unit History, 355th TFW, Maxwell AFB: USAFHRA

27. Ibid, and "CHECO Tactical EW Operations," p. 28

28. "388 TFW Tactics," (page not numbered).

29. Unit History, 355th TFW, Maxwell AFB: USAFHRA (no page number).

30. "EB-66C Out-Country Electronic Reconnaissance, 1965-1967," p.5

31. Unit History, 355th TFW, Maxwell AFB: USAFHRA (no page number).

32. Rolling Thunder operations over North Vietnam usually consisted of one morning strike and one afternoon strike, like clockwork.

33. The altitude from which one attacks a target and the way in which the target is approached depend to a large degree on the ordnance carried on board the aircraft. As we have seen earlier, certain weapons like napalm and the early cluster-bombs required low altitude, level deliveries.

34. This comes from an end of tour report by Col M.S. "Sabre" Sams of the 388th TFW as quoted in Lavelle. Tale of Two Bridges. p135.

35. "EB-66C Out-Country Electronic Reconnaissance, 1965-1967," p.2

36. "388 TFW Tactics," pp. 4-5. Telephone interviews by author with Major Jack Donovan, USAF (Ret), April, May, 1994. Specific maneuvers were situationally dependent.

37. "Battle for the Skies Over North Vietnam," p.35

38. Morocco, Thunder From Above, p. 112

39. Broughton, Going Downtown, p172.

40. Ibid, p.273.

41. Momyer, Airpower in Three Wars, p.233.

42. "CHECO Tactical EW Operations," p35. Due to known threats, terrain, or other target considerations, there were often cases where a target could only be approached from one direction no matter what other surprises came up.

43. See Tilford, Crosswinds: The US Air Force's Setup in Vietnam.

44. "CHECO Rolling Thunder," p.11

45. This combines statements and data from "CHECO Tactical EW Operations," and "CHECO Rolling Thunder." The CHECO Rolling Thunder report emphasizes the great numbers of sorties devoted to Iron Hand, but the specific numbers remain elusive. Many sorties initially "fragged" for Iron Hand became armed recon, and vice-versa. The CHECO Tactical EW Operations mentions 200 Iron Hand sorties between August and December, but that number seems awfully low given the great emphasis on the SA-2 threat. I interpreted "sortie"(one airplane, one mission) here to mean "mission."(more than one airplane).

46. "CHECO Rolling Thunder," p. 7

47. Fossier ""The Role of SAM's in Tactical Warfare in Geoffrey Kemp, ed The Other Arms Race, Toronto: Lexington Books p 37

48. "388 TFW Tactics," p.10.

49. One example of this is in the Wild Weasel mission, which became the primary player in destructive electronic combat methods. This falls under the "Suppression of Enemy Air Defenses," or SEAD. See Hewitt, "Planting the Seeds of SEAD"

Van Creveld noted that no new principles in electronic combat came to light after World War II. Despite the fact that some of SEAD's origins can be traced to WW II, SEAD as it came to be known during and after Vietnam is nowhere near the defense suppression of the 1940's in scope and doctrine. I think that SEAD became a new principle of electronic combat, but the point can be debated elsewhere.

50. "CHECO Tactical EW Operations," p. 35

NOTES, REFERENCES FOR CHAPTER SEVEN

1. "Wild Weasel I, Final Report (Southeast Asia Phase), Eglin Air Force Base, Florida: Air Proving Ground Center, Air Force Systems Command and Tactical Air Warfare Center, Tactical Air Command, March 1966, p. 4 (Hereafter referred to as "Final Report.")

2. Davis, Wild Weasel, p.4

3. See Alfred Price History of US Electronic Warfare, Volume II

4. Ibid

5. See Kuehl, "Radar Eye Blinded," pp 234-246.

6. "Wild Weasel I: Response to a Challenge," p. 34

7. "Final Report," p.6

8. Ibid, p.7

9. "Wild Weasel I: Response to a Challenge," p.36

10. "Final Report," p.6; Author's telephone interviews with Major Jack Donovan, USAF (Ret) in April and May, 1994. (Hereafter cited as "Donovan interviews")

11. Positions relative to the aircraft were almost always described in "clock" positions rather than in degrees.

12. Having trained with a similar kind of radar warning receiver while attending USAF Electronic Warfare Training in 1987, the author can attest to the scope "becoming a mess" when it detected multiple radars.

13. "Final Report," p.8

14. "Operation Plan 153, Wild Weasel I, Headquarters, USAF Tactical Air Warfare Center, Eglin AFB Florida, 16 November, 1965, Annex U.

15. "Final Report," p.15

16. Ibid, p.7

17. "Wild Weasel I: Response to a Challenge," p. 35; Donovan Interviews.

18. Hewitt, "Planting the Seeds of SEAD," p.9

19. Donovan interviews.

20. Donovan interviews; "Final Report," p.7

21. Donovan interviews

22. Ibid

23. "Final Report,", p.11

24. Ibid, p.61

25. "Wild Weasel I: Response to a Challenge," p. 37

26. Wild Weasel I: Response to a Challenge," p. 37 and Donovan interviews.

27. Donovan interviews

28. Ibid

29. Ibid

30. Davis, Wild Weasel, p.6

31. "First In, Last Out" video

32. Ibid

33. Broughton Going Downtown, p176
Hot Mike refers to a configuration in the aircraft's intercom which allows the crew to converse continuously without having to press a button each time they need to talk.

34. "Wild Weasel I: Response to a Challenge," p. 34.

35. Donovan interviews

36. The EW officer's seat in a B-52 receives only scant natural light and affords little view of anything but his own instrument panel. In many of the B-52's operational at that time this officer sat backwards as well.

37. There is no evidence included in this essay covering rates of airsickness. Based on personal experience, the experience of other professional aviators, and occasional, but pointed reference to some electronic warfare officers fighting airsickness, it can be safely said that there was a significant physiological adjustment to be made in some individuals. In time, perhaps a flight or two or three, sometimes more, the adjustment can be made. One

former Wild Weasel pilot told the author that his EWO got airsick for the first ten flights or so during training before he got used to the F-105.

38. Test Order: Project Wild Weasel, Tactical Air command/USAF Tactical Air Warfare Center, Eglin AFB, FL, 4 October, 1965, p.1 (Hereafter called "Test Order").

39. "Final Report," and Donovan interviews.

40. Donovan interviews.

41. "Test Order."pp. 1-2; Donovan interviews

42. Larry Davis, Wild Weasel, p.10

43. "Test Order," pp. 2-5

44. "Final Report," p.24

45. Ibid

46. Operations Plan 153, Wild Weasel I, Annex N, Unit Manning Document

47. Ibid.

48. Ibid, Annex U.

49. "Final Report," p.9

50. Operations Plan 153, Wild Weasel I, Annex U

51. Ibid, Annex F.

52. Ibid, Annex N.

53. "First In, Last out"

54. Ibid

NOTES, REFERENCES FOR CHAPTER EIGHT

1. "Final Report," p.44

2. Ibid, p.21

3. Hunter-Killer formations were also used in anti-submarine warfare during World War II and with US Army helicopters in Vietnam. This is simply to point out that the hunter-killer concept has been well known to the military and was not unique to the Wild Weasel program.

4. Donovan interviews

5. "Final Report," p.29

6. Ibid, p.47

7. Ibid, p.41

8. Donovan interviews

9. "Final Report,", p.49

10. Broughton, Going Downtown, p.172

11. This smoke wasn't always easy to see. "Final Report," pp. 112-116.

12. Ibid, p.29

13. Ibid

14. Ibid, p.35

15. Ibid, p.30

16. Ibid

17. Ibid, p.10

18. "First In, Last Out."

58. "Final Report," p.30.

19. Ibid

20. Ibid

21. "CHECO Rolling Thunder," p.18

22. Message: 6234 TFW to Second Air Division HQ, Tan Son Nhut Air Base, Subject: Wild Weasel Tactics, 21 December, 1965 (USAFHRA).

23. Ibid.

24. Message: 6234 TFW to Second Air Division HQ, Tan Son Nhut Air Base, Subject: wild Weasel Tactics, December, 1965 (exact date faded: USAFHRA).

25. Message: 6234 TFW to Second Air Division HQ, Tan Son Nhut Air Base, Subject: Wild Weasel tactics, 21 December, 1965 (USAFHRA).

26. "Final Report," p.30

27. Message: 6234 TFW to Second Air Division HQ, Tan Son Nhut Air Base, Subject: Wild Weasel tactics, 21 December, 1965 (USAFHRA).

28. "388 TFW Tactics," and "First In, Last Out." The origin of the Wild Weasel motto, "first in last out" comes from preceding the strike force into the target area and remaining behind after the strike force exits.

29. "Final Report," p.113

30. Ibid, p.112

31. Davis, Wild Weasel, p.12

32. Donovan Interview

33. Davis, Wild Weasel, p.12

34. Ibid

35. "Final Report," p.113

36. Ibid, p.115

37. "First In, Last Out," and Davis Wild Weasel

NOTES, REFERENCES FOR CHAPTER NINE

1. "CHECO Tactical EW Operations," p. 36

2. "Support of Specified Fighter Aircraft (The F-4, F105 and F-100)," Air Force Logistics Command Support of Forces in Southeast Asia. Office of History, Air Force Logistics Command, Wright Patterson AFB, Ohio, p.51.
There was a "Wild Weasel II," but that was an F-105D aircraft outfitted with the same modifications as the F-100F. Wild Weasel III was instead chosen because it was a two-seat F-105F.

3. "Final Report," p.6

4. "Support of Specified Fighter Aircraft," AF Logistics Command, p.51.

5. The Wild Weasel I Final Report contains over 170 pages, including recommendations for a maintenance training program to familiarize trainees with the electronic warfare equipment on board the Wild Weasels. Also included were equipment reliability figures (the number of hours between failures and specific types of problems encountered) and anticipated man-hours required for maintenance under combat conditions.

6. "Final Report," pp.128-153

7. Ibid, p.151

8. Davis, Wild Weasel, p.18

9. Hewitt, "Planting the Seeds of SEAD," p.15

10. "388 TFW Tactics," p. 8

11. "Second Generation Weaponry in Southeast Asia," Project CHECO, Headquarters, Pacific Air Forces, Directorate, Tactical Evaluation, 10 September, 1970, p.59 (Hereafter referred to as "CHECO 2nd Generation," p. 59

12. Ibid, p. 62

13. Ibid, p. 60

14. Ibid

15. "Iron Hand/Wild Weasel," Corona Harvest Report, Maxwell AFB: Aerospace Studies Institute, January, 1970, p. 7

16. "CHECO 2nd Generation," p.60

17. Hewitt, "Planting the Seeds of SEAD," p.16

18. Ibid

19. "CHECO Tactical EW Operations," figure 11

20. "Iron Hand/Wild Weasel" Corona Harvest Report, p. 9

21. "388 TFW Tactics, " p. 10

22. "CHECO Tactical EW Operations, " p. 119 and "388 TFW Tactics," p. 5.

23. "QRC 160-1 Effectiveness," Operations Analysis Working Paper No. 31, Headquarters, Pacific Air Forces, 16 March, 1967, p. 4 (USAFHRA).

24. "388 TFW Tactics," Capter III, p.5

25. Ibid

26. Ibid, pp.6-7

27. Ibid, p.7

28. "CHECO Tactical EW Operations, " p.37

29. "Battle for the Skies Over North Vietnam," p.121

30. The report, "QRC 160-1 Effectiveness," was noted above.

31. Ibid, p.9

32. Ibid, p.17

33. Ibid, p.8

34. Pacific Air Forces Command Center: Monthly Summary Reports, October - December, 1966. USAFHRA. (no pages listed)

35. "388th TFW Tactics," p. 10

36. Pacific Air Forces Command Center: Monthly Summary Reports, October - December, 1966. AFHRA.(no pages listed)

37. "CHECO Tactical EW Operations," pp 50-53.

38. Ibid, p.48

39. Ibid

40. "Iron Hand/Wild Weasel," Corona Harvest Report, p.15

41. "CHECO Tactical EW Operations," p. 123
In November 1967 the ratio dipped to 26 missiles fired per aircraft lost, because the SA-2 battalions tended to concentrate their fire only on aircraft with inadequate electronic countermeasures equipment, or those on special combat test missions which required straight and level flight over a threat area.

SOURCES FOR FIGURES

FIGURE I : "Soviet Air Defense: An Unclassified Guide," 320th Bombardment Wing Intelligence (unpublished reference pamphlet, no date); FIGURE II: Ibid, and "Wild Weasel I: Response to a Challenge;" FIGURE III through FIGURE IX: "Electronic Combat Principles," Air Force Pamphlet 51-45, 15 September, 1987; FIGURE X: Author; FIGURE XI through FIGURE XIX: "Wild Weasel I Final Report: Southeast Asia Phase;" FIGURE XX through FIGURE XXIII: "CHECO Tactical EW Operations."

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