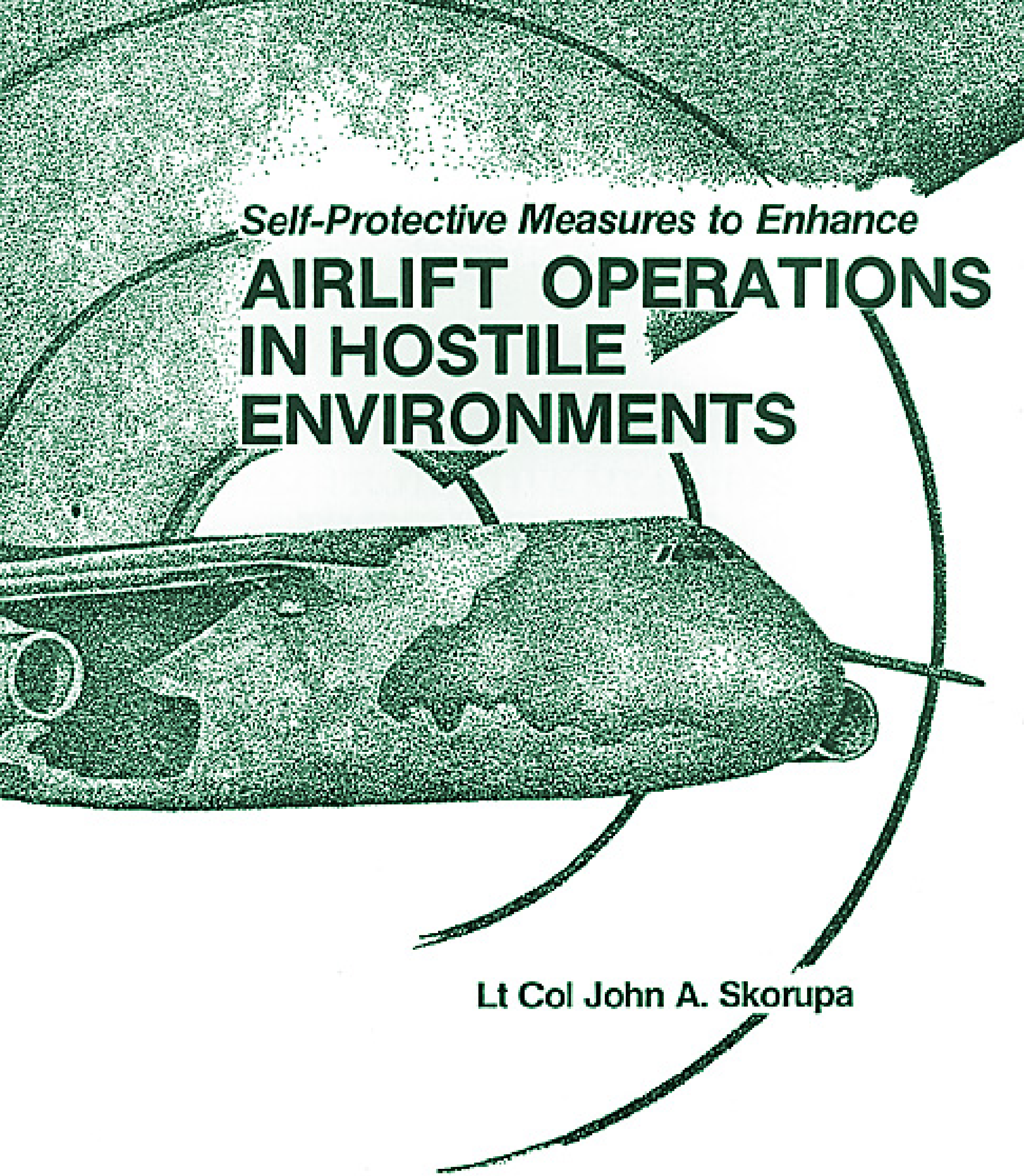

Self-Protective Measures to Enhance

AIRLIFT OPERATIONS IN HOSTILE ENVIRONMENTS

Lt Col John A. Skorupa

SELF-PROTECTIVE MEASURES TO ENHANCE AIRLIFT OPERATIONS IN HOSTILE ENVIRONMENTS

by

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FOREWORD

The national strategy of defending US interests as far from North America as possible has elevated airlift's importance in national security to a critical level. Air Force support of this strategy has led to the acquisition of new airlift aircraft and an emerging doctrine of global forward delivery that exposes airlifters to a wide range of threats across the conflict spectrum. Such a doctrine and our plans for global projection may not be supportable unless airlift aircraft are equipped with self-protective systems. A lack of airlift survivability is a potential Achilles' heel in the US global defense posture. This is an ominous and compelling reason for studying how to protect airlift aircraft in hostile environments.

Self-Protective Measures to Enhance Airlift Operations in Hostile Environments is a worthy response to this national crisis for its timeliness, comprehensive approach, and authority. The report is timely not only in addressing an issue of national strategic significance but also in doing so at a time when the Military Airlift Command is beginning its search for solutions. The report is comprehensive in its examination of strategy, doctrine, forces, threat, and technological solutions while also considering cost and fiscal issues. The report is authoritative in its blending of military art with industrial science, and only a person with the author's experience and insight could have produced it.

The author's unique perspective on this topic comes from having spent 19 years as a pilot in transports, as an aeronautical engineer developing and acquiring combat aircraft, as a staff officer at the Military Airlift Command dealing with daily operational issues, and as a research fellow studying the subject at great length. He has done a masterful job of explaining complex problems and potential solutions in easily understood terms. The study will undoubtedly stand as a landmark effort in the evolution of combat airlift. Everyone who has a role in future airlift issues or US military strategy will want to read it.

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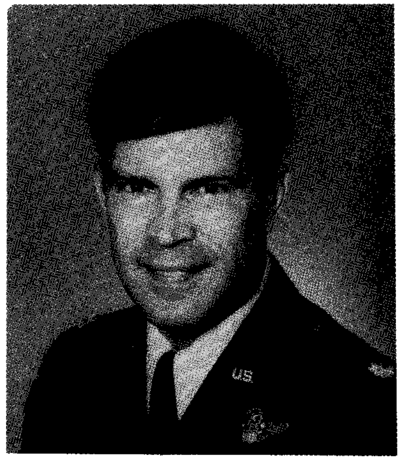

Lt Col John A. Skorupa

Lt Col John A. Skorupa is a graduate of the United States Air Force Academy, the Air Force Institute of Technology, and the Air War College. He holds bachelor of science and master of science degrees in aeronautical engineering.

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Finally and most important, I want to express my gratitude to my wife, Barb, and son, Scott, who patiently endured the many hours this effort kept me from them. Their support made it worthwhile and possible.

INTRODUCTION

The *National Security Strategy of the United States* states that "our strategy, global objectives, and the nature of the threat require that we be prepared to defend our interests as far from North America as possible."[1] That strategy "relies heavily on forward deployment of combat-ready forces, reinforced by strong alliance relationships."[2] It is unlikely, however, that the United States could station sufficiently sized and configured forces to support a sustained allied defense against a full-scale attack by a major foreign power in any theater of war. Since it is equally unrealistic to expect that our friends and allies will be able to absorb the full brunt of such an attack by themselves, success of US national security strategy may well depend on the strategic and tactical mobility of our military forces.

Given ample warning, mobility requirements could be met by sea and land transportation, but warning time is rarely ample. In Europe, for example, US forces would have to hang on three to four weeks before receiving their first resupply and reinforcement by sea. In three weeks, the outcome of the conflict could be decided. In Africa, the Middle East, and the southern Pacific basin, there are no US ground forces in place to augment or replace the defense capabilities of our friends and allies. Moreover, as anticipated in the *National Security Strategy of the United States*, US security interests may be threatened by conflicts short of general war, and some of those may require immediate and direct intervention by the United States. In all of these circumstances, the role of airlift is paramount.

To support US global strategy, airlift doctrine and force modernization initiatives are structured to provide direct delivery of forces to terminal locations adjacent to the battle area. Direct delivery to and sustainment of US forces at forward locations is a key aspect of AirLand Battle planning, but there are reasons to suspect that this doctrine will be difficult to apply in a modern conflict using airlift assets that lack self-protective devices. The purpose of this research document is to explore the implications of current airlift doctrine in terms of airlift survivability and to investigate a range of affordable options for increasing that survivability. Specifically, the research addresses the following questions: Is it operationally necessary, technically possible, and economically realistic to equip airlift aircraft with self-protective systems?

Part I of this study is devoted to examining the question of operational need. This is done by comparing doctrine, force structure, and the threat. Part II addresses technical feasibility by examining the requirements of electronic warfare and the solutions offered by technology. Part III addresses economic realism by evaluating system costs, budgetary impacts, and acquisition strategies. In conclusion it summarizes findings and makes recommendations for assisting MAC in transitioning to a force structure capable of electronic combat.

How is this study different from previous or ongoing efforts? First, it addresses the significance of doctrine in shaping the inventory; it shows how aspects of inherited doctrine have slowed the evolutionary process of force modernization; and it indicates where those aspects have created disparities in favor of the enemy. Second, it investigates the nature of the interaction between aircraft penetrating enemy defenses and the defenses as they respond. Third, it addresses acquisition strategy for countermeasures from a major command's perspective. Fourth, it goes beyond most current efforts by looking at unconventional defense opportunities that exploit emerging technology in cockpit presentations, precision navigation systems, lethal defense options, laser-guided weapon defense, directed-energy weapon defense, and stealth technology. And finally, it offers an approach by which Headquarters MAC could sponsor the development, integration, and acquisition of mission-enhancing technology.

NOTES

1. *National Security Strategy of the United States*, The White House, January 1987, 19.

2. Ibid.

PART I

OPERATIONAL NEED

Establishing an operational need for a weapon system or a military capability requires an iterative, or cyclical, process of balancing strategy, doctrine, forces, and missions against the threat. Since national security strategy defines the task and doctrine provides the architecture for fleshing out forces and assigning missions, a comparison of the capability of US forces to carry out their mission against the threat's ability to deny mission accomplishment is an appropriate departure point for establishing operational need.

Accordingly, chapter 1 accepts, as given, the national security strategy of defending US interests as far from North America as possible and begins with a discussion of doctrine and current airlift force structure. When the two are compared, a mismatch becomes apparent. The doctrine prescribes a capability for forward delivery and operations into overlapping threat regions in support of the AirLand Battle, but the current airlift force structure only reflects capability in a no-threat environment. The threat, in effect, becomes a discriminant in determining force structure shortfalls.

Chapter 2 is a general assessment of the threat to the airlift mission. That assessment makes it apparent that airlift force structure has not kept pace with the threat and is severely limited in its ability to carry out current doctrine.

The importance of chapters 1 and 2 is in establishing the operational need to equip airlift forces with self-protective devices. Establishing this need provides a logical lead-in to discussions of technical feasibility in part II and economic reality in part III.

CHAPTER 1

AIRLIFT DOCTRINE AND FORCES

The environment in which airlift aircraft must operate is becoming increasingly hostile. Man-portable, shoulder-fired, heat-seeking missiles have been supplied to armies and insurgent groups around the world and must be considered commonplace. In addition, the nature of the battlefield is changing such that airlift aircraft will be increasingly exposed to pockets of conventionally armed military units.[1] Given that MAC airlift aircraft currently carry no defensive systems, must transports accept a diminished role in future US military strategy or can they be defended? If they can be defended, should they rely on supporting forces or should they be equipped to defend themselves?

These are weighty questions whose solutions will have repercussions beyond the airlift community. In fact, they bring into question the ability of airlift forces to support national security strategy. To answer these questions, one must examine what national security strategy currently requires and how Air Force doctrine supports that strategy.

Current Airlift Doctrine

As mentioned in the introduction, the United States must "be prepared to defend our interests as far from North America as possible."[2] When economic realities, alliance limitations, and geopolitical requirements are considered, the necessity for a survivable airlift force becomes evident. National security strategy is quite clear on this point. How doctrine works to support the strategy, however, is not so clear.

Formal Doctrine

To begin with, formal Air Force doctrine is "a statement of officially sanctioned beliefs and warfighting principles which describe and guide the proper use of aerospace forces in military action."[3] Since Air Force doctrine is forged from "the study and analysis of experience," its basis is "what has usually worked best."[4] While "it is authoritative," it "requires judgment in application" to future circumstances.[5] To make doctrine relevant, the Air Force organizes it into three levels of application: basic, operational, and tactical.

Basic Doctrine. "Basic doctrine states the most fundamental and enduring beliefs which describe and guide the proper use of aerospace forces in military action."[6] Undoubtedly, the most sacred Air Force belief is the need to gain air superiority quickly. Without air superiority, US forces will lose freedom of action and tactical flexibility. Addressing this issue, Air Force Manual (AFM) 1–1, *Basic Aerospace Doctrine of the United States Air Force*, states:

> As a primary consideration, aerospace forces must neutralize opposing aerospace forces, including both aerospace and surface threats; otherwise, they cannot fully exploit their striking power to assist friendly surface forces. Aerospace superiority, therefore, is prerequisite to the success of land and naval forces in battle.[7]

The strong implication of AFM 1–1 is that without air superiority, all else is in jeopardy. So, how does one fight until air superiority is gained? What if gaining air superiority takes longer than the surface battle will permit? If the lowly Afghan insurgent could deny the Soviets air superiority, what makes the Air Force think it can achieve air superiority against the Soviets, or even an insurgent?

Basic doctrine also specifies primary roles and missions. Airlift is one of these, and its objectives are "to deploy, employ and sustain military forces through the medium of aerospace."[8] But no specific mention is made of how to defend airlift forces.

Instead, the doctrine states that the goal of the offensive counterair mission, suppression of enemy air defenses (SEAD), "is to provide the favorable situation which allows friendly aerospace forces to perform their other missions effectively without interference from enemy air defenses."[9] Also, defensive counterair (DCA) whose mission is "to detect, identify, intercept, and destroy enemy aerospace forces that are attempting to attack friendly forces or penetrate friendly airspace," would presumably help.[10]

The doctrinal question is not as clear-cut as AFM 1–1 would lead one to believe, however. For example, how do SEAD and DCA forces protect airlift aircraft targeted by a terrorist's shoulder-fired, heat-seeking missile? Or if the US concept of future war is the AirLand Battle, in which rapidly maneuvering forces penetrate to each other's rear areas, how do airlift aircraft avoid coming within lethal range of penetrating or bypassed enemy forces while keeping the friendly forces resupplied?

Operational Doctrine. Basic doctrine is too general in nature to answer these types of questions. Instead one must inquire at the operational level of doctrine.

> Operational doctrine applies the principles of basic doctrine to military actions by describing the proper use of aerospace forces in the context of distinct objectives, force capabilities, broad mission areas, and operational environments. Operational doctrine describes the organization of aerospace forces, and it anticipates changes and influences which may affect military operations, such as technological advances. The Air Force publishes operational doctrine in the Air Force 2-series manuals to provide detailed mission descriptions and methods for preparing and employing aerospace forces.[11]

On review of AFM 2–1, *Tactical Air Operations – Counter Air, Close Air Support, and Air Interdiction*, and AFM 2–4, *Tactical Air Force Operations – Tactical Airlift*, one is struck by how old they are (2 May 1969 and 10 August 1966, respectively). Conceptually, they fall short on several scores: they predate AirLand Battle doctrine (circa 1982); they contain no mention of joint SEAD missions; and short of traditional references to gaining air superiority over enemy air forces and suppressing or destroying surface-to-air defense systems, they do not say how airlift is to proceed. Thus, they assume that airlifters will be operating in areas that impose no requirement for self-protection.

Recently released AFM 2–8, *Electronic Combat (EC) Operations*, dated 30 June 1987, addresses the electronic aspect of self-protection by stating:

> Enemy threat systems most likely to impact airlift operations outside of the forward areas are enemy naval SAMs, mobile SAMs, and hostile electronic warfare against communications, navigation, and IFF [identification, friend or foe] systems. In addition to these threats, airlift forces operating in the forward combat area are susceptible to early warning and acquisition radars, antiaircraft gunlaying systems, selected SAMs, and fighter interceptor aircraft. While most airlift operations are normally conducted in relatively permissive environments, threat warnings, countermeasures, and expendables are required to protect the force from these threats.[12]

For the first time, modern wartime conditions are described and a solution is suggested, although it does not mention the role of SEAD and DCA.

The Military Airlift Command is currently in the process of drafting *United States Air Force Operational Doctrine—Airlift*, wherein it proposes:

> The relatively large size, slow speed, and poor inflight maneuverability of airlift aircraft make them vulnerable to many ground and air threats. Survivability against these threats depends on combinations of accurate intelligence assessments, combat tactics, onboard defensive systems, supporting tactical air operations, and joint suppression of enemy air defense systems.[13]

The key change promulgated by AFM 2–8 and the draft MAC manual is the concept of "onboard defensive systems." However, until the draft manual is formalized and the concepts of AFM 2–8 and AFM 1–1 are integrated in a coherent plan, Air Force operational doctrine will be lacking.

Tactical Doctrine. At the tactical level of Air Force doctrine, the gaps remain. First, tactical doctrine is intended to guide employment of specific weapon systems, and therefore avoids addressing packaging forces.[14] Second, by design, tactical doctrine flows from operational doctrine. Given the dated state of operational doctrine and the draft status of the proposed MAC version, the utility of tactical doctrine is suspect. Indeed, review of AFM 3–4, *Tactical Air Operations – Tactical Airlift*, dated 22 September 1971, illustrates the point. For instance, tactical airlift doctrine addresses capabilities and tactics that no longer apply because of the present nature of enemy defensive systems. Formal Air Force doctrine (basic, operational, and tactical), therefore, falls short of answering the questions concerning how to protect airlift aircraft.

At this point it may be instructive to point out that not all Air Force doctrine is the exclusive domain of the Air Force, nor is it all formal. Frequently, joint doctrine, in resolving joint roles and missions, obligates the Air Force to a particular course of action.

Joint Doctrine

To illustrate the influence of joint doctrine on airlift, consider the joint AirLand Battle doctrine. This doctrine requires US forces, including ground forces, to attack potential adversaries in depth. When ground forces proceed into the rear area of enemy formations, they will require periodic resupply that will expose the logistics stream to bypassed enemy forces. This constitutes a threat. Of course, not all resupply in AirLand Battle will go by air; most will probably go by truck. Still, airlift is responsible for a critical portion.

The airlift community is just now starting to address these issues. In December 1987 the joint Army–Air Force Airlift Concepts and Requirements Agency (ACRA) at Headquarters MAC submitted a draft of joint pamphlet, *Joint Airlift for Combat Operations* (MACP 55–XX and TRADOC PAM 525–XX), which strives to resolve the doctrinal requirements for deep operations. Many previously unresolved issues are addressed, but the pamphlet's solution to defending transports is, again, SEAD. "Successful conduct of airlift into the attack or combat zone requires an air corridor(s) relatively free of effective enemy air defense systems."[15]

Although this joint doctrine helps considerably in addressing airlift doctrine for the AirLand Battle, it brings one back to the starting point of this search, because it does not address, for example, the shoulder-fired missile threat. In addition, it suggests that the presence of US forces deep in the enemy's rear area will attract a strong enemy air response in the form of airborne interceptors and armed attack helicopters, creating additional threats.[16] Also it ignores the surface-to-air threat posed by enemy forces operating deep in the US rear area, a traditional "safe haven" for airlift aircraft. In fairness to the pamphlet, it recognizes the limitations of SEAD forces and only requires that corridors be "relatively" free of enemy air defense systems. Nevertheless, the pamphlet states, "Defensive systems and electronic countermeasures capability are necessary [for transports] to limit attrition and ensure mission success."[17]

Informal Doctrine

Occasionally, when formal Air Force and joint doctrines are neglected, informal doctrine fills the void. A sequence of events in the development of the C-17 aircraft illustrates this point. When the C-X Request for Proposal (from whence the C-17 came) was sent to potential builders, technology and operational efficiency had combined to make it possible for a strategic airlift aircraft to deliver cargo into the forward area's 3,000-foot runways. Consequently, the proposals spawned the concept of "direct delivery," or delivery from main staging bases to forward operating bases (FOBs). Subsequent testimony, during congressional budget hearings, advertised this capability as an important distinguishing advantage over alternative airlift options. Finally, as a requirement for releasing long-lead production funds, Congress asked the Department of Defense to detail the C-17's defensive system costs. To do so, the Air Force performed a defensive system study that validated the mission, threat, and need for specific types of defensive systems. This study was then endorsed by the secretary of defense and submitted to Congress. In the process, several doctrinal issues were decided. Although formal doctrine did not guide the development of the C-17, as formal doctrine is supposed to do, doctrine in other forms did.

To further illustrate the influence of informal doctrine, a discussion of the evolution of US airlift forces and the role they have inherited should be helpful. In addition, a review of the types of airlift aircraft currently in the force should be particularly illuminating.

To begin, the US form of airlift evolved from the early days of World War II when the Air Corps Ferrying Command was formed to move Lend-Lease materiel from the United States to Great Britain.[18] As the war expanded to the Pacific theater, airlift forces were combined under the Air Transport Command (ATC).[19] Troop carrier squadrons, however, remained with the tactical air forces.

The legacy of Air Transport Command was quickly established as it provided regular flights where no service had flown before. In addition to ferrying aircraft to the Soviet Union by way of Alaska, the command delivered aircraft to North Africa, India, and China. Of all the routes, the "Hump" to China was the most inspiring, instilling the "you call, we haul" informal doctrine. Aircraft used were primarily such military adaptations of commercial aircraft as the C-47 (DC-3).

With the formation of the Department of Defense and the creation of the Air Force as a separate organization under the National Security Act of 1947, the Naval Air Transport Service, the Air Weather Service, and the Airways and Communications Service were consolidated with the Air Transport Command to form the Military Air Transport

Service (MATS).[20] Shortly thereafter, the Soviet Union closed off highways to Berlin, and the Berlin airlift commenced. Unarmed and unprotected, MATS transports flew into the face of Soviet air defenses, tempting fate and furthering their creed of "airlift: anytime, anywhere." Military variants of commercial aircraft, such as the C-54 (DC-6), still predominated.

Airlift continued to gain in stature through the Korean and Vietnam conflicts so that Congress elevated it on 1 January 1966 to the status of a major command, the Military Airlift Command.[21] Initially, MAC controlled strategic airlift assets that operated between theaters of operations (for example, the continental United States, or CONUS, and Europe). Tactical airlift assets, which evolved from the earlier troop carrier squadrons of World War II fame, remained under the tactical air forces until 1 December 1974, when MAC assumed control of them.[22] During this period a transition from a military airline-type operation, flying commercial equipment, to combat airlift began and uniquely military aircraft (C-97, C-119, C-123, C-124, C-130, C-133, C-141, and C-5) increasingly displaced the civilian aircraft.

In recognition of MAC's growing importance to US strategy, it was designated a specified command on 1 February 1977, effectively streamlining command and control procedures during periods of hostilities.[23] On 1 March 1983 MAC took control of all Air Force special operations activities, and on 1 October 1987 it was integrated into the newly formed unified command, US Transportation Command (USTRANSCOM).[24]

Currently MAC operates at several levels. During peacetime, its primary task is deterrence, as is reflected in its motto, The Backbone of Deterrence. To fulfill this peacetime role, it must train and maintain a credible capability to deploy and employ militarily significant forces quickly to points where vital US interests are at stake. During hostilities MAC would continue the deployment and employment functions while transitioning to a sustainment function as forces were emplaced.

Whether the "can-do" attitude of the fledgling airlift forces controlled events and shaped US national strategy, or vice versa, is not significant here. The important point is that informal doctrine encompassing "can do," "you call, we haul," and "airlift: anytime, anywhere" grew regardless of the potential threat. Informal doctrine is as much a part of MAC's culture as formal and joint doctrine, and it has had as significant an influence in shaping the present airlift force structure.

Force Structure

In peacetime and in wartime MAC performs both strategic and tactical missions. Although there is a tendency to think of specific aircraft as being strategic or tactical, it is really the mission that determines the designation of a particular aircraft. Nevertheless, it is helpful to examine the various airlift aircraft in the context of their usual missions to evaluate shortfalls in doctrine or forces when compared against the threat described in chapter 2.

Strategic Airlift

The airlift forces MAC uses on strategic, or intertheater, missions include the C-5A/B Galaxy, the C-141B Starlifter, the KC-10A Extender, and aircraft of the Civil Reserve Air Fleet (CRAF). All these aircraft have considerable capability, but until recently there was no agreement on numbers required.

Quantification of Requirement. Since 1974, 18 major mobility studies have attempted to quantify airlift requirements.[25] The most widely respected was the 1981 "Congressionally Mandated Mobility Study." It evaluated US strategic airlift requirements for four European and Southwest Asian scenarios and determined that a *fiscally* achievable level of airlift would be 66 million ton-miles per day (mtm/d).[26] Note that the *real* airlift requirement was considerably higher, but its cost was judged to be too great. It was believed that the budget could only address a 20 mtm/d increase over the projected 1986 baseline of 46 mtm/d. Thus, the 66 mtm/d figure has become sacrosanct even though it is not based on national security requirements.

Confusing budgetary limits with national security requirements is only part of the problem. Since 1981 the size of Army units has grown dramatically. For example, a notional 1981 mechanized infantry division weighed in at approximately 50,000 tons; presently such a division weighs more than 79,000 tons.[27] Although the Army has attempted to rectify this situation by creating light infantry divisions, the overall airlift requirement has increased above that considered in the 1981 study.

To date MAC has increased its airlift capability to approximately 45 mtm/d. Representative numbers of current aircraft are shown in table 1.

TABLE 1
Strategic Airlift Aircraft[28]

Aircraft	*Number*	*Million Ton-Miles per Day*
C-5A	64	11.0
C-5B	44*	7.5*
C-141B	215	14.2
KC-10A	41	4.5
CRAF	330	11.3
TOTAL	694	48.5

*To be reached in July 1989.

The C-17 aircraft will join the service in 1992 and should build overall capability to the desired 66 mtm/d level by 1998.[29] The main point of this discussion is the criticality of airlift resources. Since the real airlift requirement is greater than the 66 mtm/d goal, the loss of even small numbers of airlift aircraft would have serious consequences in meeting mobility requirements.

C-5. The C-5 is an air-refuelable aircraft with a wide-body and high-bypass turbofan engines. By virtue of its size and configuration, the C-5 is the only aircraft currently in the inventory capable of transporting such outsized equipment (cargo too large for C-130s or C-141s) as the Army's main battle tank. Although it could carry up to 340 troops, its real military value is its ability to carry Army equipment that cannot fit in smaller aircraft.[30] For example, 26 percent of a mechanized infantry division's equipment is too big for other current aircraft. The C-5's ability to "kneel" on the ground and offload and onload through front and rear cargo doors enhances its utility over civilian systems. Operational experience with this aircraft, however, has resulted in restricting its operations to runways longer than 5,000 feet. Furthermore, its size frequently confines it to airfields built to jumbo jet specifications, effectively eliminating many forward area fields and fighter bases.

C-141B. The C-141B is also an air-refuelable aircraft. It is of narrow-body configuration but is otherwise similar to the C-5. Its flexible interior configuration allows it to carry 103 litter patients, 13 463L system pallets, or oversize rolling stock (equipment too large for commercial cargo aircraft) up to 45 tons in weight.[31] In an airdrop mode, it can precisely deliver up to 35 tons or 155 paratroops. It, too, is limited to airfields of 5,000 feet or longer.

KC-10A. The KC-10A is a military version of the commercial DC-10 cargo plane. Its primary function is as a tanker, but it can serve as a transport. Because its cargo floor is 17 feet above the ground, the KC-10A requires specialized ground-handling equipment. Furthermore, its cargo compartment is designed for palletized loads (no unpalletized rolling stock) that must conform to one of five contour limits and four weight limits. It is capable of carrying 27 463L system pallets or 84.5 tons of cargo. When pallets are not in place, extensive use of shoring and walkways is required. As a result of these restrictions, additional load planning and ground handling are required when this aircraft is used as a transport. Because it is built to commercial specifications, the KC-10A is restricted to large, wide-body capable airports.

C-17. The C-17 has a wide-body fuselage of the same approximate exterior dimensions as the C-141B and KC-10A, but it has superior ground-handling characteristics. It is designed for outsized rolling stock, short runways, and small parking areas. Because it will be air refuelable, it will be able to carry 102 passengers, 48 litter patients, 18 463L system pallets, or 86 tons of equipment to any place in the world that has 3,000 feet of runway. In an airdrop mode, it will precisely deliver 102 paratroops, 13 pallets, or 55 tons. As an additional feature, it will be able to deliver outsized equipment using low-altitude parachute extraction system (LAPES) procedures. Retirement of 54 older C-141s, placement of another 80 C-141s in the reserves, and purchase of 180 C-17s will bring strategic airlift capability up to 66 mtm/d by the year 2000.[32]

An interesting development in the acquisition of the C-17 has been the recent addition by Congress of the requirement to include defensive system costs in the funding profile. As a result of this requirement, the *C-17 Defensive Systems Study* was completed and submitted to the secretary of defense in September 1987. The study recommended inclusion of onboard defensive systems in the C-17's design. This sets an informal doctrinal precedent for defending other transports on similar missions or in similar threat environments with onboard systems.

Civil Reserve Air Fleet. CRAF aircraft make a significant contribution to MAC's total strategic lift capability, but they bring equally significant operating limitations. In a mobilization scenario, they would contribute 144.9 million passenger-miles per day, which is approximately 95 percent of the projected requirement for passenger airlift. CRAF assets would also contribute approximately 25 percent of current cargo airlift.[33] On the negative side, when these aircraft are used for cargo carrying, they are generally restricted to bulk, palletized cargo and to use of commercial-class airports. They can carry all but the largest oversize vehicles, but they cannot carry them in combat-ready configurations because of the various degrees of disassembly required.[34] Because of the voluntary nature of the CRAF program, its contribution could change significantly from month to month. In general, the long-range CRAF consists of the Boeing 747, Lockheed L-1011, McDonnell Douglas DC-10, Boeing 707, McDonnell Douglas DC-8, and Boeing 757. The Boeing 767 will also participate under a special medical evacuation program.

The Boeing 747 comes in numerous variants, but in general provides wide-body cargo capability along with a large passenger capability. The cargo configuration can carry up to 45 pallets or 99.1 tons, while the passenger configuration can carry up to 419 people.[35]

The Lockheed L-1011 was not designed as a cargo carrier. However, it can carry up to 274 passengers.[36]

The McDonnell Douglas DC-10 is a wide-body transport with both cargo and passenger variants. The cargo configuration can carry 27 pallets or 69.9 tons and the passenger configuration can carry up to 359 people.[37]

The Boeing 707 is a narrow-body airframe that offers both cargo and passenger variants. The cargo version carries 13 pallets or 29.9 tons. The passenger version carries up to 149 people.[38]

The McDonnell Douglas DC-8 is a narrow-body airframe with both cargo and passenger variants. The cargo version can carry up to 18 pallets or 41.4 tons, while the passenger version can carry up to 264 people.[39]

The Boeing 757 comes in only a passenger version. As such it can carry up to 185 people.[40]

The CRAF is activated in three stages, depending on the severity of an emergency. Stage I, Committed Expansion, is fairly routine and is declared at the discretion of the commander of MAC. When activated, up to three passenger and 47 cargo aircraft are identified by tail number and are made available at any location in the CONUS within 24 hours.[41]

Stage II of the CRAF, Airlift Emergency, offers an additional 24 passenger aircraft over stage I within the same 24-hour period. Stage II can be declared at the discretion of the secretary of defense.[42]

Stage III activation of the CRAF, National Emergency, offers approximately 188 passenger aircraft and 68 cargo aircraft over stage II. It can be activated at the discretion of the president or by declaration of Congress, but it allows participants up to 48 hours to respond.[43]

In the event of a NATO contingency, MAC has agreements with various European governments to gain the use of an additional 265 passenger aircraft, 88 cargo aircraft, and 34 combination variants. In addition, 14 supersonic Concorde aircraft would become available.[44]

Tactical Airlift

MAC's tactical airlift forces are intratheater assets dedicated to specific theaters. They are under the operational control of the theater commanders.

Qualification of Requirement. These aircraft have intertheater range, but they do not have the capacity to carry significant tonnage over that range. As a result, the significant measure of merit for tactical airlift aircraft is generally accepted to be in terms of tons per day.[45] Despite this convention, no acceptable criteria have been developed to quantify how much tactical airlift is required. Every attempt to do so has resulted in "scenario-dependent" values that lack the universality of the 66 mtm/d value that determines sufficiency (albeit fiscal) for strategic airlift. Table 2 reflects current fleet capability. C-23s are excluded because they are dedicated to the European Distribution System.

TABLE 2
Tactical Airlift Aircraft[46]

Aircraft	*Number*	*Tons/Day*
C-130A	104	1868
C-130B	80	1437
C-130E	237	4257
C-130H	83	1491
TOTAL	504	9053

C-130. The various models of the C-130 are all characterized by a four-engine, turboprop design that allows routine operations into austere landing fields of 3,000-foot length. The C-130A model has a maximum gross weight at takeoff of 122,900 pounds, the C-130B has a gross weight at takeoff of 133,000 pounds, and the E and H models can go up to 155,000 pounds. Maximum cargo load over a 1,000-nautical-mile range is 26,000 pounds for the C-130A, 40,400 pounds for the C-130B, 46,600 pounds for the C-130E, and 47,000 pounds for the C-130H. Each model can carry either 90 passengers or 64 paratroopers.[47]

Airlift Operations

Strategic airlift is responsible for intertheater deployment operations, moving troops and equipment from a CONUS main operating base (MOB) to a theater MOB or from one theater MOB to another.[48] Occasionally, such deployments could be airdrops using the C-141B. When the C-17 enters the inventory, it will be capable of airdrop or airland operations at forward operating locations (FOLs). Such a capability, CONUS MOB to theater FOL, is referred to as direct delivery.

Once troops and equipment reach the theater MOB, they are then moved forward via the most expeditious means, be it ground, sea, or air transportation. Such air transportation is called intratheater airlift and most likely will be by way of the C-130.

Aerial insertion of forces into combat is called employment, occurs through airland or airdrop operations, and can be intertheater or intratheater in nature. Airlanding is the preferred mode, if an airfield is convenient, because of speed, minimization of losses, and unit integrity considerations.[49] If landing is not practical, or where surprise is a consideration, airdrop is an option. Strategic assets (C-141s and C-17s) and tactical assets (C-130s) are available for airdrop. The size of the forces to be employed, field congestion during airland operations, weather, the threat, terrain, and user requirements determine whether single-ship or formation tactics are used. In the past, if the enemy threat imperiled the mission, supporting forces would be included to suppress the defense.

An important distinction between intertheater and intratheater aircraft is their beddown location. Intertheater aircraft receive support at the various theater MOBs, but they rely on their CONUS MOB for scheduled maintenance. Intratheater aircraft usually cannot get maintenance support in forward areas so aircrews must carefully assess the likelihood of safely departing from a destination before they arrive to avoid stranding the aircraft at an FOL. Intertheater aircrews are changed at appropriate intervals en route, while the aircraft keep moving. Intratheater aircraft, by contrast, keep the same crew throughout a mission.

Once US troops are in place they will be sustained using the same concept of operations used in intertheater and intratheater deployment. In addition to airland and airdrop modes of resupply, LAPES is an option for heavy pieces of equipment. The C-130 has, and the C-17 will have, this capability.

Redeployment operations are merely a reverse of deployment. If the redeploying forces remain in-theater, intratheater assets may do the job entirely. If the redeployment returns to the CONUS, intertheater assets would be used.

Other Operations

In addition to the forces already mentioned, MAC controls all Air Force special operations forces, aeromedical airlift resources, operational support airlift, presidential airlift, the Air Weather Service, and the Aerospace Audiovisual Service. For the purpose of discussing self-protective measures for airlift aircraft, however, this study is limited to those forces discussed at length in the previous sections.

Conclusions

Two doctrinal lessons can be drawn from the discussion of the evolution of US airlift. First, the early days of military airlift were not much different from airline operations. As a result, historical precedent undoubtedly influenced early Air Force doctrine to leave defense of transports to other forces.[50] Second, acquisition of the C-17 adds direct-delivery doctrine to Air Force airlift doctrine. Implicit in direct-delivery doctrine is the risk associated with flying otherwise undefended aircraft near combat zones. The *C-17 Defensive Systems Study*, the *Military Airlift Survivability Study*, and the *MAC Electronic Warfare Study* acknowledge this threat and provide justification for equipping transport aircraft with defensive systems.

In summing up the doctrinal issues, one can say that formal Air Force airlift doctrine, particularly at the operational and tactical levels, is dated and offers inconsistent guidance. Although electronic combat doctrine unequivocally requires self-protective systems on transports, airlift, electronic combat, SEAD, and DCA doctrines do not. They should be revised and standardized to acknowledge the requirement for onboard defensive systems for transports and to provide an integrated approach to operations. Joint doctrine, at least in the form of the draft pamphlet, *Joint Airlift for Combat Operations*, recommends equipping transports with defensive and electronic countermeasure systems. Informal doctrine, driven by direct delivery and the *C-17 Defensive Systems Study,* implies a strong operational need for onboard defensive systems.

Along with the doctrinal implications, the nature of the airlift fleet offers interesting options in defending transport aircraft. Depending on the nature of the threat facing intertheater aircraft, as opposed to the intratheater and direct-delivery aircraft, a distinction might be made in the type of defense required. To determine such options, however, one must consider the threat arrayed against these forces as they perform their missions.

NOTES

1. MACP 55–XX, *Joint Airlift for Combat Operations*, draft, 14 December 1987, A-3.
2. *National Security Strategy of the United States*, The White House, January 1987, 19.
3. AFM 1–1, *Basic Aerospace Doctrine of the United States Air Force*, 16 March 1984, v.
4. Ibid.
5. Ibid.
6. Ibid.
7. Ibid., 2-12.
8. Ibid., 3-5.
9. Ibid., 3-3.
10. Ibid.
11. Ibid., vi.
12. AFM 2–8, *Electronic Combat (EC) Operations*, 30 June 1987, 30, 31.
13. AFM 2–XD, *United States Air Force Aerospace Operational Doctrine—Airlift*, draft, 1 February 1987, 7.
14. AFM 1–1, vi.
15. MACP 55–XX, E-4, 5.
16. Ibid., 4.
17. Ibid., 5, 6, F-6.
18. Roger D. Launius, "MAC Airlift: A Brief History," *Airlift Association Convention Decisions*, Scott AFB, Ill., October 1983, extracted from *Airlift Operations School Supplemental Reading Text*, 503-1.
19. Ibid.
20. Ibid., 503-2.
21. Ibid.
22. Ibid., 503-3.
23. Ibid.
24. Ibid.
25. Headquarters MAC/CSR (Command Presentations), briefing, "Airlift in Support of National Objectives," May 1986, N-12.
26. *US Air Force Airlift Master Plan*, 29 September 1983, III-5.

27. Headquarters MAC/CSR, briefing, "Airlift in Support," L-26C.
28. *US Air Force Airlift Master Plan*, A-10.
29. Ibid., V-5.
30. Ibid., II-4. This table reflects the number of aircraft available for contingency purposes. For example, though there are currently 267 C-141s, the planning number is 215 to account for aircraft withheld for Joint Chiefs of Staff purposes, for training, and for depot maintenance.
31. Ibid.
32. Ibid., V-4. The *USAF Total Force Plan*, 17 September 1984, keeps 100 C-141s in the active inventory but operates them at a 2.0-crew-per-airplane ratio, as would the Reserves. The capability and airframe service life are the same either way. The 180 C-17s represent primary aircraft authorized (PAA). An additional 30 C-17s would be built as backup aircraft inventory (BAI) and trainers to keep units at full strength while aircraft were in depot overhaul and were being used to train crews.
33. Ibid., III-9.
34. Ibid., II-6.
35. Ibid.
36. Ibid.
37. Ibid.
38. Ibid., II-7.
39. Ibid.
40. Headquarters MAC/XPW (Assistant for Civil Air), point paper presented to the MAC Briefing Team, Scott AFB, Ill., 15 April 1985.
41. *US Air Force Airlift Master Plan*, II-5.
42. Ibid.
43. Ibid.
44. Headquarters MAC/XPW (Assistant for Civil Air), point paper presented to the MAC Briefing Team, Scott AFB, Ill., 28 November 1984.
45. *US Air Force Airlift Master Plan*, III-8.
46. Ibid., III-16. The C-130D is no longer in the inventory and has been omitted from the table.
47. *Military Airlift Command Data Book*, Scott AFB, Ill., October 1987, 10.
48. *US Air Force Airlift Master Plan*, II-7, 8.
49. Ibid., II-9.
50. William H.Tunner, *Over the Hump* (Washington, D.C.: Government Printing Office, 1964), 79. Capt John E. "Blackie" Porter armed two C-47s with two Bren .30-caliber machine guns each. One gun was operated by the copilot firing through his open cockpit window while the other was manned by a crewmember firing through the open cargo door. For backup they carried .45-caliber Thompson submachine guns and hand grenades. On one occasion they happened across a Japanese Zero sitting in a meadow while its pilot was repairing the engine. After seven passes they finally killed the pilot and riddled the Zero.

CHAPTER 2

THE THREAT

Emerging airlift doctrine supporting national defense strategy exposes airlifters to a variety of threats across the conflict spectrum in both peace and war. Excluding threats to parked airlifters as being outside the scope of this study, weapons that can engage airlifters fall into one of two categories – surface-to-air or air-to-air. Because MAC aircraft currently carry no defensive equipment, they are vulnerable to all such threats that can acquire, track, and intercept them.

By sorting out and assessing these threats in terms of airlift employment modes, peacetime-versus-wartime requirements, threat intensities, and threat trends, this chapter verifies the operational need for defensive systems. Additionally, organizing the chapter in these terms is helpful because the discussion of mission scenarios and lethality eliminates several types of threat from consideration and consequently minimizes the countermeasures required. The peacetime-versus-wartime discussion helps to distinguish between what equipment is needed now and what could be added later. The discussion of trends identifies threats that are not usually considered. This chapter thus lays the groundwork that enables later chapters to identify appropriate solutions and to establish priorities for developing and installing defensive systems.

Mission Scenarios

As can be seen from the discussion of strategic and tactical airlift in chapter 1, MAC mission scenarios can be organized in several ways. In a 1982 Summer Study, the US Air Force Scientific Advisory Board examined MAC operations and organized them into the following categories: deployment, force insertion/assault, resupply of engaged forces, search and rescue, and peacetime operations.[1] A more recent *MAC Electronic Warfare Study*, performed by Hughes Aircraft Company and Tracor Corporation, chose to group MAC missions as follows: intertheater airlift, intratheater landing, intratheater airdrop, and a catchall group including combat search and rescue and aerial refueling.[2] Similarly, the *C-17 Defensive Systems Study*, performed by Headquarters MAC, chose this organization: deployment (CONUS to theater), employment (to battle area or around the theater), and sustainment, including routine (from major ports to the brigade support area), resupply forward of the brigade support area, resupply of deep operations, and redistribution of critical supplies.[3]

From these efforts, one can begin to appreciate the nature of current MAC missions. However, to reach this study's ultimate goal of specifying alternatives for defending airlift aircraft, the most productive organization appears to be along the following lines: deployment (MOB to MOB) and employment/sustainment (MOB or FOL to FOL).

Note that no distinction is made in this study between a forward operating base and a forward operating location. Also note that for the purposes of this paper, sustainment missions are somewhat narrowly defined to mean forward sustainment of engaged forces. For reasons that should become clear in chapter 5, this definition will help MAC make decisions about equipping categories of aircraft with self-protective systems. In that chapter a distinction will be made between the aircraft required for employment and those required for sustainment.

Deployment

Characteristically, the deployment mission will be performed by C-5, C-141, C-17, KC-10, and CRAF aircraft. Within the deployment scenario the first opportunity for engagement by the threat is on takeoff and departure. Even at CONUS bases the potential for terrorist intrusion with a hand-held surface-to-air missile (SAM) is not insignificant.[4] At theater MOBs, where security is not always a US responsibility, the potential for terrorist, insurgent, or Spetsnaz (Soviet special forces) intrusion is greater. Once an airlift aircraft reaches moderate to high altitude, however, the threat from such forces is negligible.

Continuing on a deployment mission, the next opportunity for the threat to intrude is over international waters. Operating beyond the protective umbrella of friendly land and naval air patrol, a deployment mission is vulnerable to enemy airborne interceptors (AIs) and naval SAMs.[5, 6]

Upon descent into the theater MOB traffic pattern, the deployment mission reenters the threat envelope of the terrorist, insurgent, and Spetsnaz. In addition, confusion created by enemy communications jamming and random attacks, traffic congestion, and US operations security precautions will complicate tactical options and create distractions from defensive tasks. The return or backhaul leg of this mission would reexpose aircraft to the same threats.

Employment and Sustainment

The aircraft used on this mission will be the C-17, C-141, and C-130. The C-17 and C-130 will perform airland missions, while all three will perform airdrop missions. The C-141 airdrop mission will most likely be in conjunction with a brigade-size airdrop.

Employment missions occasionally originate from CONUS staging bases (Operation Bright Star '82, a brigade airdrop in Egypt, and Operation Urgent Fury, the 1983 invasion of Grenada), but more frequently they are intratheater operations. Nevertheless, both employment and sustainment missions are subject to Spetsnaz-type threats including hand-held SAMs on departure from the onload base, be it a MOB or FOL.

En route to the objective area, employment and sustainment missions will be subject to random AI intrusion, using either missile or gun attack. If US air superiority has not been achieved, the AI threat could be severe.[7] As the flight approaches the battle area, the transports (especially those at medium and high altitudes) will come within range of mobile and fixed-base SAMs of conventional forces. If pockets of bypassed or advancing enemy troops are overflown or if the FOL is close to an unsanitized battle area, the threat could include radar and electro-optically guided SAMs, hand-held SAMs, radar and electro-optically aimed antiaircraft artillery (AAA), and small arms fire.[8] Under these circumstances, the threat would extend from ground level up through the maximum altitude of the transport.

The *C-17 Defensive Systems Study* estimates that sustainment missions will routinely go as far forward as the brigade rear area (BRA) and will be 90 percent airland and 10 percent airdrop.[9] The BRA will be approximately 20 to 40 kilometers from the forward line of own troops (FLOT).[10] This study also estimates that 50 percent of the airdrop missions will be massed. On occasion, it will be necessary to take supplies as far forward as the battalion and company level.[11]

Threat Intensity

To assess the intensity of the threat, the *C-17 Defensive Systems Study* and the draft joint pamphlet, *Joint Airlift for Combat Operations*, suggest comparable definitions (table 3).[12, 13]

TABLE 3

Threat Levels

Category 1	Small arms, optical antiaircraft artillery (up to .50 caliber), hand-held surface-to-air missiles. Characterized by small numbers and lack of integrated defense. Evasive action may be required.
Category 2	Category 1 threat plus early generation radar surface-to-air missiles, radar antiaircraft artillery heavier than .50 caliber, airborne interceptors (no look-down/shoot-down or all-weather). Characterized by moderately integrated defenses, but limited numbers or poor deployment. Evasive action, electronic countermeasures, and/or defense suppression *may* be required.
Category 3	Category 2 threat plus advanced-generation surface-to-air missiles, airborne interceptors (look-down/shoot-down and all-weather), helicopters with air-to-air missiles, directed-energy weapons. Characterized by dense or highly integrated network. Evasive action, electronic countermeasures, *and* defense suppression *must* be employed.

The *C-17 Defensive Systems Study* applied these definitions to the perceived threat and reached the assessments shown in table 4.[14]

TABLE 4

C-17 Study Threat Assessments

Mission	*Assessment*
CONUS MOB to Theater MOB	No Threat to Category 1 Threat for C-5, C-141, C-17, KC-10, and CRAF.
CONUS MOB to FOL	Category 1 to Category 2 Threat for C-141 and C-17.
Theater MOB to FOL	Category 1 to Category 2 Threat for C-130 and C-17.
FOL to FOL	Category 2 Threat for C-130 and C-17.

Note that the C-17 study did not assign category 3 threats to airlift operations. However, under some anticipated deployment, employment, and forward sustainment modes, category 3 weapons may pose significant threats to all MAC airlift aircraft, including C-5s and airland C-141s. While the most likely threats to transports fall in categories 1 and 2 and these categories are used in this research as discriminators for computations and recommendations, discussion throughout this study recognizes the possibility that MAC aircraft will encounter category 3 threats.

Near Main Operating Bases

In the vicinity of MOBs, the most threatening weapon available to terrorists, insurgents, and Spetsnaz is the hand-held SAM of the SA-7, SA-14, Redeye, Stinger, Blowpipe, or Rayrider variety. Characteristically, such missiles home on their target using a single or dual-band infrared (heat) seeker, with varying degrees of false-target rejection capability. The Blowpipe differs in being optically tracked but manually steered by way of a thumb controller.[15] The Swedish Bofors Rayrider missile, as its name suggests, tracks a laser beam that illuminates the target.[16] All these missiles are man-portable, have a range of up to five kilometers, and have small warheads without proximity fusing.

En Route between Theaters

On the overwater leg of the deployment, long-range interceptors and naval SAMs are potential threats. If such forces are to detect, acquire, and track airlift aircraft transiting their airspace, the airlifter must give away its position or the enemy must use a search-and-tracking device. The most common type of search-and-tracking device is radar, but radar has a serious drawback in this role – it gives away the presence of the tracking party.

For naval surface forces, intercepting airlift aircraft is particularly difficult if the aircraft are interested in avoiding confrontation. Assuming that hostile naval surface forces would have an incentive to keep their radars transmitting for air defense purposes, airlift aircraft could have a relatively easy time staying beyond effective SAM range, provided they were equipped with threat-avoidance receivers. However, current MAC aircraft do not have such equipment.

In mutually passive operations, where the enemy employs bistatic radar techniques (a system consisting of as few as one transmitter and one or more listen-only tracking sets), and in situations of imperfect military intelligence, airlift aircraft might blunder into lethal encounters. For example, naval surface forces employing emission control procedures, but passively linked to an over-the-horizon radar, could trap an unsuspecting transport.

Some deployment missions may expose transports to short-range AI threats. On deployment legs to Southwest Asia, for example, MAC aircraft could come under attack from land-based interceptors belonging to countries along the coast of Africa and the Persian Gulf. Under such circumstances, the threat-avoidance option may be the only solution that can react fast enough to keep the relatively near fighter from closing and achieving a "kill." Specific equipment available to potential enemies could include that listed in tables 5 and 6.

TABLE 5

Deployment Mission Airborne Interceptor Threats[17, 18]

Fighters	*NATO Code*	*Remarks*
MiG-23	Flogger-G/K	(2xAA-7, 4xAA-8, AA-11), Soviet Union, Libya.
MiG-29	Foxbat-A	700-NM range, 4 AAMs (AA-6, AA-7, AA-8), Soviet Union, Libya, Iraq, and Syria.
MiG-29	Fulcrum	350-NM range, 6 AAMs (AA-8, AA-9, AA-10, AA-11), LD/SD, track-while-scan, 60-NM search, 45-NM track, Soviet Union.
MiG-31	Foxhound-A	LD/SD, track-while-scan (same as MiG-25 plus AA-9), Soviet Union.
Su-27	Flanker	400-NM radius, LD/SD, 130-NM search, 100-NM track, 8 AAMs (AA-8, AA-10, AA-11), Soviet Union.
Tu-28	Fiddler	Works with Tu-126 Mainstay, 4 AAMs (AA-5), Soviet Union.
F-4	Phantom II	8 AAMs (Sidewinder and Sparrow), Iran.
F-14A	Tomcat	8 AAMs (Sidewinder, Sparrow, and Phoenix), Iran, Libya, and Iraq.
Mirage III		Magic 530/550, Iraq, Libya.

Legend

AA – Air-to-Air
AAM – Air-to-Air Missile
LD/SD – Look-Down/Shoot-Down
NM – Nautical Mile

TABLE 6

Deployment Mission Air-to-Air Missile Threats[19, 20]

AAMs	*NATO Code*	*Remarks*
AA-2	Atoll	AIM-9B equivalent, IR guided, 3- to 4-NM range, Soviet Union.
AA-5	Ash	Semiactive radar guided (I/J band), 16-NM range, Soviet Union.
AA-6	Acrid	Semiactive radar homing, 25-NM range, 220-lb warhead, Soviet Union.
AA-7	Apex	IR or semiactive radar homing, 17-NM range, Soviet Union.
AA-8	Aphid	IR or semiactive radar homing, 3- to 4-NM range, all-aspect, Soviet Union.
AA-9	Amos	Radar guided, LD/SD missile, 25-NM range, high altitude, Soviet Union.
AA-10	Alamo	Radar guided, LD/SD missile, 19-NM range, Soviet Union.
AA-11	Archer	38-NM range, active terminal radar, Soviet Union.
Magic R-530		18-km range, semiactive homing or IR seeker, Iraq, Libya, and Syria.
Magic R-550		6-NM range, IR seeker, Iraq, Libya, and Syria.

En Route within Theater

En route to theater FOLs, airlifters could easily be ambushed by bypassed or penetrating enemy forces. Because of the emphasis on maneuverability in this type of warfare (AirLand Battle), surface-to-air threats will be primarily restricted to mobile SAMs and AAA. Fixed-base threats will be well known and vigorously attacked or deliberately avoided. Accordingly, the weapons of potentially hostile forces include those in table 7.

TABLE 7

Employment and Sustainment Mission Surface-to-Air Missile Threats[21, 22]

SAMs	*NATO Code*	*Remarks*
SA-4A/B	Ganef	1,000 to 80,000 ft, 5- to 45-mile range, command guidance and semiactive radar homing, salvo and guide 2 missiles per target, E-band surveillance, H-band acquisition, Soviet Union.
SA-6A/B	Gainful	50 to 30,000 ft, 2- to 12-mile range, command guidance and semiactive radar homing, E-band acquisition, Soviet Union plus 22 other nations.
SA-7	Grail	50 to 10,000 ft, 0.5- to 3-mile range, IR homing (SA-N-5), Soviet Union.
SA-8	Gecko	150 to 30,000 ft, 7.4-mile range, command guidance, semiactive radar and IR homing (SA-N-4), Soviet Union, Iraq, Syria, Libya, Nicaragua, and Angola.
SA-9	Gaskin	50 to 15,000 ft, 0.4- to 4-mile range, passive radar and IR homing, Soviet Union plus 20 other nations.
SA-10B	Grumble	Low to high altitude, 50-NM range, Mach 6, 200-lb warhead (SA-N-6), Soviet Union.
SA-11	Gadfly	100 to 45,000 ft, 1.6- to 15-NM range, command guidance, semi-active monopulse radar and IR homing, SA-6 replacement (SA-N-7), Soviet Union and Syria.
SA-12A	Gladiator	Low to high altitude, 80-km range, 330-lb warhead, Mach 3, SA-4 replacement, Soviet Union.
SA-13	Gopher	30 to 32,000 ft, 5-mile range, passive radar and IR homing, SA-9 replacement, Soviet Union.
SA-14	Gremlin	SA-7 replacement, Soviet Union.
SA-16		SA-7 replacement, Soviet Union.

Table 7 — Continued

SAMs	*NATO Code*	*Remarks*
Crotale		Low to medium altitude, 5-NM range, monopulse radar guidance, Libya.
Hawk		Low to medium altitude, 22-NM range, semiactive radar homing, Iran.
Rapier		Low to medium altitude, 4-NM range, command to line-of-sight guidance, Iran.
Roland		Low to medium altitude, 3.4-NM range, command guidance and IR homing, Iraq.

In mature theaters, such as Europe, near- and cross-FLOT operations by transports will require substantial joint suppression of enemy air defenses (J-SEAD) to avoid category 3 threat weapons. Fortunately, in such theaters an extensive transportation infrastructure exists. This should reduce the frequency with which aerial transport will be required and the volume of supplies such transport should have to carry.

In such lesser-developed theaters as Africa or Southwest Asia, the threat will likely be different in density and exposure. Less-developed regions are likely to contain fewer modern weapons, but there is likely to be an increased need for airlift because of the poorly developed transportation infrastructure characteristic of such regions. Partially because of lower numbers of threatening weapons, the possibility exists that the FLOT may not be well defined and because of the increased reliance on airlift, the number of near- and cross-FLOT airlift operations may actually be greater than in a European scenario.[23]

Comparing the two types of theaters reveals two generalizations that can be made regarding the threat to airlift aircraft. First, the mature theater threat, while potentially high in lethality, may be restricted to relatively well-defined areas. When airlift operations are required within those areas, J-SEAD operations may lessen airlifters' exposure to the threat. Second and conversely, the less-developed theater may be so disorganized that category 2 threats may be less precisely defined and may be found throughout the area. It is ironic that in such an environment, airlift aircraft may be more exposed to threats and may be more at risk than in a theater that is usually acknowledged as a higher-threat region.

Near Forward Operating Locations

The proximity of the battle area to the FOLs will increase the possibility of airborne and mobile surface threats influencing airlift operations, especially as airlifters support units below the brigade level. In addition to the threats experienced near MOBs, FOLs could have limited exposure to the weapon systems listed in tables 5, 6, and 7. Self-protection countermeasures, evasive action, and J-SEAD operations may be required.[24]

Peacetime-versus-Wartime Threats

This paper assumes three categories of conflict: normal peacetime, operations short of war (most notably peacetime contingencies and foreign internal defense), and war. This categorization of conflict is important because of the perspective it offers on several threats airlift aircraft will face. In peacetime contingencies and war, MAC aircraft must anticipate all threats, including air-to-air weaponry. Under normal peacetime conditions, the probability of hostile airborne interception is very low. However, during all categories some level of threat exists. For example, during normal peacetime, operations short of war, and war, nonstate-sponsored terrorism poses a significant threat to MAC operations. When states get involved—for instance, in state-sponsored terrorism and cross-border operations—

MAC operations may encounter more sophisticated threats at higher levels of lethality even though the United States may not be at war.

As the intensity of conflict escalates, threat systems are added to the enemy order of battle. This is not surprising, but what is significant is the quantum leap that occurs when sovereign states or groups of sovereign states enter the conflict. At this point, one begins to find categories 2 and 3 threat conditions. The Afghanistan conflict is an example of this phenomenon. By itself, the Afghan resistance presented only a low threat to Soviet airlift. Once the United States made the decision in 1986 to supply Stinger missiles to the resistance, the lethality of the conflict rose dramatically for Soviet airlift. Thus, with minimal effort, a third-party state supporting a resistance movement was able to severely curtail an unprepared superpower's airlift operation.

Three points in this discussion of peacetime-versus-wartime threats deserve emphasis. First, air-to-air threats exist during operations short of war even though they are usually not considered during normal peacetime conditions. Second, a terrorist threat exists at all times. And third, state involvement in a conflict raises the ante for airlift, including US airlift, to significant levels.

Threat Trends

The radio frequency (RF) spectrum has been much used for military measures and countermeasures since World War II. In fact, the whole concept of electronic warfare took on its present character during the Battle of Britain when the Germans attempted to establish navigation aids that would permit all-weather bombing of England.

History

The Germans' first exploitation was Lorenz, a navigational aid based on an extensive series of shortwave transmitters (200 KHz to 900 MHz).[25] Based in northern France, the transmitters beamed their broadcasts over London. German aircraft needed only to tune a loop antenna to ride these beams to their targets. Eventually the British caught on to Lorenz and countered with Meaconing. After picking up the German broadcast, the British sent the signal by land line to a transmitter situated off course, of course. As the German bombers flew toward the increasing signal strength of the British transmitter, they were increasingly misled.

As results from Lorenz soured, the Germans turned to Knickbein, a dual-transmitter system that broadcast parallel beams. One beam produced a series of aural "dots," while the other produced a series of aural "dashes."[26] If German pilots flew on the centerline of the two beams, they heard a steady tone. If they strayed from course, they picked up dots or dashes depending on which side they strayed to. The British dubbed this system Headache and countered it with a system called Aspirin. Based on the Meaconing system principle, the British merely duplicated the transmissions with transmitters located suitably off course.

By September 1940 the Germans had devised Ruffian, a navigation aid cleverly disguised as a propaganda broadcast. In normal operation the transmission was broadcast omnidirectionally, but before a raid the beam was narrowed down to 3 degrees and aimed at a timing point. The Germans then aimed a second 3-degree beam at the timing point, and their aircrews needed only to turn to the bomb-run heading and begin timing when they crossed the intersection. The British counter, Bromide, aimed crossing beams to produce intersections that the German crews passed before the designated timing points. With considerable frequency the British were successful in getting the Germans to drop their bombs in the English Channel. To cover for their success, the British used a bit of propaganda themselves in claiming the German bombers dropped early because they were running from British Spitfires.[27]

After the debacle of Ruffian, the Germans devised Benito, an interactive system using German ground controllers in France. By sending out a frequency modulated beam and having the bombers retransmit it to the ground station, the ground controllers could measure the phase difference and determine the range from London. The bombers periodically received range update radio calls from the ground controllers. To counter this the British developed Domino. Domino had several variations. In one variation, the German directional beam was rebroadcast omnidirectionally, which led to confusing and unreliable range readings. In a second variation, a British controller spoke in German to "guide" the bombers. On several occasions the British were successful in guiding German bombers to safe landings at British bases.[28]

As a final act of frustration, the Germans equipped one squadron of bombers with all of their navigation aids to act as a check on British interference. If all aids gave the same reading, it was assumed the British had not interfered. To interfere without being detected, the British would have had to coordinate all their countermeasures to provide a coherent wrong solution. Since this was not thought to be likely, the German plan was to use the consensus solution to allow the specially equipped squadron to drop incendiary bombs to mark targets for the rest of their bombers. The British counter was a plan called Starfish, whereby they set false bonfires in isolated areas after the German incendiaries were released. By placing these fires so that the rest of the bombers reached them prior to the real targets, the British were initially successful in getting the Germans to drop 95 percent of their bombs on false targets. The German counter-countermeasure was to tell their crews to drop on the second burning target. Of course, the British then set their second fire beyond the target. Ultimately, the

British calculated that 50 percent of the bombs dropped using this German system landed on Starfish targets.[29]

One might assume from this that the British had their way in the electronic war with Germany, but this was not entirely the case. In February 1942 the Germans executed a brilliant plan to sneak their warships *Scharnhorst* and *Gneisenau* through the English Channel despite the watchful eye of British radar. By introducing a daily period of jamming at dawn that appeared to be normal atmospheric static, the Germans were able to lull the radar operators. Of course, the jamming decreased the sensitivity of British radar; and by gradually increasing the period of jamming, the Germans were able to provide sufficient time for the warships to pass unnoticed on the required date.[30]

As a further illustration of the insidious effects of being unprepared to engage in electronic combat, consider the case of the German Würzburg radars. As a countermeasure to these radars, British and American aircrews began dropping precisely cut aluminum foil strips in voluminous quantities. Dubbed Window by the British, its code name was the innocuous sounding chaff.[31] Instead of acting as a window, the chaff acted on radar as if it were an opaque cloud, disguising bomber formations and intentions. In an attempt to correct what the Germans thought was a problem with their radar, they ordered approximately 4,000 of their best electronic engineers to work on the project.[32] Because this number represented approximately 90 percent of their electronic engineers, they were distracted from work on microwave radars, which the Allies had already fielded. As a measure of comparison, the United States only dedicated about 400 engineers to develop radar countermeasures—a satisfactory exchange ratio.[33] Because the Germans did not realize the Allies were operating in the microwave band, the Allies had a free ride there, compounding German befuddlement.[34]

In Korea the electronic air war closely resembled World War II. Not until Vietnam, when SAMs appeared, did the electronic countermeasures (ECM) versus electronic counter-countermeasures (ECCM) battle reach massive and full intensity. After the downing of an F-4 by a SAM-2 in 1965, US EB-66 aircraft were equipped with radar homing and warning (RHAW) gear and jammers to counter the missiles. SAM sites became priority US targets, prompting North Vietnam to integrate its air defense as a countermeasure. In addition to SA-2s, AAA and ground-controlled intercept fighters were combined to form the world's first integrated air defense network. Because this network forced the EB-66s to stand off from the defenses, attacking US aircraft were equipped with self-screening jammers. During an 11-day period in December 1972, more than 1,000 SAMs were fired over Hanoi and Haiphong in an attempt to stop massive B-52 raids. By the end of the eleventh day, North Vietnam's air defense system had been destroyed and B-52s bombed unopposed. Despite dire predictions and faulty initial tactics, only 15 B-52s out of 729 sorties were shot down.[35]

In the 1973 Arab-Israeli War (Yom Kippur War), Arab defenses achieved technological surprise with mobile SA-6 missile and ZSU-23-4 AAA systems. Lacking effective ECM against the continuous wave guidance system of the SA-6, Israeli aircraft were driven to low-altitude attacks only to be decimated by the ZSU and SA-7. By acquiring ECM pods effective against the SA-6, employing chaff and flares against the ZSU and SA-7 respectively, and using helicopters in a standoff jamming role, the Israelis were able to gain the upper hand.[36] Ultimately, the Israelis were successful in clearing every SAM site from their path while losing less than one aircraft per 100 sorties. Still, of the 103 Israeli aircraft lost, 100 were destroyed by surface systems.[37] The Arabs, on the other hand, lost 334 aircraft in air-to-air duels, mostly to heat-seeking Shafrir and Sidewinder missiles.[38]

In the Falklands campaign, both Argentina and Great Britain suffered from a lack of airborne early warning capability. While British Harriers employed the AIM-9L

Sidewinder with deadly efficiency, the ability of Argentinean pilots to get under British surface-based radar allowed them to surprise Royal Navy defenses all too frequently. Given countermeasures against the AIM-9L, the Argentineans could have turned the campaign in their favor.[39]

The Bekaa Valley, Lebanon, saw three air battles in 1982 and 1983 that offer additional insight into electronic warfare. In 1982 the Israelis shot down 79 Syrian aircraft while losing only one of their own. When Syria initiated the air battle with an attack of approximately 60 aircraft, Israel countered by jamming their communication links, isolating the attackers from their ground controllers. Then using E-2C Hawkeye airborne early warning aircraft to vector their own fighters behind the Syrians, they achieved tactical surprise. Without infrared countermeasures (IRCM), the Arab aircraft were again easy prey for Israeli Shafrirs and Sidewinders.

Against Syrian ground defenses, the Israelis were successful in destroying 19 of 20 SAM sites through expert use of ECM pods, remotely piloted vehicles (RPVs), flares, and chaff. A typical Israeli air defense suppression mission began with a series of RPVs making television surveillance passes on suspected SAM sites. When a site was discovered, two more RPVs were sent out as a team. One RPV imitated a hostile fighter to decoy the SAM radar to turn on. The partner RPV would then relay the radar signals back to Israeli forces for analysis. Armed with perfect knowledge of the Syrian electronic order of battle, Israeli fighters, defended by appropriately tuned ECM pods, antiradiation missiles (ARMs), chaff, and flares, then proceeded to destroy the site.[40]

After the Israeli success, France and the United States each took on the Syrians. In November 1983 eight Super Étendards, supported by two French F-8E Crusaders for MiG- cap and two American-operated EA-6B Prowlers for standoff jamming, attacked Islamic terrorist barracks in Baalbek. Achieving surprise, six of the eight Super Étendards were able to drop bombs before the AAA defenses were alerted. Despite having to abort the last two aircraft passes, the French destroyed the barracks with no losses.[41]

The US Navy attempted its raid at dawn on 4 December 1983, using 16 A-6E Intruders, 12 A-7E Corsair IIs, an E-2C Hawkeye, several F-14 Tomcats for MiG-cap, and two EA-6B Prowlers for standoff jamming. Unfortunately, the Soviets tipped the Syrians off to the raid and all defenses were up. The subsequent loss of two aircraft highlighted a recent hardware change in the SA-7 and SA-9 missile-seeker heads from uncooled sensors to cooled sensors. These new sensors proved invulnerable to existing Navy flares. In addition, because of carrier landing and takeoff restrictions, the tailpipe exhaust fairings on Navy aircraft had not been extended to shield against the heat-seeking missiles as were those on Israeli aircraft. Such subtle modifications were enough to tip the balance.[42]

This limited historical review shows clearly that electronic warfare has played an increasing important role in aerial combat. It should also point up the undeniable lesson that electronic warfare will be vital in determining the victor of the next conflict.

Future

Introduction of the SA-7 SAM into Vietnam and Stinger and Blowpipe SAMs into Afghanistan were disastrous events for opposing airlift aircraft. Potentially just as disastrous is the fact that these weapons are coming into the possession of governments hostile to the United States. For example, Stinger missiles meant for the Afghan resistance have been diverted to Iran and have shown up on an Iranian craft in the Persian Gulf.[43] Given the strong Iranian support for such terrorist groups as Hezbollah, it should come as no surprise if US aircraft are attacked by a terrorist group using such missiles. Furthermore, as these weapons are copied and reproduced, they will find ready markets with terrorist groups around the world. In short, one must assume that hand-held SAMs will find their way to terrorist groups opposing the United States and that they will be used.

One must also consider the intentions of the Soviet Union in building its first full-sized aircraft carriers, the *Leonid Brezhnev* and a second as yet unnamed.[44] Expected to be operational within two years and outfitted with current-generation interceptors of comparable capability to the Su-27 Flanker, these carriers will greatly improve Soviet ability to intercept airlift aircraft over international waters, especially if they are complemented by *Kirov*-class nuclear-powered cruiser groups and are protected by nuclear-powered attack submarines. They could create a formidable barrier to transiting airlift aircraft.[45]

In intratheater developments, total US J-SEAD forces have leveled off and consist of only 42 EF-111 standoff jammers and 72 F-4G Wild Weasel SAM-site killers. Since these aircraft must cover all theaters and will be heavily tasked to support air interdiction, battlefield air interdiction, and close-air-support missions, their numbers will not be adequate to support airlift operations.[46]

Surviving in the future intratheater environment will require more than passive, low-altitude flying by transports. The *MAC Electronic Warfare Study* estimates that a MAC transport at 500-foot altitude approaching an airfield 20 kilometers from the battle area in Europe will be painted by more than 50 radar emitters and tracked by at least 15.[47] Perhaps the most persistent of the radar threats, because of its resistance to SEAD targeting, will be Mainstay, the new Soviet airborne warning and control system. Exploiting a true overland, look-down capability, Mainstay could vector interceptors or tip off artillery to the presence of transport aircraft.[48]

Accidental encounters with isolated enemy ground forces promise to be more injurious in the future. In addition to expected upgrades in current units and weapons (for example, the ZSU-X mobile AAA unit), laser systems are likely to be used in large numbers.[49] Lasers could be spectacularly effective against aircraft for three reasons. First, they are difficult to jam when used as target identifiers for beam-riding weapons.[50] Second, even at their current relatively low power levels, they have temporarily blinded flight crews who have looked directly at them. Third, when viewed through heads-up displays (HUDs), the intense laser light "will almost certainly blind the pilot."[51]

Looking further into the future, two trends will put airlift under even greater stress. First, the Army 21 operational concept foresees opposing units operating in a "swarm, strike, and scatter" mode.[52] Under this concept, surface lines of communication will be subjected to sudden and unpredictable attack. To compensate, airlift will have to be the primary means of resupply.[53] Second, freedom of operation for airlift in rear areas will decrease as the enemy gains greater capability to target those areas.[54] Of particular concern to airlifters will be such Soviet helicopters as the Hokum, which will have a credible air-to-air capability.[55] In short, the air defense environment will become much more lethal.

Conclusions

From the preceding discussion of mission scenarios, types of threat encounters, threat intensity, and trends, the reader can appreciate the vulnerability of unprotected airlift aircraft. Given the doctrinal requirement that airlift aircraft carry out missions in hostile environments, the mismatch between doctrine, the available force capability, and the threat becomes apparent. Clearly, an operational need for self-protective systems exists on deployment, employment, and sustainment missions. Having established the need, the discussion can turn in part II to consideration of technical feasibility.

NOTES

1. US Air Force Scientific Advisory Board, *Report of the Ad Hoc Committee on the Enhancement of Airlift in Force Projection* (1982 Summer Study)(U), Washington, D.C., December 1982, 26. (SECRET) (Information extracted from this source is unclassified.)

2. Hughes Aircraft Company and Tracor Corporation, "Military Airlift Command Electronic Warfare Study Briefing" (U), presented to Headquarters MAC, January 1988, slide 3. (SECRET) (Information extracted from this source is unclassified.)

3. Headquarters Military Airlift Command, *C-17 Defensive Systems Study* (U), Scott AFB, Ill., 17 July 1987, 6. (SECRET) (Information extracted from this source is unclassified.)

4. Scientific Advisory Board, *Report of the Ad Hoc Committee*, 1.

5. Ibid., 28.

6. Hughes and Tracor, "Military Airlift Command Electronic Warfare Study Briefing," slide 3.

7. Scientific Advisory Board, *Report of the Ad Hoc Committee*, 29.

8. Ibid.

9. Headquarters MAC, *C-17 Defensive Systems Study*, ii.

10. Ibid.

11. MACP 55–XX, *Joint Airlift for Combat Operations*, draft, 14 December 1987, 10a.

12. Ibid., 5–6. This source refers to the threat levels as category 1, 2, and 3, respectively, to avoid the subjective "low," "medium," and "high" threat labels.

13. Headquarters MAC, *C-17 Defensive Systems Study*, 12.

14. Ibid., 13.

15. Charles H. Wiseman, "Soviet Weapons and Electronics—Radar Systems," in *International Countermeasures Handbook: 1986*, 11th ed. (Palo Alto, Calif.: EW Communications, Inc., 1986), 183.

16. Richard S. Friedman, *Advanced Technology Warfare* (New York: Harmony Books, 1985), 29.

17. Wiseman, "Radar Systems," 177–78, 235–37, 242.

18. "Specifications," *Aviation Week & Space Technology*, 9 March 1987, 139, 174.

19. Wiseman, "Radar Systems," 177–78, 235–37, 242.

20. "Specifications," *Aviation Week & Space Technology*, 139, 174.

21. Ibid., 170–75.

22. Wiseman, "Radar Systems," 184–88, 246–48.

23. MACP 55–XX, A-3.

24. Headquarters MAC, *C-17 Defensive Systems Study*, 12, 13.

25. D. B. Harris et al., "History of Electronic Countermeasures," in *Electronic Countermeasures* (Los Altos, Calif.: Peninsula Publishing, 1978), 2-2.

26. Ibid.

27. Ibid., 2-3.

28.Ibid.

29. Ibid., 2-3,2-4.

30. Ibid., 2-7.

31. Ibid., 2-11.

32. Ibid., 2-12.

33. Ibid.

34. Ibid.

35. W. D. Meskill, "Why ECCM? The Need for ECCM," *RadarElectronic Counter-Countermeasures* (Dedham, Mass.: Artech House, Inc., 1979), 28-29.

36. Ibid., 29.

37. Charles W. Corddry, "The Yom Kippur War, 1973- Lessons New and Old," *National Defense,* May-June 1974, 508.

38. Robert Hotz, "The Israeli Air Force Faces New Arab Arms,"Aviation *Week &* Space *Technology,* 10 March 1975, 16.

39. Mario de Arcangelis, *Electronic* Warfare (Poole, Dorcet, UK: Blandford Press, 1985), 282-83.

40. Ibid., 265-70.

41. Ibid., 272-73.

42. Ibid., 275-76.

43. "The Alchemy of Turning Guns into Luxury Villas," U.S. *News and World Report,* 30 November 1987, 36.

44. Department of Defense, Soviet *Military* Power (Washington, D.C.: Government Printing Office, March 1987), 66, 86.

45. Ibid., 86.

46. Ray A. Yagher, Jr., "An Immediate Imperative," *Journal of Electronic Defense,* November 1987, 46.

47. Hughes and Tracor, "Military Airlift Command Electronic Warfare Study Briefing," 8A.

48. Department of Defense, Soviet Military Power, 106.

49. Ibid., 112.

50. Friedman, *Advanced Technology* Warfare, 29.

51. F. Clifton Berry, Jr., "The British Are Coming," Air *Force Magazine,* June 1987, 75.

52. Headquarters MAC, *C-17Defensive Systems* Study, 97.

53. Ibid., 98.

54. Ibid., 97.

55. Department of Defense, Soviet Military Power, 80.

PART II

TECHNICAL FEASIBILITY

Despite the terror inspired by modern antiaircraft weapons, those weapons operate on well-known physical principles and have limitations that are readily exploitable. The intent of chapter 3 is to explore the operating principles of the primary threats to airlift aircraft and to point out realistic avenues of counterattack. The chapter explores limitations in using the electromagnetic spectrum; discusses the tasks required of the offense and defense; examines the operating principles of systems devised to exploit the electromagnetic spectrum to include radar, infrared, electro-optical, and laser systems; and discusses system weaknesses.

Chapter 4 brings the discussion of technical feasibility to a conclusion by showing how emerging technology is presenting a unique opportunity to allow relatively large and slow aircraft to counter threats, including those launched by airborne interceptors, in all portions of the electromagnetic spectrum. Provided with such options for technically feasible weapons, the discussion can then turn to affordability in part III.

CHAPTER 3

ELECTRONIC WARFARE: HOW IT FUNCTIONS

The principal adversary of the United States has developed and exported antiaircraft weapon systems of amazing variety, sophistication, and lethality. When combined in an integrated air defense system, they present a formidable array. Superficially they would even appear to be impregnable. In reality they have subtle weaknesses that are not usually advertised, but that are well worth studying and exploiting. Once revealed, these weaknesses suggest technological possibilities for increasing the survivability of airlift aircraft. The starting point in the search for weaknesses is the electromagnetic spectrum, which defines the domain of electronic warfare.

Electromagnetic Spectrum

The electromagnetic spectrum groups electromagnetic energy by wavelength and frequency and serves as the basis for describing such energy. From lowest to highest frequency, it includes radio waves, microwaves, millimeter waves, infrared radiation, visible light, ultraviolet radiation, X rays, gamma rays, and cosmic rays. By emitting from or reflecting off matter, electromagnetic energy serves as a conduit for information. It is this relationship with matter that makes it particularly useful in warfare.

The enemy exploits electromagnetic energy, in this case waveforms, to seek and obtain necessary information to detect, acquire, track, and identify the airlifter. To understand the weaknesses in detecting, acquiring, tracking, and identifying aircraft, one must understand the essential characteristics of electromagnetic waves and real-world limits on use of such waves.

To understand electromagnetic waves, one must understand the interaction of wavelength, frequency, and the speed with which the waves operate. This relationship is described by the formula, $v = f \times wl$, where v is the velocity of propagation, f is the frequency of the radiation, and wl is the wavelength. Simplifying this equation is the fact that the velocity, v, is a constant equal to the speed of light for any particular medium. (In air the speed of light is approximately 300,000 kilometers per second.) Thus frequency and wavelength are inversely related (as one increases, the other must decrease) and, because velocity is a constant, they are paired. That is, only one wavelength can occur at a given frequency and vice versa (table 8).

TABLE 8

Electromagnetic Spectrum[1]

Frequency	*Wavelength*	*Type of Radiation*
0 to approx 300 MHz	Infinitely long to 1 meter	Radio Waves
300 MHz to 1360 GHz	1 meter to .022 cm	Microwaves
1360 GHz to 4.0×10^{5} Hz	.022 cm to 7.5×10^{-5} cm	Infrared
4.0×10^{5} Hz to 7.5×10^{5} GHz	7.5×10^{-5} cm to 4×10^{-5} cm	Visible Light
7.5×10^{5} GHz to 18.8×10^{5} GHz	4×10^{-5} cm to 1.6×10^{-5} cm	Ultraviolet
18.8×10^{5} GHz to 24×10^{9} GHz	1.6×10^{-5} cm to 1.25×10^{-9} cm	X Rays
24×10^{9} GHz to 5.5×10^{11} GHz	1.25×10^{-9} cm to 5.5×10^{-11} cm	Gamma Rays
5.5×10^{11} GHz and higher	5.5×10^{-11} cm and shorter	Cosmic Rays

Legend
cm – Centimeter
GHz – Gigahertz
MHz – Megahertz

Real-world limits on using electromagnetic waves take several forms. The most difficult to overcome are those caused by propagation limitations. For example, humans are able to see objects only to the extent that wavelengths of visible light are neither scattered nor absorbed by particles, water vapor, and other components of the atmosphere. In the case of particles, the rule of physics holds that as they approach the size of waves, scattering occurs. Particles much smaller than a wavelength produce little scattering, while those much larger than a wavelength scatter waves according to the nature of the particle's composition, independently of the wavelength.[2] Thus, as particulate size approaches the wavelengths of visible light (0.4 to 0.75 microns – one micron is one one-thousandths of a millimeter), scattering occurs and vision is obscured. For this reason haze, mist, fog, smog, clouds, rain, and other atmospheric conditions limit the usefulness of systems that operate in the visible light portion of the electromagnetic spectrum (table 9).

TABLE 9

Atmospheric Particle Sizes (Diameter)[3]

Haze	0 to 0.5 microns
Mist, Fog, Clouds	0.5 to 80 microns
Rain	250 to 3,000 microns

One way around this limitation is the use of systems that operate with longer wavelengths. For example, haze is "transparent" to infrared (IR) radiation because IR wavelengths (0.75 to 2,200 microns) are larger than the particle sizes (0 to 0.5 microns) that produce haze. If scattering were the only limiting factor, one might assume that IR and longer waves have overwhelming advantages compared to visible light. Indeed, they have unique advantages, but they also have limitations caused by weather conditions and atmospheric absorption.

Absorption of electromagnetic waves occurs when the frequency of the radiation approaches the resonant frequencies of molecular gases in the atmosphere. The gases that account for most absorption under 300 gigahertz (GHz) (300×10^9 cycles per second – microwave and radio bands) are water vapor and oxygen.[4] Each gas produces several absorption bands. Water vapor's absorption bands are centered on 22 GHz and 183 GHz, while oxygen's are centered on 60 GHz and 119 GHz[5] (fig. 1). Above 300 GHz and below 10 terahertz (THz) (10×10^{12} cycles per second – infrared band), absorption due to water vapor is very high, effectively restricting use of the microwave region to 300 GHz and below.[6] Above 10 THz (infrared region) water vapor and carbon dioxide are the limiting gases. Water vapor's absorption bands reappear in the infrared range at 46 THz (6 micron), 158 THz (1.9 micron) and 210 THz (1.4 micron).* Carbon dioxide's absorption bands occur at 21 THz (14.3 micron) and 70 THz (4.2 micron).[7] In addition, water vapor and carbon dioxide combine to absorb radiation centered on 110 THz (2.7 micron) (fig. 2). Other effects – such as ionospheric absorption, tropospheric and ionospheric dispersion, refraction, polarization, and free-space propagation limits – also act to restrict use of the electromagnetic spectrum, but they are beyond the scope of this discussion.

The preceding discussion shows that scattering, absorption, and other phenomena render large portions of the electromagnetic spectrum useless for electronic warfare. Only a small number of "windows" are available to be exploited: 300 GHz and below (microwave and radio bands), two bands in the infrared region corresponding to wavelengths of 2 to 5 microns and 8 to 14 microns, and most of the visible portion of the spectrum. Enemy threats that operate in these bands tend to take the form of radar; radio frequency homing devices; infrared search, track, and homing devices; and lasers.

*When dealing with very high frequencies the practice is to refer to them in terms of the associated wavelengths.

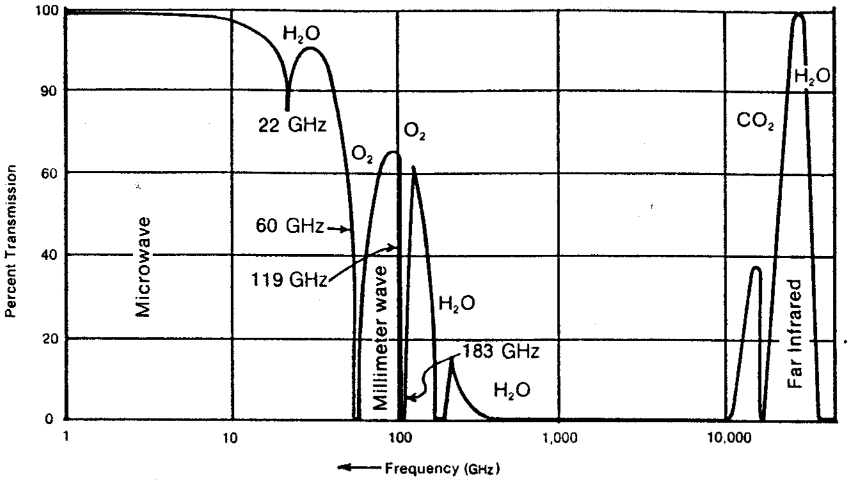


Figure 1. Radio Frequency Absorption.[8]

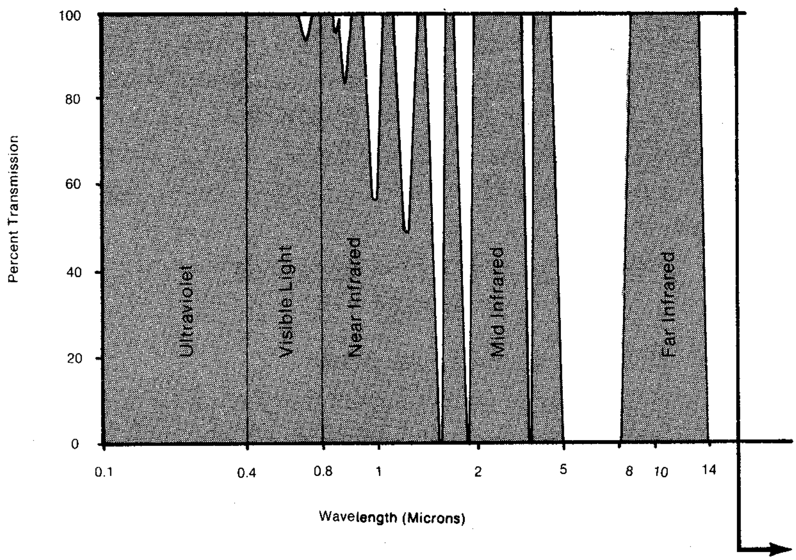


Figure 2. Visible and Infrared Absorption.[9]

Radar

Radar is an acronym for radio detection and ranging. It operates by sending out radio waves and "listening" for returning echoes. Azimuth and elevation of a target echo are determined by pointing an antenna, unless fan-shaped search beams are used. In this case, an extra elevation antenna may be required. By measuring the time delay of the echo, radar can determine range. Since radio waves travel at the speed of light, a target one nautical mile away will produce an echo in 12.35 microseconds (12.35×10^{-6} seconds). This interval is known as the radar mile. A target two miles away will take 24.70 microseconds, twice as long, to produce an echo.

In addition to atmospheric propagation limitations, the maximum range of radar is dependent on the returning echo being stronger than the ambient "noise." This relationship is called the signal-to-noise (S/N) ratio and should be greater than 1.0. If it is not, the signal will not be detected. What makes this such an interesting problem and fundamental to electronic warfare is that the signal strength and noise level are simultaneously affected by both the searching radar and the target. For example, echo power received can be expressed by the equation

$$\underline{\text{Echo Power}}^{10} = \frac{\underline{P} \times \underline{G} \times \underline{\text{Sigma}} \times \underline{A}}{\underline{16} \times \underline{\text{Pi}}^2 \times \underline{R}^4}$$

where $\underline{P}$ is the transmitted pulse power,

$\underline{G}$ is the gain or multiplying effect of the transmitting antenna,

$\underline{\text{Sigma}}$ is the radar cross section or reflecting area of the target,

$\underline{A}$ is the effective capture area of the receiving antenna,

$\underline{\text{Pi}}$ is the universal constant equal to the ratio of circumference to diameter of a circle, and

$\underline{R}$ is the distance between the radar and the target.

From this equation it is clear that the radar controls $\underline{P}$, $\underline{G}$, and $\underline{A}$ ($\underline{R}$ too if the radar is moving) while the target controls $\underline{\text{Sigma}}$ and $\underline{R}$. But this only accounts for the signal portion of the S/N ratio. Noise is just as big a factor.

Noise in the electromagnetic spectrum is a function of matter and temperature. In addition to naturally occurring noise, electronic devices are also contributors. Since the radar operator would like to maximize the S/N ratio, it is clearly in the interest of the target to minimize the ratio. This is the essence of electronic warfare.

Waveform Types

In order for a radar to "hear" an echo, it must make some provision for picking up the echo while the radar is transmitting or, failing this, it must stop transmitting. For pulse-type radars this means that they must operate on a cycle of alternating transmitting and listening. Continuous wave (CW) radars transmit continuously by constantly varying the frequency of their transmission. An echo is detected off-frequency from the ongoing transmission.

Pulse Radars. When a pulse radar transmits, it sends out a pulse of limited duration or pulse width. If the pulse is too long, short-range target echoes will return and be lost in the continuing pulse transmission. Hence, pulse width determines the minimum range of a pulse radar. Maximum range is determined by the length of time spent listening for echoes. If the radar does not listen long enough, long-range echoes will be lost in the second pulse transmission. Therefore, radars that have a high pulse repetition frequency (PRF) have relatively short range. Conversely, radars that wait for long-range echoes send out fewer pulses and update their tracking data relatively infrequently. Herein lies an essential compromise made by every pulse radar designer. A practical limit does exist, however, for how short the pulse can be. Short pulses create problems regarding how much energy can be packed into a pulse during the transmit time. Very short pulse widths with relatively low energy have difficulty producing an echo that can be "heard" above the background noise level because of attenuation. To determine the velocity of targets, pulse radars must measure the time it takes targets to change position.

Continuous Wave Radars. CW radars determine azimuth and elevation the same way that pulse radars do, by pointing an antenna in a particular direction. Determining range is not so easy. The simplest form of a CW radar would operate on one frequency. Such a radar would not be very useful because the returning pulse would be obscured in the transmission. Consequently, CW radars continuously change their frequency in a warbling fashion. As echoes return, the transmitter has moved to other frequencies to create a clear channel for listening. This leads to another problem. If a CW radar merely timed until a particular frequency echo returned, it could not "know" if that particular returning frequency was caused by range delay or by a velocity induced Doppler shift of a slightly different frequency that had been transmitted a little earlier or later.*

To get around this ambiguity, CW radars use frequency modulation schemes to code the wave, which allows range determination. Frequency shift in the coded echo can then be used to determine velocity according to the Doppler principle. As a result, CW radars are also referred to as Doppler radars. Because CW radars continuously transmit, their energy is diluted over a longer period of time than that of pulse radars. Consequently, for a given transmitter power level, CW radars have shorter range than pulse radars.

Pulse Compression Radars. Pulse compression radars extend the pulse duration while varying frequency. This technique is used to pack more energy into each pulse than can a simple pulse radar, typically up to 10 times as much, to improve the detection ability of the radar.[11] Sacrificed in the process of extending the pulse duration are echoes from close

*Doppler shift is caused by the transference of target velocity to a radar echo. An oncoming target raises the frequency of the echo, a retreating target lowers the frequency. An everyday example of Doppler shift is the shift in sound a train whistle makes as it approaches, passes, and retreats from a listener.

targets that return while the radar is still transmitting. As a result, pulse compression radars have relatively large "blind" regions close to the radar.

Pulsed Doppler Radars. A fourth class of radar is a combination of the first two and is called a pulsed Doppler radar. By interleaving pulse and Doppler functions in a coherent fashion, the radar is able to eliminate spurious echoes and discriminate nonmoving targets. As a penalty this radar retains either "blind" speeds or "blind" ranges depending on the designer's emphasis.[12] By using a staggered or variable pulse repetition frequency these "blind" speeds or ranges can be moved into regions where they are less of a nuisance.

Pseudorandom Pulse. A fifth class of radar is the pseudorandom pulse, identified with theoretical low-probability-of-intercept (LPI) radars. By spreading transmissions over a wide frequency band, using a coded pulse repetition frequency, and not using any more power than necessary, such a radar's signature can be made to resemble random noise. From this characteristic comes the low-probability-of-intercept nomenclature.[13]

All radars are derived from these five classes of radar waveforms. Discussion of some of their more common design features requires an understanding of mainlobe versus sidelobe effects, phased-array radars, synthetic aperture radars, conical-scan techniques, and monopulse techniques.

Other Design Considerations

When radars transmit energy, they try to convert what would be an omnidirectional emission into a highly focused beam. Several schemes exist for doing this, but a common failing is the transmission of side beams in addition to the main beam. In the parlance of radar technicians, these are called sidelobes and mainlobe, respectively.

Sidelobes are inconvenient because if they rival the mainlobe in magnitude the radar will yield ambiguous azimuth readings on targets it is tracking. In an electronic warfare environment, an adversary could seek to confuse the radar by injecting false targets or noise into the sidelobes, particularly if the sidelobes are prominent. In an effort to minimize sidelobes, radar designers developed the phased-array antenna.

The phased-array radar, instead of diverting a stream of electromagnetic energy, builds a beam incrementally using hundreds or thousands of individual transmitters. By also shifting the phase of each transmitter appropriately, the phased-array antenna can cancel unwanted beam effects or enhance desired effects. In addition, such an antenna can steer the beam via the same phase-shifting effects, instead of using a rotating antenna for scanning. An additional feature is the antenna's ability to form and control multiple, independent beams, all steered electronically. Unfortunately, such high-technology antennae are very expensive.

To take advantage of less-expensive scanning techniques, many modern tracking antennae still employ a conical-scan technique to keep the mainlobe centered on the target. By forming a pencil-shaped mainlobe and rotating it around the centerline to the target, a conical-scan radar reads the strength of the returning echo to measure its pointing accuracy. If the radar detects that the target is beginning to move outside the swept area, it expands the circular sweep. If the target signal is decreasing in strength toward the center of the swept area, it tightens the sweep. This continuous expansion and contraction of the antenna sweep pattern creates instabilities associated with scan rates that an adversary can exploit. To get around the inherent instabilities associated with mechanical scan rates, monopulse radars were developed.

Monopulse radars employ multiple beams to bracket a target. Instead of waiting for several scan adjustments to detect target movement, monopulse radars get position updates on a pulse-to-pulse basis. Since monopulse radars can operate at upward of 2,000 pulses per second compared to approximately a 30 Hz scan frequency for conical-scan radars, the improvement is impressive.[14]

Not all mechanical movement is a disadvantage, however. Synthetic aperture radars use movement to increase their resolution. By constructing a linear array of phase shifters, like those used in a phased-array antenna, and by moving this array along the axis of its construction, one can increase the resolving power of the antenna, severalfold. For example, if a 10-foot antenna looking over a range of 10 miles has a resolution of 500 feet (the ability to distinguish objects that are at least 500 feet long), moving a similar radiating element in a straight line at the speed of a jet aircraft "constructs" a "synthesized" antenna of 1,000 feet. Proper processing of the signals received by such an antenna yields a resolution of 5 feet.[15] The utility of such a radar in ground mapping is obvious.

Radar Usage

Exploiting radar for military purposes is quite logical in view of its potential to perform detection, acquisition, tracking, and identification tasks. As a result of conflicting requirements for long-range search and target tracking for missile guidance, military systems have evolved into basically two types: early warning (EW) and target-tracking (TT) radars.

Early warning (surveillance) radars, whether airborne or surface based, emphasize long-range performance and tend to be pulse radars. To avoid excessive attenuation over long ranges, these radars tend to operate at longer wavelengths (lower frequencies) than target-tracking types. Examples of early warning radars are the Soviet Tall King and Spoon Rest radars, which operate in the very high frequency (VHF) radio band, and the US PAVEPAWS and ballistic missile early warning system (BMEWS) radars, which operate in the ultrahigh frequency (UHF) radio band.[16] Ground-controlled intercept (GCI) radars are EW radars that also have a height-finder radar (tables 10 and 11).

TABLE 10

Land and Airborne Radars[17]

Frequency	*Radio Band*	*Radar Band*	*Radar Type*
10-30 MHz	HF		Over-the-Horizon
30-150 MHz	VHF	A	Spoon Rest-EW Radar; SA-2 Knife Rest-EW Radar; SA-2
150-400 MHz	UHF	B	Tall King-EW Radar
	UHF	C	Flat Face-TT Radar; SA-3, -6, -8 Squint Eye-TT Radar; SA-3 Hen House-EW Radar; ABM
1-2 GHz	SHF	D	SA-3 Command Link FPS-117 (US)-EW Radar Martello (UK)-EW Radar
2-3 GHz	SHF	E	Back Net-EW Radar Barlock-TT & EW Radar Big Bar/Mesh-EW Radar Crotale (France)-TT Radar Long Track-EW Radar; SA-4, -8 Long Trough-EW Radar Odd Lot-EW Radar Token-EW Radar Whiff-AAA Radar; 100-mm Gun
2-4 GHz	SHF	E/F	Fan Song-EW & TT Radar; SA-2 Fire Can-AAA Radar; 57-mm, 85-mm, 100-mm Guns
3-4 GHz	SHF	F	AWACS (US & NATO)-AEW Radar Aegis (US)-Naval EW & TT Radar Rapier (UK & US)-EW Radar

TABLE 10 – Continued

Frequency	*Radio Band*	*Radar Band*	*Radar Type*
4-8 GHz	SHF	G/H	Land Roll-EW Radar; SA-8 Straight Flush-TT Radar; SA-6
6-8 GHz	SHF	H	Pat Hand-TT Radar; SA-4 Skip Spin-AI Radar; Su-15 Flagon Yak-28 Firebar P Square Pair-TT Radar; SA-5
8-10 GHz	SHF	I	Clam Shell-TT Radar; SA-11 Crotale (France) Command Link Low Blow-TT Radar; SA-3 Spin Scan-AI Radar; MiG-21 Fishbed, Su-9 Fishpot APG-66 (US & NATO)-AI Radar; F-16
8-20 GHz	SHF	I/J	Flap Wheel-AAA Radar; 57-mm, 130-mm Guns High Lark-AI Radar; MiG-23 Flogger B/G Fox Fire-AI Radar; MiG-25 Foxbat
10-20 GHz	SHF	J	Gun Dish-TT Radar; SA-9, ZSU-23 Rapier (UK)-Command Link

Legend

ABM – Antiballistic Missile
HF – High Frequency
SHF – Super High Frequency

TABLE 11

Soviet Naval Radars[18]

Frequency	*Radar Band*	*Radar System*
0.5-1.0 GHz	C	Big Net-EW Radar; Cruisers, Destroyers and Pickets; SA-N-1, -2 Head Net A-EW Radar; Cruisers and Destroyers Top-Sail-EW Radar; Carriers and Cruisers Top Trough-EW Radar; Cruisers and Destroyers
1-2 GHz	D	Head Light-TT Radar; Carriers and Cruisers; SA-N-3, -14
1-3 GHz	D/E	Flat Spin-EW Radar; Destroyers and Smaller Ships
2-3 GHz	E	Hair Net-EW Radar; Older Frigates Slim Net-EW Radar; Newer Destroyers and Frigates

TABLE 11 – Continued

Frequency	*Radar Band*	*Radar System*
2-4 GHz	E/F	Head Net C-EW Radar; Carriers, Cruisers, Destroyers, and Frigates
3-4 GHz	F	Head Light-TT Radar; Carriers and Cruisers; SA-N-3, -14 Pop Group-TT Radar; Carriers, Cruisers, Frigates and Smaller; SA-N-4 Strut Curve-EW Radar; Frigates and Smaller
4-6 GHz	G	Fan Song E-TT Radar; Cruisers, Destroyers, and Smaller; SA-N-2 Head Light-TT Radar; Carriers and Cruisers; SA-N-3, -14
6-8 GHz	H	Bass Tilt-AAA Radar; 30-mm, 57-mm, 76-mm Guns Head Light-TT Radar; Carriers and Cruisers; SA-N-3, -14
6-10 GHz	H/I	Front Dome-TT Radar; Destroyers; SA-N-7 Pop Group-TT Radar; Carriers, Cruisers, Frigates and Smaller; SA-N-4
8-10 GHz	I	Hawk Screech-AAA Radar; 45-mm, 57-mm, 76-mm, 100-mm Guns High Sieve-EW Radar; Cruisers and Destroyers Owl Screech-AAA Radar; Carriers, Cruisers, Destroyers, and Frigates; 76-mm
8-20 GHz	I/J	Kite Screech-AAA Radar; Cruisers, Destroyers, and Frigates; 100-mm, 130-mm Top Dome-TT Radar; Cruisers; SA-N-6

Target-tracking radars, conversely, operate over relatively short ranges and thus can operate at higher frequencies. Several advantages make higher frequencies attractive. First, the higher the frequency, the smaller the antenna can be. Since radar antennae must be several times the size of the transmitted wavelength to sufficiently focus the beam for precision guidance, the higher the radar frequency is, the shorter the wavelength and, hence, the narrower the antenna. This tends to become critical for missiles that carry their own radar. Second, the higher the frequency, the lower the tracking beam's elevation can be without incurring multipath ambiguities. Third, the higher the frequency, the wider the transmission band will be because a radar usually exhibits a bandwidth of 10 percent of its nominal operating frequency.

Offensive and Defensive Tasks

Detection is simply the alerting of the operator to the presence of an aircraft within the range of the sensor system. Once alerted, the enemy will attempt to acquire, or localize, the aircraft with appropriate sensors. After localizing the aircraft, the enemy must track and identify it. Tracking is the process of building a position (azimuth, elevation, and range) history and velocity derivation of the target. Identifying the target usually means determining friend or foe status, but it can also mean classification as to the degree of threat. Modern, sophisticated weapon systems routinely detect, acquire, track, and identify virtually simultaneously. Intercepting the aircraft is the process of engaging it with the various types of weapons at the enemy's disposal. For example, to a fighter, interception means closing to within attack range. To SAMs, it means launching and guiding a missile to the transport. Intimidating the transport is to cause it to abort its mission under threat of destruction. And, of course, disablement and destruction are self-explanatory. Note that damage and destruction may be dependent not on direct impact but on warhead effects controlled by a fuse mechanism.

For the transport, avoiding the threat can mean avoiding detection, acquisition, tracking, and identification as well as avoiding the lethal envelope of the weapon. Deceiving the enemy threat is diluting it with real or imagined targets and can occur through massing of aircraft, deceptive jamming of sensors, or employment of decoys. Degrading means reducing enemy capability by confusing and overloading sensors and command and control networks. Intimidating the threat is a form of degradation that causes the enemy to operate inefficiently or not at all because of the threat of destruction. Damaging and destroying means using lethal force against sensors and weapons to eliminate components of the system or the weapon itself.

This brief delineation of the tasks facing the enemy and the airlifter should provide MAC crewmembers with reasons for hope. All of the tasks facing the enemy must be done in an unbroken chain to defeat the airlifter; only one of the airlifter's tasks need be accomplished to defeat the threat. Despite the fact that most of the tasks facing the airlifter are difficult, they are possible. Furthermore, if an airlifter only achieves partial success in several of the tasks, the net effect may sufficiently degrade the threat to defeat it. With this background the next undertaking is to examine electronic warfare tasks in detail.

Electronic Warfare Tasks

Nations conduct electronic warfare for three reasons: to exploit the electromagnetic spectrum for their own use, to deny use of the spectrum by the enemy, and to counter attempts by the enemy to deny use. Accordingly, the classical divisions of electronic warfare are electronic support measures (ESM), electronic countermeasures (ECM), and electronic counter-countermeasures (ECCM).

Electronic Support Measures. As defined by the Department of Defense, ESM is

> that division of electronic warfare involving actions taken to search for, intercept, locate, and identify immediately radiated electromagnetic energy for the purpose of immediate threat recognition. Thus, electronic warfare support measures provide a source of information required for immediate action involving electronic countermeasures, electronic counter-countermeasures, avoidance, targeting, and other tactical employment of forces.[22]

The key words for airlifters are *immediate threat recognition, source of information for immediate action involving electronic countermeasures, avoidance, and targeting.* Because it broadcasts electromagnetic energy, a radar reveals the location of the transmitter and much about its purpose. With diligent military intelligence and appropriate ESM onboard, an airlift aircraft could detect such transmissions, compare them against known threats, assess the threat, plot the location, warn the crew, suggest appropriate evasive maneuvers, and even initiate countermeasures. Under such a scenario, it is clear that the threat has weaknesses that ESM could address. The question should be "Is there a requirement for ESM on airlift aircraft and what form should it take?"

The requirement for ESM is fairly easy to establish. According to the US Air Force Scientific Advisory Board's 1982 Summer Study recommendations,

> Despite all attempts to avoid threats, however, MAC aircraft may come under attack both en route and in combat areas. We recommend they be equipped with appropriate survivability packages including . . . radar warning receivers . . . to reduce the effectiveness of missile attacks from surface and air.[23]

A radar warning receiver (sometimes referred to as a radar homing and warning or RHAW receiver), as earlier suggested, detects threatening radars and displays them to the aircrew as a strobe line or a position on a scope. For example, if the transport were heading north and a threat was displayed at the 3 o'clock position on the scope, the crew would know that a threatening radar was due east of the airplane. Such a scheme works well with a limited number of threats, but as the number increases, the crew can become quickly saturated. As noted earlier, a Hughes and Tracor study suggests that a transport aircraft approaching an airstrip in the brigade rear area at 500-foot altitude in a European war scenario would be scanned by at least 50 threatening radars and tracked by at least 15.[24] A radar warning receiver presentation under such circumstances would be of limited value. It would warn the crew of the threat, but it would not indicate how to proceed.

Instead, what the aircrew would need is some form of a threat-avoidance receiver (TAR) that not only displays threats that also analyzes them to predict a "no-detection" path, if one is possible; activate appropriate ECM devices; and predict a path of least resistance. In addition, if the threat were severe enough, the TAR could activate a weapon to damage or destroy it. Thus a TAR would allow the airlifter to conform to the sequential task hierarchy of avoiding detection then, if detected, jamming the threat, avoiding lethal threat envelopes, or damaging or destroying the threat.

To counter foreseeable threats, a TAR should include a frequency range that protects against existing and predicted threats, while coping with the anticipated pulse density. For example, the current radar threat to an aircraft at 40,000-foot altitude consists of emitters operating from VHF-band through J-band (70 MHz to 20 GHz) with pulse densities that can reach one million pulses per second. The threat in the year 2000 will extend the frequency range to at least 40 GHz and the pulse density to 10 million pulses per second.[25] At 500-foot altitude a TAR will have a slightly easier time since it is estimated that only 25 percent of the threat emitters will be able to illuminate the airlifter. In addition the TAR should rank threats for ECM to negate and should control the ejection of expendable countermeasures.

Electronic Countermeasures. The second major classical division in electronic warfare, ECM, is

> that division of electronic warfare involving actions taken to prevent or reduce an enemy's use of the electromagnetic spectrum. Electronic countermeasures include electronic jamming and electronic deception.[26]

The key concepts are jamming, deceiving, and degrading the enemy's use of the medium. To cover the subject in the context of an airlifter's mission, it is helpful to organize the topic in terms of active (observable) measures, passive (unobservable) measures, stealth techniques, and passive-active techniques. In reading the following discussion, the reader should remember that the enemy is attempting to increase the S/N ratio while the airlifter is attempting to decrease it.

Active Techniques. Active ECM, or jamming, is an attempt by one side to degrade or deceive the electronic sensors of the other by emitting energy. In the context of a penetrating airlift aircraft, active ECM need not be supplied by the transport itself. When it is, it is called self-screening jamming. When active ECM is provided by a nearby aircraft, it is called escort jamming, and when it is provided by a distant platform, it is standoff jamming. Self-screening and escort jamming give away the location of the airlift aircraft while standoff jamming only gives away the location of the jammer. Thus, standoff jamming may be thought of as passive from the perspective of the transport.

As implied, the jammer need only accomplish one of two functions: deceive the radar or degrade its capability. Deception jamming mimics the radar's waveform to gain entry to its range, velocity, and angle tracking loops where it induces the radar to track false targets. Degrading occurs through noise jamming that strives to lower the S/N ratio to less than 1.0. While less sophisticated than deception jammers, a powerful noise jammer can be more widely employed.

The jammer's pulses act on the radar receiver in one of two ways, through the radar mainlobe or through the sidelobes. Mainlobe jamming must be timed to occur during the brief interval the mainlobe is sweeping past the target aircraft and is only effective if performed by the target aircraft or a jammer on the same azimuth from the radar. If the separation between the jammer and the airlift aircraft is greater than the mainlobe beam width, both the jammer and the airlift aircraft will be visible to the radar.

Recall from the echo power equation that the strength of the echo will be attenuated as a function of the distance between the radar and airlifter/jammer to the fourth power. A jamming signal originating at the airlifter will only be attenuated as a function of the distance squared, since the signal is not making a round-trip. This conveys an advantage to the jamming aircraft (in striving to make the signal-to-noise ratio less than 1.0).

Assuming that the ground-based radar is more powerful than the airborne platform, a relationship that usually holds, the jammer can only dominate until the range decreases to the point where the more powerful radar will "burn through" the jamming (making the S/N ratio greater than 1.0) (fig. 3). At this range the advantage swings back to the ground radar.

When the mainlobe is jammed by a noise generator such that the S/N ratio is less than 1.0, the ground radar "sees" a strobe line passing through the jamming platform's position. If there is only one radar, or other radars are not "netted," and the penetrating aircraft does not intrude to the point of burnthrough, the radar cannot produce range data. Without range data, it is difficult to engage targets with any form of weaponry because operators cannot know if or when the jammer is in range of their weapons.

If more than one radar is operating and they are integrated in a defense network, noise jamming of each radar's mainlobe

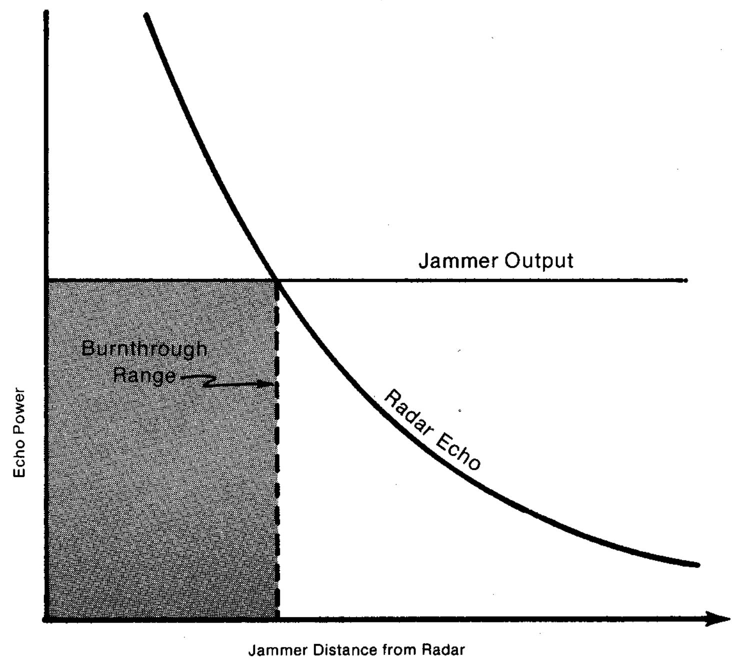


Figure 3. Radar Burnthrough.[27]

produces strobes against each. When the total picture is observed from a master scope, the strobes intersect at the position of the jammer, thereby producing range data. This technique of producing a network solution breaks down, however, when increasing numbers of jammers are introduced. To illustrate this breakdown, consider the case of two separated jammers and two separated radars. When two jamming strobes are produced against each radar, four intersections appear on the master scope. Two of these intersections contain target jammers; the other two are empty and are called "ghosts"[28] (fig. 4). Since the ghosts are identical to the target intersections, the enemy must use other means to sort out the targets. As more jammers are introduced the "ghosting" problem increases as a factor of the number of

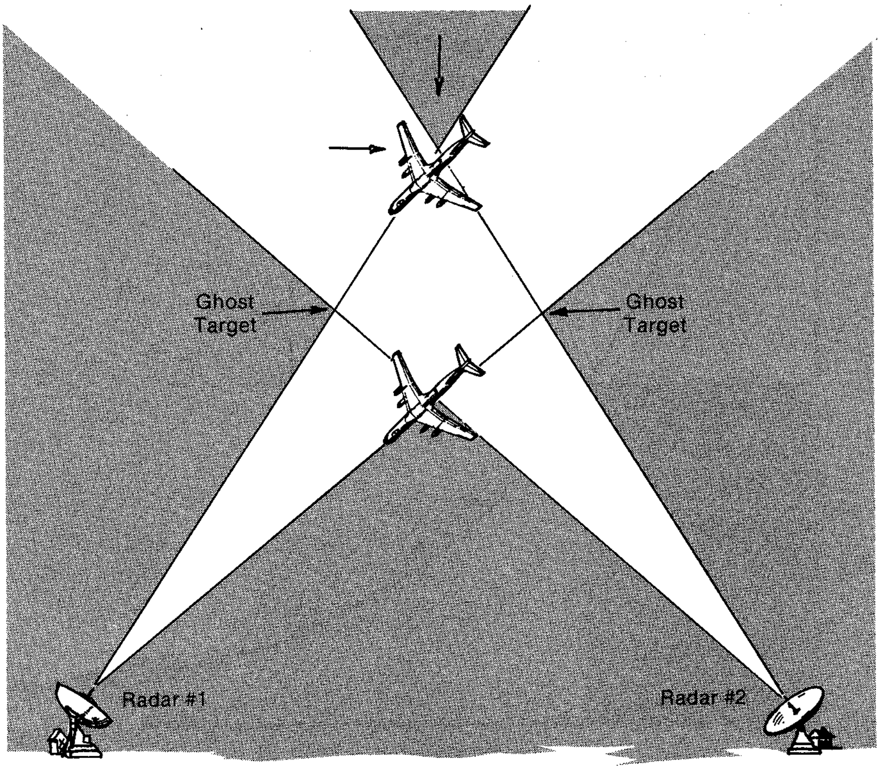


Figure 4. Ghosting Problem with Netted Radars.

jammers squared. Therefore, the integrated network solution works against only a small number of jammers.[29]

If the jammers have enough power and can inject noise into the sidelobes of the radar, instead of "seeing" one strobe, the radar "sees" multiple strobes originating from virtually every compass position. The net effect is to blank out the scope. Such antijamming hardware as coherent sidelobe cancelers and sidelobe blankers, employing auxiliary antennae and signal-processing techniques, significantly reduce vulnerability, but they cannot completely defeat sidelobe jamming.[30]

Frequency agility (the ability of a radar to change its operating frequency) requires an additional level of jamming sophistication. To this point, discussion of mainlobe and sidelobe effects has been based on a radar operating on one frequency. Even nonagile radars can be tuned to operate anywhere within 10 percent of their nominal design frequency. This increases the difficulty of jamming them and naturally favors radars designed to operate at higher frequencies since 10 percent of a larger number produces a wider margin for operation. Once such a radar is successfully jammed, however, there is an incentive to change frequency to get away from the jamming. To assure continued jamming of a radar that has frequency agility, the jammer must periodically "look through" the jamming to make sure the radar has not changed frequency or shut down.[31] To do so, the jammer must either isolate its jamming and receiving antennae or cease jamming briefly to sample the radar's output.

Noise jammers come in three basic forms: barrage, spot, and swept. When a jammer has enough power and can cover a wide band of frequencies, it is called a barrage jammer. The test is the jammer's ability to produce enough noise at all frequencies in the barrage band to reduce the S/N ratio to less than 1.0 for any radar operating within the band. To illustrate this point, consider a jammer producing 1,000 watts of power while covering a band of 1,000 MHz. Such a jammer produces a spectral power density of one watt per megahertz. In a self-screening jammer, such output against the mainlobe of a surveillance radar might be effective in reducing that radar's range-determining capability to 5 percent of its unjammed capability. Acting as a standoff jammer at a range of 50 nautical miles against the same radar's sidelobes, such output might only be effective in reducing the range to 92 percent of the unjammed value. Against the same radar with sidelobe reduction techniques, the output may only be effective in reducing the range detection capability to 98 percent.[32]

Spot noise jamming concentrates the jamming energy over a much narrower frequency band. Compared to barrage jamming, it is much more efficient, but it requires either a good automatic lookthrough capability to detect a radar frequency shift or it requires a human in the control loop.[33]

To get around the control requirements associated with spot jamming, designers developed swept jamming. Such jammers produce spot-jamming density levels, but sweep through the frequency band of interest on a repetitive basis.[34]

Against early warning radars, self-screening noise jamming appears to offer the most screening potential. Against tracking radars, which are associated with missile and AAA systems, this is not necessarily the case.

Whereas early warning radars tend to be pulse radars, target-tracking radars tend to be monopulse, conical scan, or Doppler. In the case of missile systems, if the tracking radar is assured that the target is within the range of the missile, precise range information is not needed. All the missile need do is home on the jamming or ride the jamming strobe to the target. Because of these characteristics, deceptive techniques are usually used against target-tracking radars.

The aim of a deceptive technique is to stop the radar from tracking the target. Numerous techniques are used depending on the type of radar. Since tracking radars usually feature narrow mainlobe beams, they must be fed precise target coordinates to acquire the target. Such information usually comes from a surveillance radar or a missile acquisition radar.

If the tracking radar breaks track (loses the target), it usually must recycle through the acquisition process; that is, the missile acquisition radar must reacquire the target and pass target coordinates to the tracking radar. In an automatic control mode, this process can take up to 10 seconds.[35] With a skilled human operator in a manual control mode, this time can be reduced considerably, but missile accuracy usually suffers from the less-smooth human control.

To understand how tracking radars are induced to break track requires some knowledge of their operating characteristics. For example, pulse radars track by "building" range gates around their targets. Range gates specify a period in time during which the radar will accept signals as valid echoes. Recall from the radar mile discussion that range and echo time delays are analogous. Signals falling outside the near and far gates are rejected as being too early and too late, respectively, to be echoes from the target. To get pulse radars to accept a jamming pulse instead of the echo from the target requires a deceptive technique called range gate pull-off (RGPO).[36] The RGPO jammer analyzes the radar pulse arriving at the aircraft and constructs a jamming pulse to mimic the echo. Ensuring overlap of the echo by the jamming pulse, the jammer raises the power of the jamming signal until it is much stronger than the echo. Since radars must have an automatic gain control to keep from being overwhelmed by echoes from nearby targets, the gain (sensitivity) is lowered. As the strength of the jamming pulse increases, the jammer delays the pulse so that the radar is made to "think" the target is pulling away. The radar then adjusts its range gates accordingly. This is called capturing the gate. Once the gate is captured the radar can no longer "see" the real target (because of the radar's lowered gain) as long as the jamming continues. When the range gate has been pulled off to the extent that the real echo will be rejected, the jammer shuts off. The tracking radar must then cycle through the acquisition process to reacquire the target. Such a process can be employed repetitively to defeat the pulse radar. Against radars with a stable pulse repetition frequency, range gate pull-in (RGPI) can be used by advancing the jamming pulse ahead of the echo.

Doppler radars build velocity gates instead of range gates. Against such radars, velocity gate pull-off (VGPO) must be substituted for RGPO.[37] Velocity gates are constructed by setting certain frequency limits on returning echoes once the target has been acquired. Any echo with a frequency outside these velocity gates is rejected. To institute VGPO, the jammer must first capture the gate by mimicking the echo while raising the jamming signal strength. By gradually shifting the frequency (to simulate a change in velocity of the target), the jammer causes the radar to adjust its velocity gate to the dictates of the jammer. When the velocity gate has been pulled off sufficiently to reject the real target, the jammer shuts off. As a check against such techniques, some Doppler radars test the frequency shift of echoes to make sure they conform to accepted acceleration limits. A smart jammer can compensate for these checks, however, and keep false target acceleration within bounds.

Pulse compression radars are called coherent radars because of their ability to process radar signals and remove unwanted noise. Noise jamming against these types of radars is usually counterproductive, so deceptive jamming is recommended. Against pulse compression radars, the jammer need only have the ability to decompress the pulse, analyze it, and reproduce it to accomplish VGPO. Use of repeater jamming is effective against pulse compression radars because of their inherent inability to perform leading-edge pulse tracking. Leading-edge pulse tracking derives from the phenomenon in which delayed echoes are seen as longer-range targets, with the first echo, or leading edge, being the real target.[38]

Pulse Doppler radars are also considered coherent because of the pulse phase correlation used in establishing velocity gates. Jamming only the Doppler velocity gate is not effective because the pulse aspect of the radar still provides range-derived velocity. As a result both RGPO and VGPO must be used simultaneously and within acceleration limits to be effective.[39]

Against low-probability-of-intercept radars the trick is to know they are operating in the first place. If intelligence can establish the parameters of the waveform, filters can be programmed into the jammer to screen for these signals. Otherwise, sophisticated techniques involving channelized receivers, instantaneous frequency measurement techniques, spectrum analysis, or Bragg-cell type receivers will be required to ferret out the signal. Once it is known that an LPI radar is operating, however, repeater jamming would appear to be sufficient.[40]

Jamming phased-array radars is more difficult because of their low sidelobes, concentrated mainlobe energy, and track-while-scan (TWS) capability. Otherwise, noise and the RGPO and VGPO techniques previously described are applicable.

Conical-scan radars are particularly vulnerable to ECM attacks against the tracking antenna. Against a plain conical-scan radar, inverse gain jamming (echoes are reinforced inversely proportional to the strength of the radar pulse at the target) produces a tracking error signal that tends to drive the antenna away from the target to the point of breaking lock. Later versions of conical-scan radars employ a technique called lobe-on-receive-only (LORO), which uses a nonscanning beam that is received by the conically scanning antenna. Since the jammer cannot discern the scan rate from the beam, it must search for it by sweeping the frequency range with energy and by monitoring the tracking radar beam for a reaction. When the jammer sweeps inverse gain signals through the receiving antenna's scan-rate frequency, the conical-scan transmitting antenna will temporarily go unstable. By detecting this instability in the signal and sweeping back to this frequency, the jammer can drive the conical-scan transmitting antenna off the target.[41]

Of all the radars discussed, the monopulse causes the most difficulty for a single jamming source because the radar detects tracking error signals on a pulse-to-pulse basis. Since the pulse repetition frequency is quite high, the errors induced directly are usually quite small. Instead, the more successful techniques attempt to exploit multipath signals through cross-polarization, cross-eye, or terrain-bounce techniques.[42]

Cross-polarization works on the principle that the tracking error sensing circuit in the radar has a positive feedback for cross-polarized signals (rotated 90 degrees), as opposed to the required negative feedback for tracking. This technique is easier to use against parabolic antennae than planar-array antennae.[43]

Cross-eye jamming is the simultaneous repeating of the transmitted monopulse signal from two separated antennae operating 180 degrees in phase shift. By producing a relatively powerful jamming signal and keeping the separation of the jamming sources a beam width apart, maximum error is induced.[44]

Terrain bounce is a technique that is more appropriate for decoying missiles than for deceiving ground-based radars. It relies on a bistatic jamming principle whereby the monopulse signal is repeated and bounced off the nearby surface of the earth in the direction of the radar. To be effective the jammer should employ a fan-shaped signal, wide in azimuth but narrow in elevation, with low sidelobes. When jamming is successful the SAM or air-to-air missile impacts the ground on the spot illuminated.[45, 46]

Passive Techniques. Passive ECM techniques are those that can be employed without giving away the location of the initiating platform. The most obvious is chaff (precisely sized strips of foil), which when introduced into the airstream produce a radar echo many times the size of the aircraft. To be effective, chaff must be cut to a length equal to one-half the wavelength of the victim radar.[47] The frequency diversity of threat radars listed in tables 10 and 11 suggests that aircraft using chaff should carry a range of lengths. Despite such techniques as moving target indicators (MTIs) and Doppler processing, which filter out nonmoving targets, chaff is still effective against early warning and search radars. Not only does it act to screen targets, but it also causes automatic gain control problems for susceptible radars so that detection range is reduced.

Stealth Techniques. The most effective ECM technique is to reduce an aircraft's radar cross section. Lumped under a broad category called stealth technology, radar cross-section reduction techniques can be very effective. In the evolution of the B-1B aircraft, stealth technology was successful in reducing the A-model reflection by an order of magnitude. For example, if a B-1A were first detectable by a radar 35 nautical miles away, the B-1B would not be detected until it came within approximately 20 nautical miles.[48] Radar cross-section reduction techniques fall into one of three subcategories: vehicle shape, skin design, and radar absorbent coatings and material.

The "stealthy" vehicle shape should emphasize surfaces that reflect radar waves away from the source, a blended fuselage and wing, hidden inlets and engine compressor face, and the elimination of such obvious radiating elements as antennae. When the direction from which threat radars will be radiating can be determined (i.e., always from above), steps can be taken to deflect radar echoes away from that direction. Skin design should emphasize absorbing incident waves and canceling interior waves for the range of threat frequencies that are critical.[49] Radar absorbent coatings and material are used in circumstances where the first two techniques are impractical or unsuccessful.

Passive-Active Techniques. This category includes the use of towed decoys and expendable jammers. A towed decoy is an antenna towed at some distance from an aircraft and is only caused to radiate after the aircraft is detected. The principles involved are to allow multiple decoys to create a cross-eye jamming capability while drawing missiles away from the target aircraft.[50] If a decoy is destroyed, another is reeled out in its place. A disadvantage with the towed decoy is its influence on aircraft performance.

An expendable jammer is not deployed until it is needed. It is then ejected and activated and operates while descending either in free-fall or on a parachute. A disadvantage with an expendable decoy on a parachute is that it will quickly slow while descending and, thus, is theoretically subject to a moving target filter. Additionally, expendable decoys are limited in power output compared to the towed variety.

Electronic Counter-Countermeasures. So far, this discussion has shown that the five radar classes in their many forms can be countered with ECM. However, each countermeasure has counter-countermeasures that act to restore dominance of the threat radar. Despite ongoing efforts to come up with the perfect radar and the perfect jammer, the fact remains that no radar is unjammable and no jammer is perfect. A quick review of table 12 should illustrate the nature of this continuous action and reaction cycle in electronic warfare.

TABLE 12

Early Warning and Tracking Radar ECM and ECCM Techniques[51]

Radar Type	*ECM*	*ECCM*
	Range Obscuration	
EW & TT	Spot Noise	More Power, Frequency Agile Pulse Compression.
EW	Barrage Noise	Same, Constant False Alarm Rate.
EW	Swept Noise	Same, Variable Intermediate Frequency Processing.

TABLE 12 – Continued

Radar Type	*ECM*	*ECCM*
	Range Deception	
EW & TT	Cover Pulse	Pulse Compression. Network Solution. Frequency Agility.
EW & TT	False Targets	Pulse Repetition. Frequency Jitter. Frequency Agility. Sidelobe Reduction.
TT	Range-gated Noise	Frequency Agility. Home on Jam.
TT	Range-gate Pull-in	Pulse Repetition. Frequency Jitter.
TT	Chaff	Moving Target. Indicator.
	Angle Obscuration	
TT	Inverse Gain	Lobe-on-receive-only.
EW & TT	Buddy Mode Noise	Monopulse. Pulse Compression.
	Angle Deception	
EW & TT	Inverse Gain	Lobe-on-receive-only.
TT	Jog Detector	Anticipation Circuit. Plus Frequency Agility
	Velocity Deception	
TT	Velocity Gate Pull-off	Pulse, Pulse Doppler. Acceleration Checker.

Electro-optical Countermeasures

Electro-optical (EO) systems exploiting visible and infrared radiation have been used in warfare ever since World War II when the Germans used IR signal lamps and the Italians used IR-sensitive mirror systems to locate ships. Modern systems exploit IR radiation for such uses as seeker heads in missiles, search and track systems, night-vision devices, photographic sensors, and navigation systems. In addition, visible and IR portions of the spectrum are exploited in laser (light amplification by stimulated emission of radiation) systems.

Countering EO systems is increasingly important because of their growing use on the modern battlefield. For the airlifter four adaptations of EO systems pose severe threats: IR homing missiles, antivision lasers, laser beam-riding missiles, and directed-energy weapons (DEWs).

Infrared Homing Missiles

In addition to IR's earlier-mentioned usefulness in penetrating haze, IR guidance systems make use of the fact that all matter warmer than absolute zero (-459.69° Fahrenheit) produces infrared radiation. Because IR homing devices do not have to supply the IR energy for their guidance system, they can operate passively. IR homing missiles rely on photoconductive (table 13) or photovoltaic sensors that are responsive to certain wavelengths of IR radiation.

TABLE 13

Infrared Sensitive Photoconductors[52]

Photoconductor	*Wavelength Sensitivity*
Lead Sulfide, -60°F	1 to 3.5 microns
Lead Sulfide, Room Temperature	1 to 2.8 microns
Telluride, -320°F	1 to 5 microns
Indium Antimonide, -320°F	1 to 6 microns
Germanium, Doped, Room Temperature	1 to 9 microns

The warmer matter becomes, the shorter the wavelength of radiation given off. For example, room temperature objects primarily radiate in the 6-to-10 micron region. Objects at 400 degrees Fahrenheit primarily radiate in the 3-to-10 micron region, and objects at 900 degrees Fahrenheit primarily radiate in the 2-to-10 micron region. Because of the atmospheric absorption band between 5 and 8 microns, a heat-seeker looking for a jet engine's nozzle area would need to concentrate on the 2-to-4 micron region. If a sensor sought other aircraft body heat as a target, it would concentrate in the 8-to-10 micron region.[53]

Early heat-seeking missile designers, in fact, used room temperature lead sulfide sensors, but they found that their missiles went astray whenever their sensors scanned past the sun, sunlit clouds, or bright spots of illuminated earth reflecting in the 2.5-micron range. To achieve better false-target rejection capability, rotating reticles were used to "chop" incoming radiation. Chopping periodically blocked the sensor from view, thereby setting up an alternating signal current. By amplifying the alternating signal, better noise rejection was achieved.[54]

Infrared countermeasures (IRCM) in the form of pyrotechnic flares and IR-strobe jammers were then developed to offset the improved performance of the reticles. Flares are used to flood the IR sensor with so much energy that the target (for example, jet exhaust) becomes insignificant and thus "invisible." The IR-strobe jammer attempts to synchronize its flashes with the openings of the chopper. If synchronization is achieved, the missile has two targets within its sensor's field of view and its homing becomes erratic.

To keep missiles from homing on decoys, IR seeker designers developed dual-band sensor systems that can recognize the signature of real targets and reject poor imitators. Such techniques would appear to be vulnerable to IR decoys more effectively tuned to mimic jet-exhaust characteristics.

Antivision Lasers

Lasers can transmit sufficient energy to temporarily or permanently blind personnel. Incidents cited by US Navy and Norwegian aircrews, which involved flying past Soviet ships, serve to emphasize the serious nature of this threat. In each case, "naked" eyes were temporarily blinded when attacked by relatively low-powered devices. If a low-powered laser were viewed through lenses, such as conventional heads-up displays (HUDs), or if beams emanating from higher-powered devices were used against the unaided eye, permanent blindness could result.[55] If a high-powered beam happened to pass through a HUD, explosive delamination of the HUD optics could occur. One weakness associated with such weapons is the monochromatic nature of the light they produce. Countermeasures might exploit that characteristic by filtering or reflecting the frequency of the laser's energy.

Laser Beam-Riding Missiles

Such weapons as the Swedish Bofors Rayrider man-portable SAM pose a unique threat to airlift aircraft. To date, effective countermeasures have not been demonstrated although possibilities include attacking the illuminating laser operator with another laser, attacking the missile directly, and back-lighting reflective (optical) chaff.

Directed-Energy Weapons

Use of lasers as directed-energy weapons is being pursued with great vigor as part of antiballistic missile defense. An early and certain application of such weapons will be against aircraft. Since numerous sources have projected the mid-1990s to the year 2000 as a feasible time frame for producing such weapons, the threat appears imminent. Because such a weapon would probably be aimed in an analogous fashion to radar and optically aimed SAMs, antiradar and antioptics (laser) tactics would appear to be feasible.

System Countermeasures

In the discussions of radar and electro-optical weapon weaknesses, the focus has been on internal operation and exploitation of electromagnetic phenomena. Such weapons also have weaknesses inherent in their functions: they are subject to time constraints, human operator limitations, and guidance and control problems.

Time

To avoid being destroyed by a missile, an airlifter need only frustrate a targeting solution long enough to escape the missile's envelope. By causing the tracking radar to break track periodically, a jamming aircraft buys time and comes closer to escaping. Accordingly, speed is an ally of the transport along with delayed detection. Since low-altitude penetration delays detection, speed and low altitude have synergistic effects.

Countering Humans

Many tracking radars employ a human backup to automatic tracking circuitry to allow countering of ECM techniques. Whenever a human manually controls a radar, however, its accuracy suffers, resulting in as much as a 30-percent reduction in probability of kill.[56] Furthermore, humans have saturation limits and resonant frequencies that can be attacked as well. For example, a strobe lamp cycled at approximately five cycles per second will eventually incapacitate a person viewing it. Another way to attack humans is psychologically by placing them at risk, as use of an antiradiation missile would do. If a threat radar appears and is not deterred by ECM, airlift aircraft could wield the ultimate countermeasure: destruction of the radar. Such a threat might cause operators to be more selective in using their radars, creating greater opportunity for transports to avoid the threat.

Missile Guidance Countermeasures

Missile guidance schemes also offer opportunities for defeating a missile. Basically there are three types of guidance techniques: homing, beam riding, and command guidance. Homing is the process of proceeding to a source of radiation and, in turn, is divided into three paths: a pursuit course, a collision course, and a proportional navigation course. Pursuit guidance is characterized by constant turning to place the target in the center of the seeker. Turn rate is proportional to the line-of-sight (LOS) angle from the missile centerline. Since this path results in continuously turning flight, a drag penalty is incurred that decreases range. A collision course is a constant bearing course that requires instantaneous course corrections. In theory this is the most efficient path, but in practice it is not realistic, and any attempt to turn instantaneously usually results in a suboptimum range capability. The optimum range path is a proportional navigation course, in which the missile turns with a rate proportional to the rate of change of the bearing to the target.

When flying any of the homing paths, a missile operates in one of three modes: passive, active, or semiactive. Passive operation does not require that either the launching platform or the missile radiate. An example of a system that operates passively is a heat-seeking missile. Active guidance requires the missile to illuminate the target, usually with radar. An example of a system that uses active guidance is the advanced medium-range air-to-air missile (AMRAAM) in its terminal phase. Regardless of the relative positions of the launch platform and the target, a missile relying on passive or active homing guidance becomes more accurate the closer it gets to its target. A variation of the two homing modes just discussed is semiactive guidance. In this mode the launch platform must illuminate the target for the missile. The farther the target gets from the launch platform, the less accurate the guidance. Most modern radar missiles are semiactive.[57, 58]

Beam-riding missiles center themselves on a radio, radar, or laser beam transmitted by the launching platform. In general, they do not "sense" targets and destroy them by detonation on impact. Such missiles follow a constantly turning and relatively inefficient flight path, they may have to perform severe corrective maneuvers as they near intercept, and they suffer accuracy degradation proportionally with distance. Because they receive their guidance from their aft direction, ECM directed at them usually must act through the backside of their highly directional antennae, which is most difficult.[59]

Command guidance relies on two radar beams, one tracking the target and another tracking the missile. The missile turns on command from the controller and relies on a proximity fusing system, a command link, or impact for detonation. As a result, the missile can be fired to a point ahead of the target, efficiently using its propulsive energy. As target range from the tracking platform increases, accuracy suffers.[60]

Concepts for defeating missiles are only limited by one's imagination, but they generally focus on the weak links in guidance systems. Since homing missiles are guided by energy radiating from or reflecting off the target, efforts to reduce, suppress, conceal, or decoy this radiation can be effective.

Any missile that does not have a proximity fuse is vulnerable to a last-minute flight path change by the target. If the target can delay its maneuver until the missile requires more than its maximum turning acceleration (G-limit) to follow the target, the higher-speed missile will invariably overshoot. For example, a Mach-3 missile homing on a Mach-0.7 target would have to "pull" more than 18 times the G-load of the target to fly the same track. If the target maneuvers too early, however, a missile need not fly the same track, but can "cut" the corner to reduce the required G-load to within its capability. Since the lead time required to "cut" the corner is proportional to the G-load capability of the target, a low-G capable aircraft like a transport would have a very small margin of time, or window of opportunity, within which to act. Automating this maneuver, however, could make it feasible.

Beam-riding weapons expose their tracking beam apparatus and personnel during their time of flight while protecting their rearward-facing, beam-riding antennae against ECM. The inherent weakness of the system is in the vulnerability of the exposed components. Since a laser system would be optically sighted, it would be theoretically vulnerable to laser energy aimed back through the optical components.

Command-guided weapons require a communication link, which opens another avenue for deception. If the tracking radar is negated, the missile is lost. If the command link is negated, the missile is lost. Countermeasures against such systems would undoubtedly jam both tracking and communication links while maneuvering to exploit the system's long-range inaccuracies.

Against fused weapons, the possibility exists that the weapon could be deceived into detonating prematurely. Homing weapons that rely on CW radar illumination may be vulnerable to a descending frequency VGPO technique to trick the weapon into "thinking" it is passing the target.[61]

Conclusions

From the preceding discussion of the electromagnetic spectrum and electronic warfare, four concepts should emerge. First, the threat has imposed a requirement on MAC to become proficient at electronic warfare. Second, despite its technical nature, electronic warfare is too important to be relegated to technicians; all levels of leadership will have to acquire warfighting skill in electronic warfare. Third, the action-reaction nature of ECM and ECCM requires persistent command attention in developing countermeasures on a continuous basis. And fourth, despite the myths attached to certain antiaircraft weapons, they all can be countered, even by airlift aircraft.

NOTES

1. Ovid Eshbach, *Handbook of Engineering Fundamentals,* 2d ed. (New York: John Wiley and Sons, Inc., May 1963), 10–07.

2. Richard E. Fitts, *The Strategy of Electromagnetic Conflict* (Los Altos, Calif.: Peninsula Publishing, 1980), 159.

3. Ibid., 160.

4. M. D. Earle, "Characteristics of Infrared Radiation," *Electronic Countermeasures* (Los Altos, Calif.: Peninsula Publishing, 1978), 21-4.

5. Ibid., 31-4.

6. Fitts, *Strategy of Electromagnetic Conflict*, 145.

7. Earle, "Characteristics of Infrared Radiation," 21-4.

8. Stephen L. Johnston, "Millimeter Waves Present New Opportunities for EW Techniques," *International Countermeasures Handbook: 1986*, 11th ed. (Palo Alto, Calif.: EW Communications, Inc., 1986), 323.

9. Earle, "Characteristics of Infrared Radiation," 21-4.

10. Fitts, *Strategy of Electromagnetic Conflict*, 12.

11. Ibid., 116.

12. D. Curtis Schleher, *Introduction to Electronic Warfare* (Dedham, Mass.: Artech House, Inc., 1986), 32.

13. Ibid.

14. Ibid., 150–51.

15. Fitts, *Strategy of Electromagnetic Conflict*, 25.

16. Schleher, *Introduction to Electronic Warfare*, 343.

17. Charles H. Wiseman, "Soviet Weapons and Electronics—Radar Systems," *International Countermeasures Handbook: 1986*, 11th ed. (Palo Alto, Calif.: EW Communications, Inc., 1986), 270–76.

18. Ibid., 262–69.

19. Johnston, "Millimeter Waves," 324.

20. Schleher, *Introduction to Electronic Warfare*, 346.

21. Ibid., 344.

22. Ibid., 258.

23. US Air Force Scientific Advisory Board, *Report of the Ad Hoc Committee on the Enhancement of Airlift in Force Projection* (1982 Summer Study) (U), executive summary, Washington, D.C., December 1982, 1. (SECRET) (Information extracted from this source is unclassified.)

24. Hughes Aircraft Company and Tracor Corporation, "Military Airlift Command Electronic Warfare Study Briefing" (U), presented to Headquarters MAC, January 1988, EW-1. (SECRET) (Information extracted from this source is unclassified.)

25. Schleher, *Introduction to Electronic Warfare*, 38.

26. Fitts, *Strategy of Electromagnetic Conflict*, 257.

27. Ibid., 84.

28. Ibid., 104.
29. Ibid.
30. M. A. Johnson and D. C. Stoner, "ECCM from the Radar Designer's Viewpoint," *Radar Electronic Counter-Countermeasures* (Dedham, Mass.: Artech House, Inc., 1979), 143.
31. Fitts, *Strategy of Electromagnetic Conflict*, 85.
32. Schleher, *Introduction to Electronic Warfare*, 126.
33. Fitts, *Strategy of Electromagnetic Conflict*, 90.
34. Ibid.
35. Schleher, *Introduction to Electronic Warfare*, 115.
36. Ibid., 116.
37. Ibid.
38. Ibid., 173.
39. Ibid., 283.
40. Ibid., 173–78.
41. Ibid., 239.
42. Ibid., 152.
43. Ibid., 152–55.
44. Ibid., 158–59.
45. Ibid., 249.
46. A. I. Leonov, and K. I. Fomichev, *Monopulse Radar* (Dedham, Mass.: Artech House, Inc., 1987). Reprinted in part in "Soviet Book Describes Techniques for Jamming Monopulse Radars," *Aviation Week & Space Technology*, 9 February 1987, 61–67.
47. G. S. Sundaram, "Expendables in Electronic Warfare—Proven Decoys for Survival," *Interavia Data*, 1980, 74.
48. Richard S. Friedman, *Advanced Technology Warfare* (New York: Harmony Books, 1985), 19.
49. Richard N. Johnson, "Radar Absorbing Material: A Passive Role in an Active Scenario," *International Countermeasures Handbook*, 11th ed. (Palo Alto, Calif.: EW Communications, Inc., 1986), 377.
50. "Towed Expendable RF Decoy to Defeat Classified Threats," *Aviation Week & Space Technology*, 21 September 1987, 23.
51. Stephen L. Johnston, "Guided Missile System ECM/ECCM," *Radar Electronic Counter-Countermeasures* (Dedham, Mass.: Artech House, Inc., 1979), 122–23.
52. Earle, "Characteristics of Infrared Radiation," 21-7.
53. Ibid., 21-3.
54. Ibid., 21-10.
55. Department of Defense, *Soviet Military Power* (Washington, D.C.: Government Printing Office, March 1987), 113.
56. Fitts, *The Strategy of Electromagnetic Conflict*, 98.
57. Johnston, "Guided Missile System ECM/ECCM," 123–24.

58. A. Ivanov, "Improved Radar Designs Outwit Complex Threats," *Radar Electronic Counter-Countermeasures* (Dedham, Mass.: Artech House, Inc., 1979), 457–58.

59. Leroy B.Van Brunt, *Applied ECM* (Dunn Loring, Va.: EW Engineering, Inc., 1978), 958–60.

60. Ivanov, "Improved Radar Designs," 457–58.

61. Schleher, *Introduction to Electronic Warfare*, 163.

CHAPTER 4

TECHNOLOGICAL SOLUTIONS

Having established operating principles and weaknesses of threat systems, this study's next task is to develop concepts for effective countermeasure systems. Fortunately, MAC can start with a clean slate to design self-protective systems and can profit from the lessons of the past while exploiting new technological opportunities.

Design Philosophy

One lesson of the past is the need to apply the correct design philosophy. In general there are four prominent design philosophies available to an ECM system designer: one is to counter the current enemy electronic order of battle (EOB), a second is to counter the current EOB and anticipated enemy changes, a third is to counter the current enemy EOB and a "mirror image" of one's own capability to improve the EOB, and the fourth is to counter generic systems (radar for example) improved to optimum levels. Each philosophy has its own advantages and liabilities.[1]

Attempts to counter only the enemy's current EOB minimize short-term costs, but they do not protect against change. Since some change is inevitable, the risk of battlefield surprise is high. Also, long-term costs could be relatively high because each change introduced by the enemy will require a rapid countering reaction, which is usually very inefficient.

Adopting the second design philosophy (assessing the enemy's capability to change current systems and then countering those systems) increases short-term costs over the first choice and possibly reduces long-term costs, depending on the accuracy of one's assessments. This philosophy also protects against some changes. However, this approach tends to ignore optimum use of physical principles; it tends to miss major breakthroughs; and, ultimately, it underestimates the enemy's capability.[2]

The third design approach (countering the current EOB while giving the enemy "mirror-image" capabilities) tends to cost more over the short term than the second approach, but it may save more over the long term. Of course, this approach assumes a technological lead over the enemy. Although protection against surprise is improved further, estimates of one's lead over the enemy tend to be optimistic. Worse, this design approach condemns one to continue the action-reaction design cycle, thus keeping long-term costs relatively high.

The fourth design approach (countering generic systems developed to optimum capability) requires one to continuously improve state-of-the-art technology. Consequently, it tends to be very expensive in the short term and relatively inexpensive over the long term. By its very nature, it tends to overestimate the enemy's capability. Thus this approach offers the most protection against surprise. In new fields of technology, however, the fourth design approach is often constrained by the state of the art and never quite reaches the theoretical optimum. As technology matures in a particular field, such as radar, the fourth option becomes increasingly possible.

All four design approaches have utility depending on the urgency of the need. For example, when the SA-2 SAM was first used by North Vietnam, specific countermeasures were developed on a rapid-reaction basis using the first design approach. However, upgrades to the first-generation countermeasure system tended to use a combination of design approaches two and three. As second-generation systems were developed on a more orderly basis, the fourth design approach was used to a greater extent.

Currently MAC has no self-protective systems on its aircraft and the threat has reached the level at which MAC must react. Unfortunately, MAC cannot afford to wait the 10 or more years it takes to develop new systems. As a result, a two-stage program seems in order: develop a minimally sufficient system in short order while designing a longer term, more robust fix.

For the short term, MAC should exercise caution with regard to which off-the-shelf systems it adapts to airlift aircraft use. Many existing ECM systems trace their lineage to rapid-reaction projects of the Vietnam era. As a result, their designs tended to neglect reliability, maintainability, and availability. Furthermore, these early ECM systems were designed for use by aircraft with radar and infrared signatures much smaller than those of current airlift aircraft. Adapting such systems may require extensive modifications (for wiring, antennae, cooling, power generation, etc.) that may foreclose future options or, worse yet, only provide partial protection.

Over the long term, a prudent approach would emphasize modular hardware, designed along the philosophy of the fourth design option, with performance controlled by software. This approach recognizes that individual hardware modules will reflect the then current state of the art instead of theoretically optimum performance. As significantly improved levels of performance are obtained, newer modules can be substituted on a preplanned product improvement (P^3I) basis. For instance, a long-term approach to designing a radar-jamming and -deception system might break the system into functional subsystems: receiving antennae, signal processing, power generation, transmitting antennae, and software. Within each subsystem, modules could be designed to deliver state-of-the-art performance. Then, for example, as improvements in K-band power generation become available, the K-band module could undergo retrofit. An added benefit of using this approach is that classified operational features will tend to be in the software, which can be changed and protected more easily than hardware.

Adopting the fourth design approach, where feasible, has subtle but compelling logic. When dealing with a dynamic threat, as in electronic combat, one must assume that technical intelligence will lag the introduction of new enemy capabilities. Consistent with this reality, ECM systems should be designed to be effective even when US units are ignorant of threat system operating parameters and design features. Although such an approach, for example, might seem to favor noise jamming over deception (all electronic systems are vulnerable to noise), a balanced approach would exploit all feasible countermeasures, including deception.[3]

An often overlooked facet of the fourth design approach is the psychological dimension. Attacking all nonhuman links in the enemy's EOB while ignoring the human makes little sense. Despite significant success with "hunter-killer" tactics employing Wild Weasel aircraft and their killer counterparts, the United States has yet to take the next step in electronic combat evolution, namely providing a broader base of forces with this capability. So long as the only Air Force physical threat specifically directed at radar transmitters is the limited number of F-4G aircraft, enemy tactics can be relatively simple. If a significant portion of Air Force assets could wage such warfare, the enemy's options would be much more constrained. Considering that large aircraft are relatively insensitive to the size and weight penalties that hunter-killer systems impose on fighter-size platforms, a unique opportunity presents itself to increase US electronic combat capability.

Benefits of Low Altitude

The first rule of combat airlift operations is to avoid the threat whenever possible. An effective way to avoid both surface and airborne threats is to make maximum use of low-altitude flight. The advantage of low-altitude flight in regard to surface threats can be seen from the line-of-sight horizon equation:

$$d = (2H)^{0.5}$$

where <u>d</u> is the approximate distance to the horizon in miles and <u>H</u> is altitude in feet.[4] As the equation demonstrates, the higher one is, the greater the distance one can see; the farther one can see, the farther one can be seen. The farther one can be seen, the greater the likelihood one will be seen. Being seen (acquired) is undesirable because it is a prelude to being attacked.

Whether one can survive at any particular altitude is a function of a sequence of events in which both the attacker and evader participate. Ultimately, the preferred altitude will be determined by the chances of success. An expression for the probability of being killed in a single encounter might be stated as follows:

$$P_k = P_{det} \times P_{acq} \times P_{tr} \times P_{int} \times P_{des}$$

where P_k is the probability of being killed,

P_{det} is the probability of being detected,

P_{acq} is the probability of being acquired,

P_{tr} is the probability of being tracked,

P_{int} is the probability of being intercepted, and

P_{des} is the probability of being destroyed by the weapon.

The factors that an airlift aircraft can influence in such an engagement, P_{det}, P_{acq}, and P_{tr}, tend to favor low altitude (P_{int} has benefits both ways, so it tends to be neutral). In other words, whatever tactics, ECM, or defensive steps an airlifter can employ at high altitude can also be employed at low altitude and usually with better effect. As a result, the factors that would tend to favor high altitude for the airlifter must be determined by the enemy's circumstances.

Since the equation is for a single engagement, adding a second engagement of equal P_k would double the chances of being killed. Therefore the point of equal probability of being killed between low- or high-altitude cruise occurs when the number of engagements at high altitude drops off to the point where it is balanced by the savings in P_{det}, P_{acq}, and P_{tr} at low altitude. If the number of engagements does not drop off as altitude increases (it would not against conventional Soviet forces in such regions as the Fulda gap, even at maximum cruising altitudes for airlifters), low altitude is favored. Conversely, over the ocean where the threat density is light, high-altitude flight would make sense.

In the case of radar, low altitude has an additional benefit generated by "multipath" effects. Multipath is the tendency of radar beams to propagate along multiple paths as the radar elevation angle is lowered toward horizontal and the mainlobe interacts with the ground. In practical terms, this creates ambiguous echoes and scope clutter. To avoid this, radar operators increase the radar elevation angle until it is above the region where this phenomenon occurs. The net effect of multipath and raising the radar elevation angle is to decrease the range at which a low-flying object can be first acquired. In effect, multipath and ground clutter effects require the radar to be closer than the horizon to "see" a low-altitude target (over-the-horizon radars excepted). Under these circumstances, the line-of-sight horizon equation serves as a worst-case estimator of the range at which an aircraft can be acquired by radar. In addition, the equation illustrates the opportunity to lessen exposure to hostile radars by flying close to the ground.

Low-altitude flight also has benefits against airborne threats, particularly jet fighters. In any engagement, a fighter pilot places considerable emphasis on maintaining as high an energy level as possible for his aircraft because energy translates to maneuverability and maneuverability translates to ability to survive. In a one-versus-one fighter engagement, for example, the fighter with the higher energy level usually wins, all else being equal.

To understand how this applies to a fighter-versus-transport engagement, recall from early physics lessons that energy consists of two components, potential and kinetic. Potential energy is stored energy, and an aircraft's potential energy comes from its position and fuel supply. Position in this case relates to altitude; the higher the altitude, the higher the potential energy. Kinetic energy is energy of motion and can be expressed as:

$$K.E. = 1/2 \times \text{mass} \times \text{velocity}^2.$$

In other words, the faster one goes, the higher the kinetic energy.

A fighter closing on a transport at low altitude and slow airspeed will have to sacrifice much of its potential energy and a portion of its kinetic energy, particularly if it intends to make a gun pass. To use its guns it must drop to near the altitude of the target and if it does not slow down, the time available to make a gun pass is so short that its chances of success are small. This is so because an air-to-air cannon is only effective at ranges of less than 3,000 to 4,000 feet. Inside 1,000 feet the fighter employing a cannon runs the risk of shooting itself down as it flies through shrapnel. Therefore, the window of opportunity is open only as long as it takes the fighter to traverse the range from 4,000 feet to 1,000 feet. A 500-knot fighter overtaking a 250-knot transport would enter and exit the window of opportunity in about seven seconds. Against a non-maneuvering target at moderate altitudes, this time would be sufficient for even the least proficient of fighter pilots, but against a maneuvering target at low altitudes, the available time is much less.

The way a fighter's cannon is boresighted dramatically affects a low-altitude gun pass. If the cannon were aligned with the fighter's centerline, the cannon would point along the flight path when the fighter was flying at a zero angle of attack. However, fighters generally require some angle of attack to produce lift. The slower the airspeed, the greater the angle of attack required; the higher the G-load (turn rate), the higher the required angle of attack. These constraints present the fighter designer with design compromises: At what angle does one incline the gun? Ground attack cannons are usually aligned close to centerline, because expected targets are relatively immobile and the attack maneuver can be done at one G. Air-to-air cannons are usually inclined a couple of degrees up from centerline partially to compensate for the cut-off angle and the maneuvering angle of attack needed for attacking high-speed, highly maneuverable opponents. Thus fighters are at a disadvantage in trying to attack slow, low-flying aircraft.

For example, consider a fighter making a gun pass on a transport that is flying at 300-foot altitude and 250 knots. If the fighter's cannon is inclined above centerline 2 degrees and the fighter requires 3 degrees angle of attack to maintain level flight, its cannon will be pointed 5 degrees above horizontal. Therefore, to aim the cannon at a co-altitude target, the fighter must enter a 5-degree dive. (If the fighter starts the gun pass at a higher altitude than 300 feet, it must increase its dive angle by 1 degree for every 69.8 feet above 300 feet. Since a higher dive angle also increases the sink rate of the fighter, little is to be gained so close to the ground.)

Assuming the fighter begins the maneuver at 500 knots, it has about 4 seconds of aiming before it hits the ground. Since the fighter must begin to pull out at some time before the projected ground impact point to compensate for downward momentum, it will have even less tracking time. If the transport maneuvers in the vertical plane (like a roller coaster), the fighter must also. Any dipping below the 300-foot level will increase the angle that the fighter must point its nose below the horizon. If darkness, weather, rough terrain, turbulence, or some combination of these factors is added, a low-altitude gun pass becomes a risky maneuver.

Examining the complexities of a low-altitude gun pass, one sees that a fighter must sacrifice much altitude and at least some airspeed to be effective. Having sacrificed altitude and airspeed, the attacking fighter becomes more vulnerable to attack. If one arms the transport so it can fight back, one has created a significant disincentive for interceptor attack of transports at low altitude. Much of the same arguments would hold true for low-altitude missile attacks if the methods for defeating radar and IR missiles, discussed later in this chapter, were used.

As the preceding examination has demonstrated, flying at low altitude can have great benefits for the airlifter, but flying low is not always practical. For instance, transoceanic flights require every bit of range that high-altitude flight affords. Also, as the radar threat density increases, flying low may not in itself guarantee avoidance. In such circumstances the aircrew must have a threat-avoidance system.

Countering Radar Systems

Having explored various design philosophies and the benefits of low altitude, this chapter next discusses countering radar threat systems. In keeping with the airlifter's task hierarchy, the discussion considers avoiding and defeating radar systems separately.

Avoiding Detection and Acquisition

Early radar threat warning systems were called radar homing and warning (RHAW) gear. The presentation given to the aircrew amounted to nothing more than a strobe line or an alphanumeric symbol on a plan-position indicator, which showed the direction (but not range) from which the emission came. Such a presentation was appropriate for the limited number of threat systems of those days. Also, RHAW gear was created not to avoid radar but to allow fighters to dodge SAMs. Use of such systems to avoid radar detection and acquisition would be futile; they have no avoidance mode nor could they cope with modern threat densities. Instead, what is needed for airlift aircraft is a system that not only indicates the direction to the threat radar but also calculates detection and acquisition parameters and provides steering guidance to the pilot. When penetration of the threat radar's space is required, the equipment should provide steering guidance to allow minimum duration of exposure to the threat. For lack of a better phrase, the author calls this minimum threat exposure path the path of least resistance.

Warning-versus-Avoidance Systems. Clearly, a radar-avoidance system goes beyond RHAW gear in capability and function. Whereas RHAW gear requires only sufficient accuracy to locate the threat in the appropriate quadrant, a threat-avoidance system would require azimuth accuracies on the order of 1 degree in angle of arrival (AOA) to assist in range determination and signal sorting.[5] Although this accuracy requirement may sound severe, it is not a significant technical problem and it is well worth the effort. For example, a 1-degree AOA provides 90-percent range accuracy after 10 degrees of azimuth passage.[6] The better the range accuracy, the more effective the avoidance function can be.

From this discussion of radar-warning and -avoidance systems, it should be clear that threat avoidance is a requirement for airlift; that early generation warning systems are now inadequate; that airlift pilots will need capable cockpit presentations to follow avoidance paths or, if penetration is required, paths of least resistance; and that all of this is technologically feasible now.

Passive Navigation. A threat-avoidance system for airlift aircraft is essential, but it can do little good if the airlifter gives away its position by way of careless electromagnetic emissions. Just as a threat-avoidance system can locate a threat radar, the enemy can locate spurious and intentional emissions from airlift aircraft. Included in the category of spurious and intentional emitters are ground-mapping radars, Doppler ground-speed radars, radar altimeters, station-keeping equipment, and unshielded electronic equipment. Although a thorough scrub of electronic systems could eliminate spurious emitters, elimination of the intentional emitters would, among other difficulties, cause navigation problems. The solution to navigational emissions is passive navigation.

Passive navigation is possible through a system that uses a digitized map data base and a technique to position oneself over the map. For example, a digitized map of a flying area could be supplied by the Defense Mapping Agency and placed in an aircraft's navigation computer. "Fixing" the aircraft's position in relation to the computer map by way of inertial navigation equipment, the satellite-based global positioning system (GPS), or a radar beam to correlate ground contours makes extremely accurate navigation possible. Potential features of such a system include terrain-following, terrain-avoidance, threat-avoidance, and terrain-masking flight.

Since the strong possibility exists that the GPS would not survive for long in a war, more reliable methods of fixing position are needed, and they might include use of a low-powered radar altimeter. To prevent radar altimeter transmissions from revealing an aircraft's position, two phenomena—high frequency and absorption bands—can be used to advantage. High frequency is important because, for a given antenna size, the higher the frequency, the narrower the mainlobe can be. The narrower the mainlobe, the more directional the signal can be. The more directional the radar altimeter's signal, the lower the chance that it will be intercepted.

Absorption bands in the electromagnetic spectrum are important because they can be exploited as well as the windows (discussed in chapter 3). Recall that atmospheric oxygen absorbs virtually all radiation at 60 GHz within a short distance of wave travel. In engineering terms, this attenuation is measured at approximately 10 decibels (dBs) per kilometer (10 dBs reflects a signal ratio of 10 to 1, 20 dBs a signal ratio of 100 to 1, and 30 dBs a signal ratio of 1,000 to 1). A good signal-ferreting system may be able to distinguish signals that are attenuated by 50 dBs. Intentionally transmitting radar altimeter pulses at 60 GHz from several hundred feet above the ground would produce echoes attenuated less than 10 dBs (excluding reflection losses), which is well within the 50 dBs reception ability. But a ferret system beyond five kilometers would only hear noise because at that distance the signal would have attenuated to the background noise level. In this manner, accurate altitude information could be obtained at low altitude while denying the enemy detection ability beyond approximately five kilometers. Use of the altitude data in a contour comparison scheme between the terrain and the digitized map could then determine position.

Several concepts already in development that rely on digitized landmass data are Aeronautical System Division's Integrated Terrain Access/Retrieval System (ITARS) and Tactical Flight Management Program, British Aerospace's Terrain Profile Matching (TERPROM) system, and Texas Instruments' Enhanced Terrain Masked Penetration (ETMP) system. The TERPROM and ETMP systems illustrate the advantages of these concepts. TERPROM in its present form is a precision navigation system with terrain-following and obstacle-avoidance features. Terrain-avoidance, threat-avoidance, and terrain-masking functions would have to be developed. The Texas Instruments' ETMP system is more sophisticated in providing terrain following, terrain avoidance (TF/TA), and threat avoidance by way of terrain masking. To accomplish the terrain-avoidance function, a radar periodically scans the terrain ahead of the aircraft. By operating only when necessary and in an irregular fashion, such a radar takes on characteristics of a low-probability-of-intercept radar. Power levels for this radar are scaled down to transmit only enough energy to see the terrain of interest. To accomplish the threat-avoidance function, threat data are preprogrammed or provided in real time by way of data link with an onboard threat warning system. Both the TERPROM and ETMP systems would appear to offer a high degree of covertness in operation; however, the ETMP system's reliance on a scanning radar somewhat increases its probability of detection. Nevertheless, the scanning beam offers a safety margin for avoiding digitized mapping errors (which are not uncommon) and for avoiding man-made obstacles.

A possible variation of the Texas Instruments scheme would employ a laser radar in place of conventional radar, thereby shifting the emitted energy into a less-detectable portion of the spectrum. Sfena, a French avionics company, has already tested a carbon dioxide laser, presumably operating at the 10-micron wavelength in the midinfrared region, for just such a purpose.[7]

Aside from the obvious advantage inherent in the passive nature of the foregoing navigation systems, their adoption appears to be likely for other reasons that are equally compelling.[8] Such systems are self-contained and cannot be jammed. They can see beyond nearby ridge lines that block radar-based systems. They promise to be an order of magnitude more reliable than radar TF/TA systems. They can be automated to further reduce cockpit work load. They are not affected by weather conditions. They allow users to preview planned flight routes on the ground or in flight as they will actually appear. Their accuracy is on the order of 30 meters vertically and 130 meters horizontally, which approaches GPS performance. From the foregoing, it is clear that passive TF/TA systems are not only feasible but are also advisable.

For the same reason that passive navigation is required, spurious and intentional emitters onboard airlift aircraft must be eliminated. To do this, a screening of all airlift models will be required, and some existing systems—such as station-keeping equipment, Doppler ground-speed equipment, radar, and radio altimeters—will either have to be shut off during combat or eliminated. In addition, communications transmissions will have to be eliminated, converted to low-probability-of-intercept means, or shifted to higher, more directional frequencies (laser link with a satellite).

Stealth Technology Applications. While the overall shape of MAC aircraft cannot be changed inexpensively, aircraft skin treatments and coatings can be applied to achieve significant reductions in their radar cross sections. The purpose of such reductions is not to make the aircraft invisible to radar, since that is probably not possible, but rather to degrade enemy radar performance sufficiently to allow a threat-avoidance system to be more effective.

Stealth skin treatments and coatings, also known as radar absorbing materials (RAM), have been available since World War II. The Germans used a magnetically tuned rubber sheet material to coat submarine periscopes for protection against 3 GHz radars. Unfortunately for them, the British used microwave frequencies to counter this ECM. This points out an important characteristic of such "resonant" absorbers—they only work against specific frequencies, not across the spectrum.

A second type of RAM is a "graded dielectric." Graded dielectric absorbers work by gradually tapering the impedence (inverse of resistance) from the value of free space to a highly "lossy" or heat-producing state. If done smoothly in transitioning from outboard to inboard (looking at a cross section of the aircraft skin), little radar reflection occurs at the outboard skin layer. Moreover, such a technique can be used to achieve broadband frequency coverage.[9]

Two recent advancements in graded dielectric RAM technology are particularly exciting for their application to ECM. The first is a discovery by Prof Robert Birge of Carnegie-Mellon University involving retinyl Schiff base salts. Black in color and resembling graphite, these salt crystals have the potential for reducing radar reflectance by 80 percent. They are tuneable to specific frequencies so that a mixture of crystals could be assembled to provide full-spectrum coverage. In addition they offer better performance than ferrite-based coatings for less than one-tenth the weight, can be produced relatively cheaply, and appear to be adaptable to coatings.[10]

The second promising advancement in graded dielectric RAM technology is Lockheed Corporation's development of polyaniline and polyacetylene plastic materials with varying degrees of electrical conductivity, which are suitable for use as aircraft skins. Skins with stealth characteristics could be built by bonding layers of varying impedence to form the graded dielectric properties required. Moreover, such skins could be simultaneously tailored with phased-array antenna characteristics to eliminate the need for protruding antennae anywhere on the aircraft. In addition to eliminating antennae and reducing drag, Lockheed's "smart skins" have the potential for lower weight than that of traditional metal skins.[11] Both of these technologies should be of immediate interest to MAC.

Defeating Radar Systems

Once radar acquisition of the airlift aircraft has occurred, the rationale for "silent running" is no longer applicable. As a result, new and aggressive options become available to jam, deceive, destroy, or intimidate the threat.

Countering Tracking. Just as a threat-avoidance system would work to deny detection and acquisition, it could also work to interrupt tracking, particularly if a terrain-masking feature were available. Since the threat-avoidance system would "know" what the masking potential of the land is from the digitized landmass data base and since it would sense the direction from which the tracking signal emanates, it could seek to maneuver the aircraft behind suitable terrain to block the tracking signal. Also, if the acquisition envelope of the radar were inadvertently entered, the threat-avoidance system could direct an appropriate exit path. If avoidance is not possible and a path of least resistance is required, ECM or lethal defense could be used to complement the threat-avoidance system.

Accomplishing either jamming or deceptive ECM functions requires a system tailored to the radar cross section of the target it is defending. Two problems come to the fore if fighter-type ECM systems are used to defend larger aircraft. The first problem is power output. Since transports have radar cross sections that are typically an order of magnitude greater than that of fighters, an order of magnitude increase in power output would be required to afford the same level of protection. Since this is usually not possible with off-the-shelf systems, radar burnthrough would occur at much greater range, as the B-1A versus B-1B bomber example in chapter 3 demonstrates. Another problem with using fighter systems for large aircraft is where to put them. Putting such a system at virtually any external location on a transport causes the fuselage or some other structure to blank out the opposite side of the aircraft. If one opts for an internal location, the length of antenna wires becomes critical in preserving the jammer's time-delay and pulse-phase relationships.

For a suitable long-term solution, airlift aircraft need ECM systems tailored to their needs. In the process of designing such ECM systems, every opportunity should be explored to take advantage of large aircraft advantages. For example, should the ECM transmitting antenna be on the aircraft if it is likely to face home-on-jam weapons? The answer is, probably not. In that case, an alternative solution would be to develop an offboard, expendable antenna system in the form of a towed decoy, or a pair of towed decoys, with onboard sensors, processing, and power generation. Although such systems have not been practical for fighter aircraft because of the performance penalty and the fouling potential of the tether, they are inviting options for transports.

Towed decoys, perhaps one mounted on each wing tip, could be reeled out when needed to trail up to 500 feet behind and above the aircraft, and they could be reeled in for landing. When active jamming becomes necessary, the onboard ECM system could be activated to jam or deceive a hostile radar through the decoy. So long as the decoy remains within the width of the threat mainlobe beam from the deploying aircraft, the decoy and aircraft would be indistinguishable. Such a system offers airlift aircraft a defense against home-on-jam missiles not available to fighters that must rely on onboard ECM.

Recall from earlier discussions that radars tend to function as either early warning or target-tracking types and that noise jamming of early warning types and deception of target-tracking types are the preferred ECM responses. Since MAC aircraft will encounter both early warning and target-tracking radars, the airlift ECM system should be designed to counter both types. As can be seen from the discussion of Soviet radar characteristics and the discussion of window regions in the electromagnetic spectrum, any new system, including those mentioned here, should protect against inevitable K-band threats (20-40 GHz).

The ECM systems on the market tend to group themselves in two categories: fighter systems and bomber systems. Of the fighter systems now available, the Westinghouse ALQ-131 and the Raytheon ALQ-184 are the only readily transferable systems. The ALQ-131 is still in production, but the ALQ-184 is only a conversion of an earlier pod. All ALQ-184s are apparently required by the fighter community. The advanced self-protection jammer (ASPJ) just now entering production is programmed for 3,000 units. This system would be able to cope with the latest threats, but further development may be needed to adapt it to airlift aircraft use. Currently, the ASPJ occupies 2.4 cubic feet and weighs only 238 pounds.

The bomber systems consist of the ALQ-172 from the B-52 and the ALQ-161 from the B-1. Both are large, expensive, and heavy, and each requires an electronic warfare officer operator. These are the reasons they were rejected for airlift use by the US Air Force Scientific Advisory Board in 1982. These reasons still tend to rule out their conversion.

Destroying and Intimidating Threats. Countering radar systems with ECM is a tactical necessity for airlift aircraft. Transports have a variety of means to defeat threats, but from a strategic perspective of waging electronic combat, the most effective means of dealing with radar threats is to destroy them as they are encountered. The early Air Force response, when threat densities were relatively light, was to create Wild Weasel radar hunters and pair them with ordnance-delivering killer aircraft for that purpose. Since the Vietnam War, threat densities have increased so that they outstrip the capability of the hunter-killer teams. Thus relying on those tactics in the future could be disastrous.

A better solution, and one that affords the lone transport an option, is to equip the airlifter with a radar-killing capability, particularly if the transport is employed in airdrop and forward sustainment missions. If a threat is encountered and cannot be avoided, rather than run the risk of being shot down or leaving the threat safe to surprise an unsuspecting following aircraft, the transport (and all other transiting aircraft) should have the capability of destroying it. Such a capability could come relatively cheaply if airlift aircraft developed the capability to carry an antiradiation missile (ARM).

Four ARMs are possible contenders for airlift use. At the small end is the 200-pound AGM-122A Sidearm. Sidearm is actually a modified AIM-9C Sidewinder designed for short-range use against such J-band threats as the ZSU-23-4.[12] In the midsize range are the 400-pound class AGM-45A Shrike and the British Aerospace air-launched antiradiation missile (ALARM). Shrike is currently out of production, but the ALARM is a recent development that has the appealing feature of being self-contained to the point that its use does not require modification of the carrying aircraft. At the large end is the 800-pound AGM-88A high-speed antiradiation missile (HARM). HARM is the only US ARM currently in production and it is the most capable. In its prebriefed mode, it attacks fixed sites by flying up and over the threat mainlobe beam to home in undetected. Used during ingress to a target area, the missile can be launched ahead of the assault force to attack any radar that activates as the assault force approaches. In its target-of-opportunity mode, it scans the spectrum for any radar operating and alerts the pilot to possible targets. If the carrying aircraft is illuminated by a target-tracking radar, the HARM switches automatically to its self-protection mode, providing a rapid-reaction capability.[13] All three modes of operation fit airlift employment and sustainment missions ideally.

Countering Airborne Interceptors

A threat-avoidance system would also have to handle airborne threats, particularly on overwater legs. Under such a scenario, the threat could either be active or passive in searching for airlift targets.

Avoiding Airborne Interceptors

Avoiding airborne interceptors is the preferred course of action for transports and, because of the performance differential between the two classes of aircraft, requires passive operation of the airlifters. The interceptor, however, is not constrained to either the active or passive mode. Still, airlift aircraft can be equipped with responsive systems that could cope with either mode of engagement.

Active Threats. The active threat, because it radiates radar energy that tends to give away its position, would be the easier to handle. For example, if both the airlifter and the interceptor were at 30,000 feet and the airlift aircraft had a radar threat-avoidance system, a radiating interceptor could be detected approximately 490 statute miles away (twice the distance to the horizon in accordance with the line-of-sight horizon equation). Exploiting the "knife-edge" diffraction phenomenon, where wave-like propagation tends to fill in "shadow" areas, an airlifter could extend detection range into regions beyond the horizon (fig. 5).

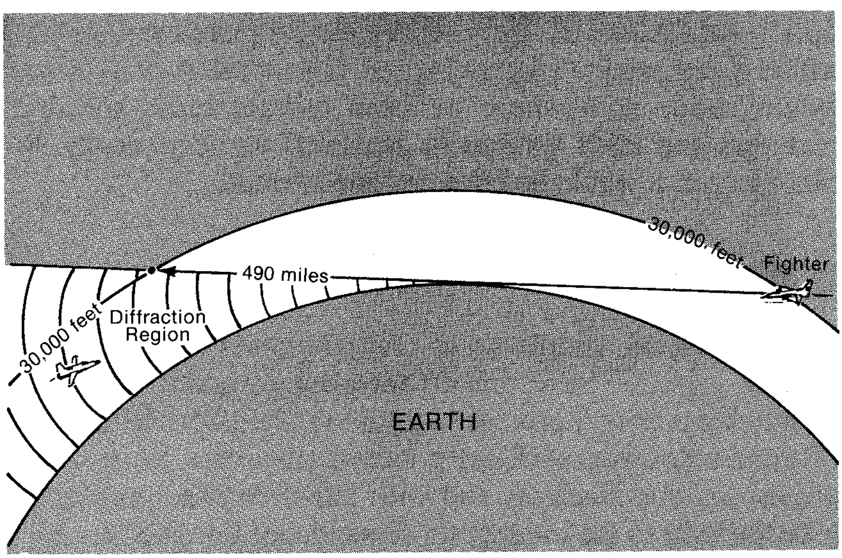


Figure 5. Knife-Edge Diffraction.

To illustrate an avoidance scenario, assume the airlift aircraft is traveling at 0.74 Mach and turns away from the interceptor when the range closes to 200 statute miles. If the interceptor, traveling at 0.95 Mach (to avoid supersonic wave drag and afterburner operations), must close to within 25 miles before launching a missile, the resultant chase would take 73 minutes. If, instead, the interceptor accelerated to 1.5 Mach (in afterburner) when the airlifter turned away, the chase would still take 20 minutes. Fuel consumption would be a limiting factor for the interceptor, reducing the operational practicality of either fighter approach. If the interceptor were operating off of an aircraft carrier or had tanker support, the airlifter could extend the avoidance point to foil the tactic, presuming intelligence knows of the threat.

Passive Threats. If the interceptor could remain passive and rely on bistatic radar operation (another platform acts as the transmitter), the threat could increase considerably. To counter this possibility, Hughes Radar Systems Group has recommended a concept called "splash track" in which a passive fighter can be detected by a passive transport via reflected energy originating from a third party.[14] Hughes has developed realistic design-to-cost goals for just such a system, which is explored in a later chapter. In general, such a system would reside somewhere between current radar warning receivers and ESM systems in capability and complexity. In other words, it would be fairly routine to build.

Defeating Airborne Interceptors

Conventional wisdom holds that transports would be easy prey for airborne interceptors. That no longer need be the case. Technology can now provide large aircraft with sensors to warn of interceptor approach, with countermeasures to frustrate acquisition and tracking, and with lethal defense options to take the fight to the interceptor if avoidance does not work.

Sensors. To provide airlift aircraft with warning of approaching airborne threats, two basic types of systems offer great potential. The first is the radar threat-avoidance system employing the Hughes splash-track concept previously discussed. The second is an infrared search and track (IRST) system developed by Northrop that takes advantage of recent IR sensor advances.

Instead of relying on a scanned IR image, the advanced IRST system uses a nonscanning (staring) mosaic focal-plane array to build an image. Much as the human eye focuses an image on the retina, the lens of the IRST system focuses the image on an IR-sensitive mosaic focal-plane array. Just as the human eye has multiple sensors lining the retina, the IRST system has multiple IR-sensitive "chips" forming the mosaic. Because the IR sensors dwell on the IR-producing object, rather than scanning it, the sensitivity of the system is greatly increased. Tests of Northrop's IRST system have shown that the system has a 50-percent chance of producing a recognizable image of a MiG-25 Foxbat at 15 nautical miles. Against such larger aircraft as a Tu-26 Backfire there is a 50-percent chance of recognition at 30 nautical miles. Both aircraft could be detected as hot spots at more than 100 nautical miles. Range could be determined using a ranging laser, such as a neodymium-YAG at 0.265 microns, which is outside the visible spectrum.[15]

Countermeasures. Countering an airborne interceptor's radar is analogous to countering a mobile target-tracking radar. Since the interceptor usually has the speed advantage and can close on the transport at will, it controls whether or not the engagement proceeds inside burnthrough range. This is especially true in a tail-chase scenario where fuel consumption may become critical for the interceptor. Under those conditions, it is difficult for the transport to determine when to switch from noise jamming to deception jamming. Therefore deception jamming is the preferred ECM mode. Since deception jamming will not prevent the interceptor from closing to within visual range for a gun pass, even if the transport attempts to disengage, ECM against an interceptor should be used in conjunction with a form of lethal self-defense. The ECM systems already discussed in the section on countering radar tracking are appropriate departure points for solutions.

Lethal Defense. While the airlift aircraft is slower than the interceptor, it has substantial carrying capacity for systems that can equalize the engagement. Four concepts that offer significant promise are an air-to-air version of the HARM for radar threats; the AIM-9L/M/R against forward hemisphere attacks; a tube-launched, rocket-assisted, IR-homing artillery round for rear-hemisphere defense; and a blinding laser (and target designator) system for all-quadrant defense.

High-Speed Antiradiation Missile. The AGM-88 HARM, previously discussed in an air-to-surface role, also has air-to-air capability provided by its new, single-structure, gimballed antenna.[16] With its ability to make an immediate 180-degree turn after launch, HARM could now pose a threat to airborne interceptors approaching transports from any quadrant. Interestingly enough, Boeing Military Airplane Company indicates interest in a similar concept in their *Advanced Transport Technical Mission Analysis Study.*[17] Such versatility invites serious consideration of HARM as a self-protective weapon for use by transports against both surface and airborne threats.

Sidewinder. The AIM-9 will be a necessary addition to the airlift aircraft's arsenal not just for interceptors, but also for such helicopter threats as the Soviet Hokum, which will have an air-to-air capability. In the case of interceptors, exercises that simulated C-130s with tail guns have invariably resulted in interceptors using what is called a "face shot." Thus tail protection alone merely moves the threat to the front. The front hemisphere, therefore, cannot be left vulnerable. In the case of the Hokum-type helicopter threat, this point is further reinforced. Since a helicopter would probably be using terrain masking for its own survival, the potential is great that an airlift aircraft would not see the helicopter until the transport is well within the range of the helicopter's missile. Since turning "tail" to escape would only present a more inviting IR target, the airlifter must be prepared to continue on while minimizing its exposure. In such a circumstance, attacking the helicopter directly would be an excellent way to defeat it or to force it to keep out of the way.

The AIM-9L, M, and R model Sidewinders are unique in their excellent all-aspect attack capability, which perfectly suits airlift aircraft because they cannot outmaneuver threats to reach a stern attack position. Weighing approximately 190 pounds each, these missiles could be easily carried by transports. The R model is currently in development and should be available in 1990. It features greatly improved acquisition range over the M model while eliminating the need for a cooled seeker head.[18]

Copperhead. Defending the rear hemisphere cannot be done directly with a rearward-firing missile because of the forward velocity of the aircraft. Firing a missile rearward would cause the missile to fly backwards until its motor could cancel the forward velocity of the aircraft. As a result of this backwards flight and the fact that the missile would have to power itself through a zero-velocity point, severe instabilities would be introduced (just as in shooting an arrow, feather end first). An excellent way around this phenomenon, however, is to use rocket-assisted artillery. In this case, the projectile accelerates through the zero-velocity point inside the gun tube, exiting with flying velocity and a rocket assist. The projectile would not be an average artillery round, however. Borrowing from the same technology that created the Martin Marietta Copperhead laser-homing projectile, the artillery round would contain an air-to-air seeker head, a small warhead, control fins, and either laser beam-riding or IR-homing guidance. Despite the 9,000-G launch acceleration load, the Copperhead projectile works well, is relatively inexpensive, and is in the inventory.

Depending on its design characteristics, such a system has potential for achieving ranges in excess of 10 kilometers.[19]

As electromagnetic launchers (hypervelocity or rail guns) increase in capability their potential as substitutes for the artillery tube increases. Such devices have the potential for firing projectiles at speeds approaching tens of kilometers per second, which could eliminate the need for homing projectiles. With such velocities, one need only put the aiming pipper on the target and fire. At the ranges under discussion, the projectile would cover the distance seemingly instantaneously and hit with such kinetic energy as to eliminate the need for a warhead. Unfortunately, such systems are still a few years away. Their potential is so great, however, that laboratory development and continued monitoring are advisable.

Blinding Laser. The final self-protective device against an interceptor, particularly one interested in making a gun pass, is the blinding laser. In this scenario, the interceptor would be making a visual intercept and probably would be using a heads-up display. The laser could be manually controlled or automatically aimed by the IRST system. Since a visible laser beam would give away the position of the airlift aircraft and might alert the interceptor to employ countermeasures, infrared or ultraviolet lasers would offer tactical advantages.

Even though the human eye sees only visible light, damage to the eye can be caused by laser energy outside the visible spectrum. Damage to the eye is a function of laser power, intervening distance, filter effects, and duration of exposure; an effective blinding laser may require 10 or less watts of power. If passed through a HUD, laser energy would be amplified, increasing its effectiveness. Even at energy levels below that at which retinal burns occur, temporary blinding or dazzling can incapacitate vision for 20 minutes or longer. In a high-performance jet, such incapacitation would be devastating.

To preclude filter countermeasures, frequency agility would be desirable. Although frequency agility may have to wait for free-electron lasers to mature, numerous single-frequency lasers are readily available, are relatively inexpensive, and are readily adaptable to airlift use.[20]

A side benefit of the blinding laser is that it could be used as a target designator for the rearward-fired, air-to-air artillery round. (In addition such a system could form the basis of a shoulder-fired missile defense and a directed-energy weapon defense, but examination of these applications is deferred until the discussion of electro-optical threat defenses.) An advantage of a laser beam-riding weapon is its relative invulnerability to ECM, compared to IR-homing seekers.

Defeating Radar Missiles

Defeating a radar-guided missile may require simultaneous attack against the illuminating radar beam, the missile receiver, the command guidance channel(s), the warhead fusing mechanism, and the maneuver capability of the missile. Coordinating these split-second operations would require a missile (launch) warning receiver, a control system to synchronize flight controls and ECM, an ECM system of comparable capability to the advanced self-protection jammer, and such augmenting systems as towed and expendable decoys and chaff.

During silent-running airlift operations, the key to successfully dodging a missile may be the ability to detect missile launch. A not uncommon ECCM technique employed by SAM operators is to keep the tracking radar passive (on, warmed-up, but not transmitting) until after missile launch to surprise the target. To allow the airlift to detect such a launch passively, the US Air Force Scientific Advisory Board recommends a missile warning receiver (MWR).[21] Based on IR- and ultraviolet-sensing techniques, such a system would recognize the hot rocket plume of the missile as a threat and provide the cue to turn on active ECM. (Honeywell's AAR-47 passive missile detection system would appear to fulfill this function.) The ECM system could then attack acquisition and tracking functions to defeat the missile.

If the ECM system included towed decoys in pairs, it would have considerable capability against such sophisticated threats as monopulse tracking systems. First, towed decoys move the jamming signal offboard to protect against home-on-jam techniques. Thus the decoys, not the aircraft, attract the missile's attention. Second, use of decoys in widely separated pairs makes such monopulse jamming techniques as blinking, cross-polarization, and cross-eye jamming much more effective. If jamming is unsuccessful in breaking the missile's tracking solution, an offboard concept has additional benefits. As the missile approaches the aircraft and decoys, the jamming signal will be much stronger from the decoys than the echo off the transport. Thus the missile will be lured away from the transport. As the missile acquires the two decoys, it faces a dilemma "deciding" which to attack. In many cases, it will compromise by aiming for the centroid of the jamming signal, thereby splitting the distance between the decoys. If a decoy is damaged or destroyed, a new decoy can be reeled out.

Although towed decoys have an advantage in transmitting power, expendable electronic decoys have an advantage in that they separate themselves farther from the ejecting aircraft. Also, expendable decoys, if released in even modest numbers, can saturate an incoming missile's target-sorting capability. Even if they contain their own power supply, these miniature jammers can be built to fit standard flare and chaff dispensers. Texas Instruments' Gen-X and Brunswick's radio frequency expendable decoy (RFED) are two of the more promising examples already on the market.

Against certain radar missile systems, chaff remains a viable countermeasure. Particularly susceptible to chaff are those radars that do not have moving target indicator capability or Doppler processing. A substantial number of older Soviet AAA and SAM systems do not have these capabilities. When artfully deployed, chaff can create false targets for a tracking gun or missile and screening for massed operations.

By integrating flight maneuvers with ECM techniques, the transport can achieve maximum effectiveness of ECM while exploiting the flight characteristics of a missile. In chapter 3, the discussion pointed out that a Mach-3 homing missile may have to pull up to 18 times the G-load of a Mach-0.74 target to fly the same flight path. By delaying a hard turn or "break" maneuver until a missile requires a maneuvering capability in excess of its G-limit, the target can cause the missile to overshoot. The challenge in making such a maneuver work for a transport rests in precise timing and execution. Given the life or death consequences, the complexity of the calculations, and the reaction times required, such a maneuver could only work if it were automated.

Automating a missile "break" maneuver could be fairly easy. What would be required is a means to track the missile, an autopilot, a flight control computer, and software delineating the control laws. However, against radar-guided missiles, radar tracking could invite home-on-radiation guidance. Therefore a passive IRST system with laser ranging would be more appropriate. Although such IRST systems as Northrop's are early in development, they have great potential for providing a solution to this self-protective need of airlift aircraft.

Countering Electro-optical Weapons

In addition to the threat posed by radar-based systems, airlift operations are severely threatened by electro-optical systems. Included in this category are infrared search and track systems, IR missiles, optically aimed weapons, and directed-energy weapons. Although the threats include many exotic weapons, they also include the infantryman's rifle. The following discussion covers this wide spectrum of threats and shows that airlift aircraft can acquire formidable defenses against each.

Avoiding Infrared Detection and Acquisition

Earlier discussion showed there are promising steps that can be taken to avoid ground radars, SAMs, airborne interceptors, and radar missiles and to defeat or destroy them if necessary. The same is true for IR threat-detection and acquisition systems. Because IR-tracking systems do not radiate energy (i.e., they are passive), methods for detecting them are quite limited. One of the best techniques for avoiding IR threats is to fly low to the ground, as was discussed earlier in this chapter. Two other avenues of approach appear to offer great potential to reduce the chance of detection and acquisition. The first is to reduce one's thermal output to blend in with the background noise as much as possible. The second is to conceal the sources of thermal energy.

Reducing Thermal Output. Attempting to reduce the thermal output of an aircraft causes one to focus on the largest source of thermal energy—the engines. Although other systems may produce hot spots, those hot spots are usually insignificant until the heat of the engines is drastically reduced or concealed. In either instance, the effort is directed at eliminating hot metal parts from view.

One technique for reducing a jet engine's thermal output is to exploit turboprop designs. A turboprop is, basically, a jet engine that converts its exhaust energy to propeller motion. In the process, successive stages of turbines reduce the energy of the gas flow to the point where it exhausts with little residual energy. While the internal temperatures of a turboprop may be just as hot as that of other types of jet engines, the exhaust is much cooler.

Current turboprop technology development is focusing on General Electric's unducted fan (UDF) and Pratt and Whitney's ultrahigh bypass (UHB) designs. Using National Aeronautics and Space Administration (NASA) counter-rotating propeller technology, these designs will be adapted for all sizes of aircraft, including the largest aircraft in the world. These engines will permit cruising at Mach 0.8 and will be at least 20 percent more efficient than the most efficient turbofans flying today. If used on a C-141 carrying a 38,000-pound payload, for example, the GE-36 UDF would be 40 percent more efficient overall than the TF33-P7 engine currently in use. On a 3,700-nautical-mile flight this would translate to either an 84-percent increase in payload or a 64-percent increase in range. General Electric expects the GE-36 UDF to be certified for commercial use in 1991.[22]

Once an engine is designed, its operating cycle is determined and little can be done to extract further energy from the core gas flow. What can be done is to control areas where heat is allowed to surface at the face of an inlet or on the side of a nacelle forward of the exhaust or nozzle area. To date these techniques have not been priority design requirements, but the development of IRST systems and the emphasis on passive, "stealthy" operations will force designers to give them more consideration.

Concealing Thermal Output. Short of a design change that makes the engine more efficient in extracting energy from the gas flow, concealing the hot sections is the next best alternative. Insulating nonexhaust areas of the nacelle takes on meaning if exhaust treatments are accomplished simultaneously. One way to insulate the face of a compressor is to lengthen the inlet while channeling the flow through an S-turn. An IR sensor looking at the front of such an engine would not have a clear view of any hot metal parts. Similarly, the sides of nacelles can be shielded by using either insulation material or insulating air flow (by feeding a cooling flow back to the exhaust area, the nacelle IR signature can be reduced).

Another method of reducing IR signature, which appears more feasible than insulating, is to shield it. Several excellent examples are already in existence. The Fairchild A-10 Thunderbolt II uses the main wing, the horizontal stabilizer, and the twin vertical stabilizers to shield the exhaust from all but the stern and overhead aspects. The Israeli Air Force adopted a slightly different approach with their McDonnell Douglas A-4 Skyhawk. By lengthening the exhaust several feet and armor plating it, the Israelis have shifted the attention of a heat-seeking weapon away from the fragile turbine area to a hard point farther aft where less damage is likely.[23]

Defeating Infrared Tracking

Beyond the passive steps already discussed, two measures can be taken to frustrate an IR missile. The first is using a strobed-IR jammer and the second is using an IR flare.

The strobed-IR jammer takes advantage of spatial-filtering design features of IR missile trackers to subject the missile to intense bursts of IR energy, momentarily creating a more attractive target. By shutting off cyclically, the strobe forces the missile tracker to jump back and forth from the engine exhaust to the jammer. If the jammer can manage to do so at a resonant frequency of the missile's tracking error feedback loop, large control errors result.

Sanders Associates and Northrop have several IR countermeasure systems to offer, including one similar to that used on Air Force One. The Sanders Self-Defense System consists of one strobe transmitting unit per engine (possibly two for large engine diameters), weighing approximately 65 pounds, an electronic control unit weighing 5 pounds, and a cockpit control unit weighing 3 pounds. Power required for each transmitter is 5 to 15 kilovolt-amperes, which should be easily accommodated on any transport.

Whereas the Sanders system uses a mechanical shutter to create the strobe effect, the Northrop AAQ-8, which is in use on Air Force F-4, A-7, and MC-130 aircraft, electronically modulates a cesium lamp to produce the IR strobe. Electronic modulation has the advantage of being readily programmable to counter newly emergent threats. Mounting either system's transmitting unit near the engine exhaust would require some aerodynamic refairing of the transmitter housing, but this would be a minor effort. Activated for landing and takeoff, the system would be deactivated in flight (to avoid giving away aircraft position) until a missile launch was detected.

The second IR-antitracking concept is the use of expendable flares. Deployed manually when operating into or out of airfields and drop zones in hostile areas or deployed automatically when a missile launch is detected, the flares would serve as decoys to lure missiles away. Because they compensate for lack of size by an increased intensity of emission, current flares have weaknesses that the enemy can exploit, particularly if they are spectrally different from the aircraft engine.

Since aircraft engines emit peak IR radiation in the 3-to-5 micron band and since early generation, visible flares spread their emissions across the spectrum to include even visible light, spectral differences exist that create ECCM opportunities for the enemy. In fact, the loss of two Navy aircraft over Baalbek, Lebanon, in 1983 while using flares against Soviet-made SAMs confirms this problem. Using filters and dual-band seekers, the newer SAMs apparently detect that the flare's radiation peaks outside the 3-to-5 micron band and disregard the flare. Newer flares will have to adjust for this capability by more closely mimicking a jet engine signature. Additionally, for routine carriage on airlift aircraft in peacetime, next-generation flares will have to comply with the International Pyrotechnic Treaty so that transports can operate out of commercial airports.

Fortunately, Alloy Surfaces is marketing a pyrophoric flare that meets this requirement and has a very low visible signature. In addition, Alloy Surfaces can tailor the flare to shift its spectral emissions as needed.

Defeating Infrared Missiles

Defeating a modern IR missile will require either or both of the antitracking methods just discussed. During takeoff or landing, these methods can be employed preemptively. These active measures can also be used near drop zones and other hostile environments where detectability of the aircraft is secondary to accomplishing mission objectives. At other times, the principle of passive operations will require the antitracking systems to remain dormant until the aircraft "knows" it is being tracked. Key to passive operations, then, is a cueing system that can detect a missile launch and activate the appropriate systems.

The ultraviolet-sensitive Honeywell AAR-47 missile warning system is currently in production. It draws approximately 70 watts of power and weighs less than 25 pounds. Current data indicate it has a higher than desired false-alarm rate, but it does provide 360 degrees of launch coverage.

Under development by the Air Force Wright Aeronautical Laboratories Avionics Laboratory is the silent attack warning system (SAWS) missile launch detector. Major contractors are Honeywell, General Electric, and Texas Instruments. The primary goals of the SAWS development program is to apply state-of-the-art technology to improve launch-detection probability and decrease false-alarm rate as compared to the AAR-47.

Whatever missile warning system is used, once a missile launch is detected, the aircraft will require accurate range data on the missile to permit effective flare launch. To acquire this range information, radar appears to be the best option. Two systems are readily available: the Westinghouse AN/ALQ-153 and the Sanders AN/ALQ-156.

Both the Westinghouse and Sanders products are pulse Doppler radars that provide 360 degrees of azimuth coverage and can operate independently of the AAR-47, if required. The Westinghouse model requires approximately 2.36 cubic feet of space, requires 53 watts and 1,800 volt-amps of power, and weighs 138 pounds. The Sanders model requires approximately 1 cubic foot, requires 425 watts, and weighs 50 pounds. Both appear suitable for an integrated threat-detection and countermeasures system. In operation, they would activate upon signal from a missile warning system, acquire the inbound missile, and feed range information to a countermeasures controller. At the appropriate range for maximum flare effectiveness, the countermeasures controller would cue flare ejection and possibly an evasive tactic to introduce the maximum angular separation between the flare(s) and the aircraft.

For flare ejection, Tracor Corporation has three models to chose from: the AN/ALE-40, the AN/ALE-45, and the AN/ALE-47. With the upgrade of the AN/ALE-40 to the -(V)X version, all models incorporate a solid-state threat adaptive programmer that accepts information from a radar warning receiver and a missile warning receiver to optimally dispense the cartridges. The ALE-40 and ALE-47 were designed for the MJU-7/B flare, which is used to protect single-engine fighter aircraft. For such smaller airlift aircraft as the C-130, the MJU-7 flare may be adequate, but larger aircraft, such as the C-5 and C-17, may require much larger flares. As a result, a flare dispenser patterned after the ALE-45, which can accommodate flares as large as the new MJU-10/B (2 inches by 2.6 inches by 8 inches) might be required. Presently, the Tracor dispensers can carry 15 MJU-7/B or 6 MJU-10/B flare cartridges and weigh approximately 27 pounds. At least one dispenser would be required for each side of the aircraft.[24]

Under development for the MAC C-130 fleet is Lockheed's Survivability Augmentation for Transport Installation-Now (SATIN) system. It consists of a Litton AN/ALR-69 radar warning receiver, an AN/ALQ-156 missile warning receiver, and an AN/ALE-40 flare and chaff ejector. As a stopgap program aimed primarily at the IR missile threat, it contains excellent core elements of a respectable self-protective system. What it lacks is an adequate threat-avoidance function, a capability to detect K-band threats, a capability to operate passively, and an ability to deal with the more modern Soviet radar SAMs and airborne interceptors.

To operate and survive in an AirLand Battle scenario, SATIN would have to be upgraded to overcome these deficiencies. A true threat-avoidance system should replace the AN/ALR-69, a system comparable to the SAWS/AAR-47 is needed to permit passive operations, a digitized landmass navigation system would be needed to permit passive terrain-following/terrain-avoidance, low-altitude, all-weather flight, and a towed-decoy ECM system should be added to provide a capability to defeat the most modern monopulse guided missiles. To defeat airborne interceptors, several concepts are possible. A blinding laser could protect against gun attacks. A tube-launched Copperhead variant could be added for rear-hemisphere missile defense, and AIM-9L/M/R Sidewinders could be added for forward-hemisphere missile defense. To defeat unavoidable air and surface radar threats, the AGM-88 HARM could be added.

Avoiding Optical Detection

Avoiding optical detection is analogous to avoiding radar and IR threats. Two tasks are critical in avoiding optical detection: minimizing opportunities for detection and reducing observable characteristics.

Attempts to minimize optical detection are much like those previously discussed in regard to minimizing radar and IR detection. Common to all three is the benefit of low-altitude flight. Similarly, making maximum use of terrain masking to block the enemy's view would be advantageous. Darkness and weather may also provide sanctuary, but operating in these environments requires precise navigation. To navigate precisely while not giving away the aircraft's position will require such passive navigation systems as the TERPROM and Enhanced Terrain Masked Penetration systems previously discussed.

The task of minimizing distinguishable characteristics of airlift aircraft suggests the use of camouflage. In this context, camouflage includes disguising aircraft features in visible wavelengths as well as at other wavelengths that EO systems operate. During daylight, the IR energy coming from an aircraft includes self-generated radiation as well as reflected solar radiation. Although current IR sensors have limited capability against a daylight-earth background, future systems will not. As high-speed integrated circuitry permits spectral analysis on a near-real-time basis, it will become increasingly possible to detect, track, and target moving IR and reflected light sources against a daylight-earth background.

Defeating Optical Tracking

Soldiers peering through the sights of their rifles, AAA crews aiming through optical devices, personnel sighting shoulder-fired missiles, and individuals using laser target designators all control devastating weaponry, but all are susceptible to preemptive laser attack. In each case a blinding laser system, perhaps using multiple beams to scan sectors from the aircraft out to the horizon, could radiate enough energy to prevent aiming of the various weapons. If aiming were attempted, the dwell time and energy of the laser would cause blinding or dazzling.

Two steps in employing antivision lasers could be taken to preclude giving away aircraft position unnecessarily. Operating frequencies could be shifted into the ultraviolet or IR regions, where fewer sensors (including eyeballs) operate. Second, the scan pattern of the laser could be adjusted so that coverage extends only to the maximum range of expected threats; anyone outside that range would not be scanned. Thus covert operations could be maintained.

Countering Directed-Energy Threats

Lasers are not only useful weapons for airlift aircraft, they are also useful against airlift aircraft. Such weapons would be used primarily to blind pilots, to illuminate aircraft for beam-riding weapons, or, in the extreme, to attack the aircraft directly. Defeating the foreseeable directed-energy threat, then, is a matter of effectively dealing with these three subareas.

Countering Antivision Lasers

Current efforts at countering antivision lasers are focusing on the use of protective filters, absorbing dyes, phosphate glass, dielectric coatings, and holographic filtering in windscreens and glasses.[25] Original interest in this area arose out of concern for industrial safety, but the advent of battlefield lasers creates a military incentive.

Optical Filters and Dyes. Optical filters and dyes come in the forms of coatings or sandwich material between two layers of glass. They operate by absorbing a particular band of radiation, visible or invisible, and by converting the radiation to heat. Protection against laser weapons would require optical densities as high as 18. To lend some meaning to this measure, note that common sunglasses provide an optical density of less than one. An optical density of one absorbs 90 percent of incident radiation and passes 10 percent. An optical density of two absorbs 99 percent and passes 1 percent. A density of three absorbs 99.9 percent and so on. Obviously the demands on laser filters and dyes are quite severe.[26]

Until frequency-agile lasers appear, filters and dyes can offer inexpensive protection against known threat frequencies. Current challenges with dyes are to narrow the band of light that specific dyes filter so as not to impair normal vision, to preserve dye potency over time, and to overcome saturation effects where filtering abruptly stops.

Phosphate Glass. Phosphate glass filters light by varying its optical density, dependent on the amount of incident light. It has been in use for many years, but it offers little protection in the near infrared region. Since damage from an IR laser would be just as devastating as that produced by a visible laser, phosphate glass would have to be augmented with additional protection.

Dielectric Coatings and Holographic Filters. Both dielectric coatings and holographic filters provide narrow-band protection, but currently their performance is degraded when the angle of the incident laser beam decreases from the perpendicular. While it remains to be seen whether this disability can be overcome, the holographic technique appears promising because of its ability to split light into parallel paths, filter or discard the offensive path, and then recombine the light.

Frequency-Agile Laser Protection. A broad-based military effort exploring 15 to 20 different techniques against frequency-agile lasers is under way. Promising technologies include optical switches that regulate optical density of filters, liquid crystal filters, nonlinear reactors to light, and plastics that rapidly polarize to near opacity and just as rapidly return to a state of normal transmissivity. Although frequency-agile tactical lasers appear to be a few years from maturity, countermeasures to afford eye protection inevitably will be a feature of future cockpits.[27]

Countering Laser Beam-Riding Weapons

Laser beam-riding weapons, like Bofors Rayrider missile and the US Air Defense Antitank System (ADATS), operate by homing on reflected laser light. In most cases, the laser is controlled by the person operating the missile launcher. Countering such a system is possible either by the blinding laser defense mentioned above or by providing a more reflective target than the aircraft. For example, if a warning system detected an illuminating laser, it could cue ejection of a programmed sequence of optical chaff bundles. Each bundle would contain fast-blooming reflective confetti or sequins that would form a cloud between the aircraft and the beam source. Being much more reflective than the aircraft, such clouds would make a much more attractive target.

Since a skilled operator would not be fooled by the cloud and would attempt to keep the laser pointed at the aircraft, other methods of deceiving the missile are necessary. If the enemy's laser frequency were known beforehand, the targeted aircraft could illuminate the clouds to create an even more attractive target for the missile. If optical chaff cartridges were developed to fit standard flare and chaff dispensers, a laser defense could be integrated into radar and IR missile defenses.[28]

Two systems to alert crewmembers that their aircraft has been illuminated by laser energy are under development: the advanced laser warning system and the detection of laser emitters (DOLE) system. In addition, the Coronet Prince laser countermeasure pods being competitively developed by Westinghouse (ALQ-179) and Martin Marietta (ALQ-180) may have application to airlift aircraft.[29]

Countering Directed-Energy Weapons

Countering directed-energy weapons will require the same avoidance concepts already explored for radar and IR weapons. Similarly, precautions will need to be taken against admitting hazardous levels of laser energy into the cockpit, as discussed previously. In addition, two steps (one defensive, one offensive) can be taken to counter directed-energy weapons.

Defensively, critical areas of transports can be shielded against destructive lasers by employing laser-resistant materials. Harlamor-Schadeck, a research firm in Yuba City, California, has developed a man-made polymer called *laser shield* that is impervious to laser energy. Under development by the Air Force and Army at the Army's Materials Technology Laboratory, laser shield has remained unaltered when subjected to significant power levels.[30]

Offensively, airlift aircraft can detect unconcealed directed-energy weapons by scanning for them. Scanning would employ an aircraft-mounted laser with a reflection tracker to detect backscatter of laser energy from the optical components of enemy laser weapons. Once a laser weapon had been detected, precise range and bearing information could be extracted from the laser scanner and fed to an air-to-surface weapon for targeting. Since battlefield directed-energy weapons are not yet on the scene, the nature of such an air-to-surface weapon is undefined. However, if built with foreseeable technology, destructive lasers would be rather large and not particularly well hardened against munitions effects. Present munitions should be able to achieve a kill if delivered to the near vicinity of such a laser.

Augmenting System Solutions

Up to this point, only self-protective systems have been considered as counters to the threats that airlift aircraft face. While this was done by design to limit the topic, in fairness, the author must at least mention some protective systems of great potential that might be placed on other aircraft.

The discussion of radar jamming pointed out that noise jamming can deny range information, but that it also gives away the azimuth of the jammer. This is true of mainlobe jamming only. If the jammer were placed on a standoff platform, such as another aircraft, and equipped with extremely powerful transmitters, it could force enough jamming energy into the sidelobes of early warning radars to completely blank out their scopes. One US development effort that could lend such support to airlift operations is the Big Crow program.

The Big Crow program will equip a Boeing 707 testbed with four additional Allison T-56 engines to produce approximately four megawatts of jamming potential. Extremely accurate Rotman lens antennae will precisely direct this jamming energy at threat emitters. Because of its combination of power and precision aiming, the system offers significant ECM potential for airlift operations and deserves MAC support.[31]

Further in the future are electromagnetic pulse generators that may be able to produce nuclear ECM effects through conventional means. The Soviets have already succeeded in generating single pulses with peak power of more than one billion watts and repetitive pulses of more than 100 megawatts.[32] Such systems will have disruptive effects not only on electronic combat assets but also on everything employing electronics. Friendly systems of such capability deserve support, and research must be conducted to provide countermeasures against unfriendly systems.

Conclusions

From the discussion in this and the previous chapter, the reader should be able to see that not only do the primary threats to airlift operations have exploitable weaknesses, but that there are systems and technologies readily available as solutions. Therefore, it is indeed technically feasible to provide airlift aircraft with defenses against all appropriate threats.

To this point this study has only considered the operational need for and technical feasibility of self-protective systems. Having cleared those hurdles, it is now time to evaluate the economic realism of equipping airlift aircraft with these systems.

NOTES

1. D. Curtis Schleher, *Introduction to Electronic Warfare* (Dedham, Mass.: Artech House, Inc., 1986), 28, 29.

2. Ibid.

3. Richard E. Fitts, *The Strategy of Electromagnetic Conflict* (Los Altos, Calif. : Peninsula Publishing, Inc., 1980), 53–54.

4. A. T. Waterman, "Propagation," *Electronic Countermeasures* (Los Altos, Calif.: Peninsula Publishing, 1978), 31-5.

5. Hughes Aircraft Company and Tracor Corporation, "Military Airlift Command Electronic Warfare Study Briefing" (U), presented to Headquarters MAC, January 1988. (SECRET) (Information extracted from this source is unclassified.)

6. Ibid.

7. "Sfena Investigates CO^2 Laser for Combat Aircraft Radar," *Aviation Week & Space Technology*, 23 June 1986, 124.

8. Headquarters Military Airlift Command, *C-17 Defensive Systems Study* (U), Scott AFB, Ill., 17 July 1987, 138–39. (SECRET) (Information extracted from this source is unclassified.)

9. Richard N. Johnson, "Radar-Absorbing Material: A Passive Role in an Active Scenario," *International Countermeasures Handbook: 1986*, 11th ed. (Palo Alto, Calif.: EW Communications, Inc., 1986), 375–77.

10. "New Materials Promise Low Radar Reflectance," *Aviation Week & Space Technology*, 18 May 1987, 22.

11. Bruce D. Nordwall, "Lockheed Conductive Plastics to Have Stealth Applications," *Aviation Week & Space Technology*, 25 January 1988, 120, 123.

12. Michael A. Dornheim, "Navy Laboratory Specializes in Antiradiation Missile Programs," *Aviation Week & Space Technology*, 20 January 1986, 63, 65.

13. "Navy, Air Force Plan HARM Upgrade to Extend Missile Life through 1990s," *Aviation Week & Space Technology*, 9 February 1987, 101, 103.

14. Hughes and Tracor, "Military Airlift Command Electronic Warfare Study Briefing."

15. "Northrop Developing Tactical Infrared Focal Plane Array," *Aviation Week & Space Technology*, 2 November 1987, 82–83.

16. "Texas Instruments Boosts Reliability of Navy High-Speed Antiradiation Missile," *Aviation Week & Space Technology*, 7 April 1986, 96–98.

17. Boeing Military Airplane Company, *Advanced Transport Technical Mission Analysis (ATTMA) Study*, appendix 3A, vol. 5, ASD-TR-87-5038, October 1987.

18. "China Lake Readies Data for 1990s Sidewinder Upgrade," *Aviation Week & Space Technology*, 20 January 1986, 80, 83.

19. "Martin Upgrades Copperhead Projectile to Reduce Production Time, Costs," *Aviation Week & Space Technology*, 25 January 1988, 112.

20. Bruce D. Nordwall, "Laser Advances Spur Pentagon Efforts to Protect Flight Crewmembers' Eyes," *Aviation Week & Space Technology*, 22 February 1988, 73, 75, 79.

21. US Air Force Scientific Advisory Board, *Report of the Ad Hoc Committee on the Enhancement of Airlift in Force Projection* (1982 Summer Study) (U), Washington, D.C., December 1982, 39. (SECRET) (Information extracted from this source is unclassified.)

22. General Electric Company, "UDF Development Status," briefing presented to Military Airlift Command, September 1986.

23. Doug Richardson, *An Illustrated Guide to the Techniques and Equipment of Electronic Warfare* (New York: ARCO Publishing, Inc., 1985), 28.

24. "New Lure for Radar-Guided Missiles Expands Countermeasures Role," *Aviation Week & Space Technology*, 7 April 1986, 87.

25. Nordwall, "Laser Advances Spur Pentagon," 75.

26. Ibid., 79.

27. Ibid.

28. Mario de Arcangelis, *Electronic Warfare* (Poole, Dorset, UK: Blandford Press, 1985), 219.

29. Richard S. Friedman, *Advanced Technology Warfare* (New York: Harmony Books, 1985), 39.

PART III

ECONOMIC REALISM

Up to this point, the discussion has established the operational need for and the technical feasibility of equipping airlift forces with self-protective systems. The remaining question to be addressed is: "Is it economically realistic to do so?" To answer that question, this section focuses on affordability and budgetary realism. Having addressed the economic issues, this section concludes the study with a summary and recommendations chapter.

Chapter 5 begins the discussion of economic affordability by introducing approximate costs for two alternatives available to airlift force planners. In addition to familiarizing the reader with the various weapon system costs, chapter 5 demonstrates that the cost of the do-nothing alternative is not necessarily the least expensive option. The chapter's intent is not to accomplish a rigorous cost accounting of acquisition, installation, operating, and other life-cycle expenses, but rather to convey the idea that self-protection is affordable and will create savings as transports are increasingly exposed to hostile environments. Finally, the chapter returns to a central theme, the importance of airlift to national security strategy, to show that, ultimately, the cost of securing survivable airlift must be assessed against the value of maintaining a viable US national security strategy.

Chapter 6 acknowledges budgetary constraints and proposes acquisition options to lessen the cost of securing survivable airlift. By focusing on differences between peacetime and wartime self-protection requirements, on trends affecting self-protection technology, and on the flexibility of modular enhancements, it shows that there are options to allow a gradual but steady buildup of capability.

Chapter 7 concludes the study with a summary of the findings from the sections addressing operational need, technical feasibility, and economic realism. In addition, some recommendations are made to guide MAC's preparation for future combat.

CHAPTER 5

ECONOMIC AFFORDABILITY

To address cost and affordability, it is necessary to tie together missions, aircraft associated with particular missions, threat requirements, and technological solutions in a coherent plan. Only then can costs be assigned and budgetary impacts assessed. Determining affordability, however, implies a comparison of alternatives, especially if one deems the cost to be high. For example, it is insufficient to say that a particular purchase costs too much. The query must be: "Compared to what?" Accordingly, to address affordability, the cost of equipping airlift aircraft with defensive systems should be compared to the cost of not doing so.

To accomplish these objectives this chapter links MAC's airlift missions with aircraft, aircraft with threat requirements, threat requirements with technological solutions, and solutions with approximate costs. Having done so, the chapter explores the cost of doing nothing as a counterpoint. From this perspective, affordability is assessed.

Linking Missions, Aircraft, Threats, and Solutions

Which defensive system goes on which aircraft should be determined by the missions each aircraft has and the threat encountered on each mission. The reader should recall from chapter 2 that the deployment mission and the employment and sustainment mission were assessed and assigned threat categories of 1 and 2, respectively.

In that discussion, category 1 threats included small arms, optical AAA up to .50 caliber, and hand-held SAMs. Numbers of threats were assessed as few and lacking integration. Evasive action might be required.

Category 2 threats included category 1 threats plus early generation radar SAMs, radar AAA heavier than .50 caliber, and airborne interceptors (AIs) without look-down, shoot-down, or all-weather capability. Numbers of threats were assessed as limited and possessing only moderate integration or poor deployment. Evasive action, electronic countermeasures, and defense suppression might be required. Assuming that an airlift aircraft will be equipped for its primary mission, it is possible to assign threat categories to aircraft in the MAC inventory as in table 14.

TABLE 14

Mission, Aircraft, and Threat Linkage

Mission	*Aircraft Model*	*Threat Category*
Deployment	C-5	1
	Airland C-141	1
	KC-10	1
	CRAF	1
Employment & Sustainment	C-17	2
	Airdrop C-141	2
	C-130	2

System Requirements for Category 1 Threats

It is now possible to associate particular technological solutions with missions, aircraft, and category 1 threats by assigning appropriate self-protective systems. The reader should recall from chapter 2 that the deployment mission must counter current and future threats associated with departure and arrival at main operating bases and also must counter intertheater en route hazards (table 15).

TABLE 15

Self-Protective Systems for Deployment Mission

Technological Solution	*Rationale*
Radar Threat-Avoidance System with Splash Track or AN/ALR-69 RHAW	Offers midocean protection against airborne and surface threats; AN/ALR-69 is a lower-cost, less-capable option.
Missile Warning Receiver (AN/ALQ-156) (AN/ALQ-153)	Detects missile launch, warns crew, and directs optimal flare launch and missile break maneuver; manually selected for takeoff and landing.
Missile "Break" Maneuver	Incorporates autopilot maneuver to provide maximum separation from the missile.
Flare Dispenser (AN/ALE-40)	Ejects decoy flare (nonpyrotechnic).
Laser Energy Detector (AN/AVR-2)	Alerts crew of beam-riding weapon lock-on.
Blinding Laser	Counters hand-held SAMs, optical AAA, and small arms.
Engine-Exhaust Extension, Armor, and Shielding	Lessens destructive potential of small IR missiles.

Legend

IR—Infrared
RHAW—Radar Homing and Warning

System Requirements for Category 2 Threats

As in the earlier discussion, it is possible to associate technological solutions with missions, aircraft, and category 2 threats by assigning responsive self-protective systems. Since category 2 threats include category 1 threats, the solutions proposed apply, but more capability will be needed in the more demanding threat environment. In addition, category 2 threats describe the hazards associated with airland and airdrop operations near the battle zone, operations into and out of forward operating locations, and intratheater transit in an AirLand Battle context (table 16).

TABLE 16

Self-Protective Systems for Employment and Sustainment Missions

Technological Solution	*Rationale*
Radar Threat-Avoidance System with Splash Track or AN/ALR-69	Provides SAM, AAA, and airborne interceptor avoidance; AN/ALR-69 offers lower-cost, less-capable option.
Passive Terrain Following/ Terrain Avoidance System	Permits all-weather, low-altitude passive operations.
Stealth Treatment Retinyl Schiff Base Salt Paint	Augments avoidance; delays radar acquisition.
Towed Decoys with Associated ECM Equipment	Permits high-power, off-board electronic countermeasures; low-cost counter to monopulse threat.
Silent Attack Warning System (AN/AAR-47)	Permits passive warning of hostile missile launch; cues active countermeasures.
Missile Warning Radar (AN/ALQ-156) (AN/ALQ-153)	Sequences expendable countermeasures and missile "break" maneuver.
Missile "Break" Maneuver	Incorporates autopilot capability to provide maximum separation from the missile.
Chaff, Flare, and Expendable Jammer Dispenser (AN/ALE-40)	Provides radar, IR, and laser expendable countermeasures.
Laser Energy Detector (AN/AVR-2)	Provides warning of beam-riding weapon lock-on.
Blinding Laser/Rangefinder	Counters airborne interceptor, IR, and electro-optical threats; guides rear-firing Copperhead-type weapon.

TABLE 16 – Continued

Technological Solution	*Rationale*
Engine-Exhaust Extension, Armor, and Shielding	Lessens destructive potential of small IR missiles.
Cockpit Vision Protection against Laser Weapons	Negates antivision laser.
Lethal Defense	
Rear-Firing Copperhead-type	Provides rear hemisphere airborne interceptor defense.
AIM-9R Sidewinder	Provides forward hemisphere AI defense.
HARM	Provides AI, SAM, and AAA radar suppression.

Weapon System Costs

Assigning costs to particular weapons is a risky procedure for several reasons. As indicated earlier, cost can include research and development, acquisition, installation, spares, and operations and maintenance totals, so any effort to consider only nonrecurring expenses has pitfalls. Costs also become confusing when multiyear totals are considered on a then-year dollar basis. Nevertheless, one must start somewhere. Accordingly, the following totals reflect approximate fiscal year 1988 acquisition costs per aircraft. In some cases, such as the rear-firing Copperhead-type weapon, engine-exhaust extensions, blinding laser, antilaser windscreens, and threat-avoidance systems, the systems envisioned are still conceptual. Thus their costs reflect truly approximate estimates (table 17).

TABLE 17

Weapon System Acquisition Costs

Threat Avoidance System with Splash Track	$400,000[1]
or	
AN/ALR-69 RHAW	$100,000[2]
Passive Navigation System Terrain Following, Terrain Avoidance	$550,000[3]
or	
TERPROM with Inertial Navigation and Global Positioning Systems	$250,000[4]
Stealth Treatment	
Retinyl Schiff Base Salt Paint	
C-5	$120,000[5]
C-17, C-141.	$100,000
C-130.	$ 60,000
Towed-Decoy ECM System	
Two Decoys for C-5, C-17, C-141	$500,000[6]
Two Decoys for C-130	$500,000
Silent Attack Warning System (AAR-47)	$ 90,000[7]
Missile Warning Radar	
AN/ALQ-156	$100,000[8]
Chaff, Flares, and Expendable Jammers	
C-5 (10 AN/ALE-40)	$ 90,000[9]
C-17 (8 AN/ALE-40)	$ 70,000
C-141 (6 AN/ALE-40)	$ 50,000
C-130 (4 AN/ALE-40)	$ 30,000
Missile "Break" Automated Flight Maneuver	$ 50,000[10]
Exhaust Extension, Armor, and Shielding	
C-5 and C-17	$ 50,000[11]
C-141	$ 40,000
C-130	$ 30,000
Laser Energy Detector (AN/AVR-2)	$ 20,000[12]
Blinding Laser/Rangefinder	$ 50,000[13]
Cockpit Vision Protection	$ 20,000[14]
Lethal Defense	
Copperhead-type Rear Defense	$ 50,000[15]
AIM-9R (two each)	$150,000[16]
HARM (two each)	$520,000[17]

Legend

AIM – Air Intercept Missile
HARM – High-Speed Antiradiation Missile
RHAW – Radar Homing and Warning

Organizing the various self-protective system acquisition costs by aircraft type, one can arrive at the cost of equipping each aircraft (table 18).

TABLE 18

Acquisition and Installation Costs of Fully Capable Self-Protective Systems
(in Thousands of Dollars)

		Airland		*Airdrop*	
	C-5	*C-141*	*C-17*	*C-141*	*C-130*
Threat Avoidance Syst	$ 400	$ 400	$ 400	$ 400	$ 400
Passive Navigation Syst			550	550	550
Stealth Paint			100	100	60
Towed Decoy ECM Syst			500	500	500
Silent Attack Warning Syst			90	90	90
AN/ALQ-156-type Syst	100	100	100	100	100
Chaff, Flares, Expendable Jam	90	50	70	50	30
Missile "Break" Syst	50	50	50	50	50
Exhaust Armor/Shielding	50	40	50	40	30
Laser Energy Detector	20	20	20	20	20
Blinding Laser	50	50	50	50	50
Cockpit Vision Protection			20	20	20
Copperhead-type Syst			50	50	50
AIM-9R (2 each)			150	150	150
HARM (2 each)			520	520	520
Estimated Installation[18]	500	500	500	500	500
TOTAL	$1,260	$1,210	$3,220	$3,190	$3,120

To outfit the entire MAC inventory, individual aircraft costs would be multiplied by anticipated Total Force Plan levels. To keep this exercise simple, no consideration is given in the accounting to the fact that acquisitions would be phased over a number of years. Since KC-10 and CRAF aircraft do not belong to MAC, they are not included in table 19 calculations.

TABLE 19

Acquisition and Installation Costs of Fully Capable Self-Protection for MAC Inventory

Aircraft	*Number of Aircraft*	*Cost per Aircraft*	*Total Fleet Cost*
C-5	114	$ 1,260,000	$ 143,640,000
Airland C-141	118	1,210,000	142,180,000
C-17	180	3,220,000	579,600,000
Airdrop C-141	62	3,190,000	197,780,000
C-130	342	3,120,000	1,067,040,000
TOTAL	816		$2,130,240,000

When confronted with the $2 billion-plus cost of defending this nation's airlift capability, some readers may immediately decide that the nation cannot afford the outlay. As mentioned earlier, such an assessment is premature without consideration of the cost of other courses of action. To allow a balanced assessment of affordability, the next step is to consider a baseline option, the cost of doing nothing.

Cost of Doing Nothing

The *C-17 Defensive Systems Study* developed six aircraft configurations and computed simulated flights against European and Southwest Asian theater threats over a 54-day period. Its baseline configuration, a C-17 with a night-vision goggle compatible cockpit and no other defenses, approximates the do-nothing option of this study. The results in the study averaged 59.4 aircraft lost in Europe and 37.4 aircraft lost in Southwest Asia out of 180 aircraft in the inventory.

Another option in the *C-17 Defensive Systems Study* equipped the C-17 with a threat-avoidance receiver, a missile warning receiver, chaff and flares, a towed-decoy ECM suite, and an actively emitting terrain-following, terrain-avoiding radar. Against the same threats, this option averaged 3.5 and 5.7 losses over the same period. Such a defensive suite has significant capability, but it falls short of the fully capable suite proposed herein. Since one can safely assume that the fully capable suite would yield losses at least as low as the less-capable *C-17 Defensive Systems Study* option, the difference between the two options in the C-17 study should reflect a minimum cost of doing nothing. Using the fiscal year 1988 unit flyaway cost of the C-17 (approximately $95 million) as a basis, the dollar costs of the do-nothing option are reflected in table 20.

TABLE 20

Cost of Doing Nothing to Defend the C-17 Fleet
(in Billions of Dollars)

Theater	*Do-Nothing Losses*	*Fully Capable Syst Losses*	*Delta Aircraft Losses*	*Do-Nothing Cost*
Europe	59.4	3.5	55.9	$5.31
SW Asia	37.4	5.7	31.7	$3.01

Comparing the do-nothing option with the fully capable self-protection option proposed herein produces the required alternative cost from which it is possible to determine affordability (table 21).

TABLE 21

Affordability of Defending Airlift Aircraft
(in Billions of Dollars)

Theater	*Do-Nothing C-17 Cost*	*Fully Capable MAC Fleet Cost*	*Net Savings*
Europe	$5.31	$2.13	$3.18
SW Asia	$3.01	$2.13	$0.88

From these data it is clear the C-17 savings alone would offset the cost of equipping the entire MAC fleet with self-protective systems. If human lives (crew and passengers) were considered, the rewards would be more dramatic.

Some might argue that the data and reasoning just presented are biased because they are based on a higher-cost aircraft, the C-17. They might contend that it would be marginally ineffective to similarly equip a relatively inexpensive aircraft, such as the $18 million C-130, but such a contention can easily be disproved. For example, the C-130 would experience disproportionately greater losses than the C-17 because the C-130 would not be flying the safer deployment mission that the C-17 flies. Disregarding this and applying the lower C-17 loss rate to C-130 missions produces the following data (table 22).

TABLE 22

Cost of Doing Nothing to Defend the C-130 Fleet
(in Billions of Dollars)

Theater	*Do-Nothing Losses*	*Fully Capable Syst Losses*	*Delta Aircraft Losses*	*Do-Nothing Cost*
Europe	112.9	6.7	106.2	$1.912
SW Asia	71.1	10.8	60.3	$1.085

Comparing the do-nothing option with the proposed fully capable self-protection option produces the required alternative cost to determine affordability (table 23).

TABLE 23

Affordability of Defending C-130 Aircraft

Theater	*Do-Nothing Cost*	*Fully Capable Cost*	*Net Savings*
Europe	$1.912 Billion	$1.067 Billion	$845 Million
SW Asia	$1.085 Billion	$1.067 Billion	$ 18 Million

Thus, in a European scenario, the fully capable C-130 produces a sizable savings. Although the Southwest Asian scenario seems to indicate only a slight advantage in equipping C-130s with self-protective systems, readers are reminded of the approximate nature of the fully capable costs and the fact that the scenario does not reflect the likelihood of higher than shown do-nothing losses because the C-130 would not fly deployment missions as the C-17 would. Consideration of lives saved and other intangible savings adds weight to the contention. When these factors are added, the data strongly favor equipping C-130s.

Using the same procedure for determining the affordability of the options for the airdrop C-141 is complicated by the fact that the C-141 is no longer in production. Since the *US Air Force Airlift Master Plan* rates a C-17 as the equivalent of 2.3 C-141s in terms of ton-miles per day, an arbitrary conversion is possible. Proceeding on this track, the cost of doing nothing for the C-141 is reflected in table 24.

TABLE 24

Cost of Doing Nothing to Defend the Airdrop C-141 Fleet
(in Millions of Dollars)

Theater	*Do-Nothing Losses*	*Fully Capable Syst Losses*	*Delta Aircraft Losses*	*Do-Nothing Cost*
Europe	19.3	1.2	18.1	$748
SW Asia	10.9	2.0	8.9	$368

Comparing the do-nothing option with the fully capable option produces the required alternative cost to determine affordability (table 25). Again, the data clearly demonstrate that equipping aircraft for self-protection makes economic sense.

TABLE 25

Affordability of Defending Airdrop C-141 Aircraft
(in Millions of Dollars)

Theater	*Do-Nothing Cost*	*Fully Capable Syst Cost*	*Net Savings*
Europe	$748	$198	$550
SW Asia	$368	$198	$170

Assessing deployment mission losses is much more difficult since the *C-17 Defensive Systems Study* scenario is heavily biased toward the employment and sustainment-type mission and no other authoritative, unclassified source adequately models deployment mission losses. However, one can arrive at a subjective decision that favors self-protective equipment for C-5s and airland C-141s by comparing the cost of that equipment to the replacement value of the two aircraft.

Assuming that MAC would not replace either aircraft in kind (the C-141 is not in production and the C-5 lost to the C-17 in a head-to-head competition), but rather with C-17s, a conversion of C-5s and C-141s to C-17s is required. In terms of ton-miles per day the *US Air Force Airlift Master Plan* indicates that a C-5 is equivalent to 1.125 C-17s while a C-141 is equivalent to 0.434 C-17s. Since the cost of equipping all C-5s with self-protective equipment is $143 million and a C-5's replacement value is approximately $107 million (1.125 times the C-17's $95 million cost), a savings of two or more C-5s would be cost effective. Similarly, since the C-141 equipment would cost $142 million, and a C-141's replacement value is approximately $41 million (0.434 times the C-17's $95 million cost), a savings of four or more C-141s would be cost effective. In other words, the cost of equipping C-5s and airland C-141s is effective if two or more C-5s and four or more C-141s are saved over the do-nothing alternative. Judging subjectively by Soviet aircraft losses to Stinger missiles in Afghanistan, the fully capable self-protection system should produce at least this level of savings in a full-scale European or Southwest Asian conflict.

that it scans the spectrum instead of continuously monitoring all frequencies leaves it vulnerable to brief threat transmissions.

3. The $550,000 figure represents a *MAC Electronic Warfare Study* estimate for a digitized landmass system that includes a low-probability-of-intercept radar altimeter and a terrain-correlation scanner to permit terrain-following and terrain-avoidance flight.

4. "British Aerospace Offers TERPROM Navigation System to U.S. Military," *Aviation Week & Space Technology*, 4 May 1987, 85. The article stated that TERPROM would be marketed for $50,000–$100,000. Combining US Air Force Scientific Advisory Board estimates of $70,000 for a global positioning system receiver and $80,000 for a 0.5-nautical-mile-per-hour drift inertial navigation system [US Air Force Scientific Advisory Board, *Report of the Panel on Enhancement of Special Operations Forces* (U), Washington, D.C., 30 August 1985, 86 (SECRET) (information extracted from this source is unclassified)], the total cost could reach $250,000.

5. "New Materials Promise Low Radar Reflectance," *Aviation Week & Space Technology*, 18 May 1987, 22. Dr Birge, the discoverer of these salts, estimates the cost of painting a tactical aircraft to be approximately $30,000. Since transports are somewhat bigger than the average tactical aircraft, conservative sizing factors are used to estimate transport costs.

6. The $500,000 figure represents approximately $200,000 for a towed-decoy system plus $300,000 for an ECM system. Both figures are *MAC Electronic Warfare Study* estimates. The ECM figure is highly dependent on the jamming techniques exploited, however.

7. Headquarters Military Airlift Command, *C-17 Defensive Systems Study* (U), Scott AFB, Ill., 17 July 1987, 150. (SECRET) (Information extracted from this source is unclassified.) The AN/AAR-47 is priced at $82,000, but $90,000 is used to indicate some upgrade under the silent attack warning system program.

8. US Air Force Scientific Advisory Board, *Report of the Ad Hoc Committee on the Enhancement of Airlift in Force Projection* (1982 Summer Study) (U), Washington, D.C., December 1982, 39. (SECRET) (Information extracted from this source is unclassified.) The SAB estimated this cost to be between $80,000 and $100,000. With the passage of time, the higher figure appears more likely.

9. Ibid., 41. The AN/ALE-40 is listed here because the -(V)X version has an automatic expendable selection capability and a threat-adaptive programmer. The SAB estimated the price range to be $7,000 to $9,000 per dispenser. Using the SAB estimated number of dispensers for each aircraft and the conservative $9,000 figure, system costs were calculated and rounded to the nearest $10,000.

10. The missile "break" maneuver system is the author's approach to exploit kinematic differences between the missile and the target aircraft. The cost attached reflects a software program that would integrate sensors with

the existing autopilot systems. Given the conceptual nature of the system, its cost is speculative.

11. The exhaust extension system would mimic Israeli success with their A-4 Skyhawks. On a transport aircraft with thrust reversers, implementation could be a problem. As a result these costs are nominal to reflect any damage-limiting treatment possible near the turbine section of each engine.

12. The cost is an estimate based on projected AN/AUR-2 costs.

13. The cost is approximate for a blinding laser/rangefinder given its conceptual nature.

14. The cost is estimated for cockpit vision protection, given the rapidly evolving nature of development. Since most cockpit windscreens are laminated plastics already, the alteration of existing "sandwich" material to provide a laser filter should not create excessive costs.

15. The Copperhead-type system would consist of a shock-mounted artillery tube, possibly an aiming system, and one or more rounds of ammunition. Each Copperhead round is priced at about $32,000, but the air-to-air version could be considerably smaller and lighter.

16. "Gallery of USAF Weapons," *Air Force Magazine*, May 1988, 189. The 1988 buy was $61.1 million for 956 missiles, which equates to approximately $64,000 per missile. A figure of $75,000 per missile was used to account for group A-type hardware, which would permit use of the missiles.

17. "Texas Instruments Boosts Reliability of Navy High-Speed Antiradiation Missile," *Aviation Week & Space Technology*, 7 April 1986, 97. The price of the HARM is coming down from over $350,000 per copy in the early 1980s to the 1986 quoted price of $260,000. Improved ways of making the seeker head should continue to lower the price in the future.

18. Scientific Advisory Board, *Report of Ad Hoc Committee*, 39. The 1982 SAB report estimated installation costs for less extensive systems at $400,000 for C-5s and C-141s and $300,000 for C-130s. The figure of $500,000 was inserted to account for the increase in complexity and the passage of time. For C-5s and C-141s the installation cost could well be higher, but for C-17s and C-130s the cost could just as easily be lower. The listed figure, therefore, reflects a measure of uncertainty and compromise.

CHAPTER 6

BUDGETARY REALISM

Having determined that it is cost effective to equip airlift aircraft with self-protective systems, it is now appropriate to address ways of lessening the budgetary impact of doing so. Starting with the fully capable self-protective systems described in chapter 5, this chapter investigates ways that peacetime-versus-wartime threat considerations can lead to core systems that can be augmented for hostilities and future threats. The discussion shows how the process of augmenting such core systems can be managed to delay costs and produce realistic budget increments. Building on the core-augmentation concept, the chapter introduces auxiliary strategies, involving strap-on systems and partial system purchases, that can further delay acquisition costs. Finally, the chapter discusses aircraft-unique considerations, such as aging of the C-141 and declining supportability of the C-130, and how they affect acquisition options. In the process, certain groupings of defensive systems and sequential, time-sensitive needs appear that lead to policy recommendations.

Peacetime-versus-Wartime Considerations

Ideally, MAC aircraft would be equipped to deal with all threat categories across the conflict spectrum. If this is not feasible because of funding limitations, the provision of self-protective devices on MAC aircraft should be based on the threats most likely to be encountered during future airlift operations.

During military operations short of war, the most likely threats to MAC airlifters are in category 1. Category 1 threats may be encountered during airlift operations where hostile fire is not anticipated and may occur with no advance warning. Examples are attacks by terrorists or guerrilla insurgents during US support of foreign friends and allies. Category 2 threats, though less likely, may be encountered by airlifters during certain peacetime contingency operations, such as the Grenada operation or the Libyan raid. Wartime airlift operations will definitely expose MAC aircrews to category 2 threats. Category 1 threats must, of course, be anticipated at all levels of conflict intensity.

There appears to be a rather sharp difference between category 1 and category 2 threats in terms of technical sophistication and availability of weapons. Small, light weapons can be acquired, transported, maintained, and brought to bear with relative ease by terrorist organizations and guerrilla insurgents, but these activities are much more difficult with larger, heavier, and more sophisticated weaponry. As a result, peacetime threats consist primarily of light surface-to-air weapons found in category 1.

Force structure planners and managers concerned with budgeting for defensive systems might ask if there is a useful distinction between war and operations short of war that provides a foundation for acquisition flexibility and planning. Based on the previous discussion, table 26 appears to confirm a positive answer. Since category 1 threats extend throughout the conflict spectrum and since MAC airlift aircraft are most likely to be engaged in operations short of war (where such threats predominate), funding priorities should stress the development and provision of self-protective devices for category 1 threats. After providing self-protective devices for category 1 threats, the program could be augmented with equipment and funding for higher-threat levels involving peacetime contingency operations and wartime activities.

TABLE 26

Category 1 Threats and Solutions versus Normal Peacetime Need

Threat	*Solution*	*Normally Needed in Peacetime?*
Small Arms	Blinding Laser	No
Small IR Missile	Missile Warning Receiver	Yes
	IR Decoy System	Yes
	Missile "Break" Maneuver	Yes
	Engine-Exhaust Extension	Maybe
Small Laser-Guided Missile	Laser Energy Detector	Maybe
	Blinding Laser	Maybe
	Optical Chaff	Maybe

From table 26, it can be seen that a possible budgetary option would be to purchase missile warning receivers, IR decoy systems, and a missile "break" maneuver capability over the near term; to add engine-exhaust extensions, laser energy detectors, blinding lasers, and optical chaff over the intermediate term; and to acquire radar threat-avoidance receivers over the long term. Using the same approach with category 2 threats yields the results depicted in table 27.

TABLE 27

Category 2 Threats and Solutions versus Normal Peacetime Need

Threat	*Solution*	*Normally Needed in Peacetime?*
Small Arms	Passive TF/TA Navigation System	No
	Blinding Laser	No
Infrared Missile	Passive TF/TA System	No
	Silent Attack Warning System (SAWS)	No
	Missile Warning Receiver	Yes
	Infrared Decoy System	Yes
	Missile "Break" Maneuver	Yes
	Engine-Exhaust Extension	Maybe

TABLE 27 – Continued

Threat	*Solution*	*Normally Needed in Peacetime?*
Small Laser-Guided Missile	Passive TF/TA System	No
	Laser Energy Detector	Maybe
	Blinding Laser	Maybe
	Optical Chaff	Maybe
Radar Systems	Radar Threat Avoidance	No
	Passive TF/TA System	No
	Stealth Treatment	No
	Electronic Countermeasures	No
	HARM	No
Airborne Interceptor	Radar Threat Avoidance with Splash Track	No
	Passive TF/TA System	No
	Blinding Laser/Rangefinder	No
	Copperhead-type System	No
	Sidewinder Missile	No
	Air-to-Air HARM	No
Radar Missile	Radar Threat Avoidance	No
	Passive TF/TA System	No
	Towed-Decoy ECM System	No
	Chaff Dispenser System	No
Directed-Energy Weapon	Cockpit Vision Protection	No
	Laser Shield	No

Comparing the results of table 26 with table 27 reveals short- and intermediate-term needs are the same for category 1 and category 2. Over the long term, category 2 threat solutions would add passive TF/TA systems, silent attack warning systems, stealth treatment, towed-decoy ECM systems, chaff, Copperhead-type systems, Sidewinder missiles, HARMs, cockpit vision protection, and laser shield armor.

Organizing the results of table 18 (chapter 5) into short-, intermediate-, and long-term categories provides a time-phased perspective of acquisition and installation costs. Note that the short-, intermediate-, and long-term installation costs (table 28), when added, increase above the estimated installation cost (from table 18) because of the piecemeal nature of the time-phased installation.

TABLE 28

Short-, Intermediate-, and Long-Term Acquisition and Installation Costs of Fully Capable Self-Protective Systems

(in Thousands of Dollars)

	Airland C-5	Airland C-141	C-17	Airdrop C-141	Airdrop C-130
Short-Term Need					
AN/ALQ-156-type Syst	$100	$100	$ 100	$ 100	$ 100
IR Decoy Syst	90	50	70	50	30
Missile "Break" Syst	50	50	50	50	50
Est Installation[1]	350	350	350	350	350
Subtotal	$590	$550	$ 570	$ 550	$ 530
Intermediate-Term Need					
Exhaust Armor/Shielding	$ 50	$ 40	$ 50	$ 40	$ 30
Laser Energy Detector	20	20	20	20	20
Blinding Laser	50	50	50	50	50
Optical Chaff	—	—	—	—	—
Est Installation	200	200	200	200	200
Subtotal	$320	$310	$ 320	$ 310	$ 300
Long-Term Need					
Threat Avoidance Syst	$400	$400	$ 400	$ 400	$ 400
Passive TF/TA Syst	—	—	550	550	550
Silent Attack Warn Syst	—	—	90	90	90
Stealth Paint	—	—	100	100	60
Towed-Decoy ECM Syst	—	—	500	500	500
Copperhead-type Syst	—	—	50	50	50
AIM-9R (2 each)	—	—	150	150	150
HARM (2 each)	—	—	520	520	520
Cockpit Vision Protection	—	—	20	20	20
Laser Shield Armor	—	—	*	*	*
Est Installation	100	100	300	300	300
Subtotal	$500	$500	$2,680	$2,680	$2,640

*To be determined.

Also, note that the cost of optical chaff would be insignificant if an IR decoy dispensing system were installed in the short-term option. As a result no entry is made in table 28. The same would be true for radar chaff and expendable radar decoys. In addition, note that laser shield armor is still in the early stages of its development, which results in a to-be-determined entry.

To determine MAC inventory costs, individual aircraft costs would be multiplied by anticipated Total Force Plan levels. To keep this exercise simple, no consideration is given in the accounting to the fact that acquisitions would be phased over a number of years (table 29).

TABLE 29

Short-, Intermediate-, and Long-Term Acquisition and Installation Costs for the MAC Inventory

	Number of Aircraft	*Cost per Aircraft*	*Total Fleet Cost*
Short-Term			
C-5	114	$ 590,000	$ 67,260,000
Airland C-141	118	550,000	64,900,000
C-17	180	570,000	102,600,000
Airdrop C-141	62	550,000	34,100,000
C-130	342	530,000	181,260,000
TOTAL	816		$ 450,120,000
Intermediate-Term			
C-5	114	$ 320,000	$ 36,480,000
Airland C-141	118	310,000	36,580,000
C-17	180	320,000	57,600,000
Airdrop C-141	62	310,000	19,220,000
C-130	342	300,000	102,600,000
TOTAL	816		$ 252,480,000
Long-Term			
C-5	114	$ 500,000	$ 57,000,000
Airland C-141	118	500,000	59,000,000
C-17	180	2,620,000	471,600,000
Airdrop C-141	62	2,680,000	166,160,000
C-130	342	2,640,000	902,880,000
TOTAL	816		$1,656,640,000

Comparing the all-at-once total cost of the fully capable system from table 19 (chapter 5) with the results of table 29 indicates a potential for having to fund only the near-term costs, for example, in one lump sum while incrementally investing in intermediate- and long-term programs. Instead of needing $2.1 billion to start (and finish) the all-at-once program, this particular approach reduces the entry fee to approximately $450 million. Of course, other approaches are possible.

Core Systems versus Augmentation and Future Requirements

Continuing with the results from the preceding section, one might ask if the solutions identified at this point are independent or is there overlap in capability suggesting that sequential acquisition could provide more protection earlier. Against airborne interceptors, for example, if one delays purchase of a rear-firing Copperhead-type defense and relies on forward-firing Sidewinders instead, the rear hemisphere could be protected to a limited extent by maneuvering the transport. And before purchasing a Sidewinder defense, it would be possible to rely on a blinding laser defense to deter attacks. Since a blinding laser defense has applications against surface-launched weaponry as well, its utility would be higher than other one-dimensional defensive systems. Accordingly, the systems from table 27 can be ranked as follows for sequential acquisition (table 30).

TABLE 30

Rank Order of Protective Systems

Threat	*Solution*	*Rank within Class*	*Rank Overall*
Small Arms	Passive TF/TA Navigation System	1	6
	Blinding Laser	2	5
Infrared Missile	Passive TF/TA System	4	6
	SAWS	4	6
	Missile Warning Receiver	1	1
	Infrared Decoy System	1	1
	Missile "Break" Maneuver	2	2
	Engine-Exhaust Extension	3	3
Small Laser-Guided Missile	Passive TF/TA System	1	6
	Laser Energy Detector	2	4
	Blinding Laser	2	5
	Optical Chaff	3	1

TABLE 30 – Continued

Threat	*Solution*	*Rank within Class*	*Rank Overall*
Radar Systems	Radar Threat Avoidance	1	7
	Passive TF/TA System	2	6
	Stealth Treatment	4	8
	ECM	3	9
	HARM	5	11
Airborne Interceptor	Radar Threat Avoidance with Splash Track	1	7
	Passive TF/TA System	2	6
	Blinding Laser/Rangefinder	3	5/10
	Copperhead-type System	5	12
	Sidewinder Missile	4	10
	Air-to-Air HARM	6	11
Radar Missile	Radar Threat Avoidance	1	7
	Passive TF/TA System	2	6
	Towed-Decoy ECM System	3	9
	Chaff Dispenser System	4	1
Directed-Energy Weapon	Cockpit Vision Protection	1	13
	Laser Shield	2	14

Rationale for this particular grouping is as follows. The short-term systems receive the highest overall rankings, 1 and 2, because of their utility in peacetime. Since the radar-based missile warning system (ALQ-156-type system) controls expendable countermeasures, it is rated equal to the IR decoy (flare) dispensing system. The missile "break" capability is rated lower because it would augment the IR decoy system in this configuration.

The intermediate-term systems receive overall rankings 3 through 5 because they reflect upgrades to the category 1, or core suite. Because the intermediate systems are needed for defense in normal peacetime, they are rated ahead of systems that would not be needed until war or operations short of war require them. Within the intermediate-term group, the engine-exhaust extension is rated highest because it augments systems against an existing, peacetime threat. The blinding laser is ranked below the laser energy detector because, with initial laser warning, the crew might rely on such passive countermeasures as TF/TA or terrain-masking flight before resorting to such active countermeasures as a blinding laser. Note that optical chaff receives a rating equal to the IR decoy dispenser, reflecting the ability of such a system to handle various types of expendable cartridges.

The long-term systems receive overall rankings of 6 through 14. The passive TF/TA navigation system receives the highest ranking because of its universally applicable navigation component. Furthermore, its low-altitude flight capability would provide protection against the combination of threats that airlift is likely to encounter. Equally ranked is the silent attack warning system because of its provision of complementary passive missile launch warning and infrared search and track against airborne threats. Seventh ranked is the radar threat-avoidance system, acknowledging the first priority of airlift, avoid the threat if possible. Eighth ranked is the stealth-paint treatment because of the emphasis on threat avoidance. Ninth ranked is the towed-decoy ECM system to allow transports to blend in with strike packages and to defeat radar threats that cannot be avoided. Tenth ranked is the laser rangefinder capability that would provide range data to Sidewinder missiles and Copperhead-type weapons. Since the rangefinder works with the Sidewinder and the Sidewinder could provide limited rear hemisphere protection, the Sidewinder is also ranked tenth, ahead of the Copperhead-type system. Eleventh ranked is the HARM system, providing air-to-ground and air-to-air capability against radars that cannot be avoided or defeated by ECM. Twelfth ranked is the rear-firing, Copperhead-type system to complete the lethal defense capability against current airborne threats. Thirteenth ranked is cockpit vision protection against laser defenses, reflecting the lack of a widespread threat. Fourteenth is laser shield armor. The pace of laser research and Soviet willingness to use blinding lasers in peacetime emphasize that there is a need to develop this defensive capability.

Although the particular rankings and rationale reflect the author's assessment of the effectiveness and priority of the various defensive systems, the greatest value of this exercise is in pointing out a method to discriminate between the various systems and their acquisition costs. By organizing table 30 into a matrix of core, augmenting, and future periods, some costs in table 29 could be delayed even further (table 31).

TABLE 31

Incremental Buildup of Protective Systems

		Augmenting/Future Periods			
	Core	*1*	*2*	*3*	*4*
Short-Term Need					
AN/ALQ-156-type Syst	X				
Infrared Decoy Syst	X				
Missile "Break" Syst		X			
Intermediate-Term Need					
Exhaust Armor/Shielding		X			
Laser Energy Detector		X			
Blinding Laser		X			
Optical Chaff	X				
Long-Term Need					
Threat-Avoidance Syst			X		
Passive TF/TA Syst			X		
Silent Attack Warning Syst			X		
Stealth Paint			X		
Towed-Decoy ECM Syst			X		
AIM-9R Sidewinder (2 each)				X	
HARM (2 each)				X	
Copperhead-type Syst					X
Cockpit Vision Protection					X
Laser Shield					X

Reaccomplishing table 28 with the additional time periods generated in table 31 produces a multiperiod schedule of acquisition and installation costs. Note that in the interest of conservatism and simplicity, installation costs for short-, intermediate-, and long-term programs are front-end loaded (table 32).

TABLE 32

Incremental Buildup: Short-, Intermediate-, and Long-Term Acquisition and Installation Costs

(in Thousands of Dollars)

		Airland		*Airdrop*	
	C-5	*C-141*	*C-17*	*C-141*	*C-130*
Short-Term Need					
Core Suite:					
AN/ALQ-156-type Syst	$100	$100	$ 100	$ 100	$ 100
IR Decoy Syst	90	50	70	50	30
Est Installation	350	350	350	350	350
Core System Total	$540	$500	$ 520	$ 500	$ 480
Augmenting Period One:					
Missile "Break" Syst	$ 50	$ 50	$ 50	$ 50	$ 50
Intermediate-Term Need					
Augmenting Period One:					
Exhaust Armor/Shielding	$ 50	$ 40	$ 50	$ 40	$ 30
Laser Energy Detector	20	20	20	20	20
Blinding Laser	50	50	50	50	50
Optical Chaff	–	–	–	–	–
Est Installation	200	200	200	200	200
Subtotal	$320	$310	$ 320	$ 310	$ 300
Long-Term Need					
Augmenting Period Two:					
Threat Avoidance Syst	$400	$400	$ 400	$ 400	$ 400
Passive TF/TA Syst	–	–	550	550	550
SAWS	–	–	90	90	90
Stealth Paint	–	–	100	100	60
Towed-Decoy ECM Syst	–	–	500	500	500
Est Installation	100	100	300	300	300
Subtotal	$500	$500	$1,940	$1,940	$1,900
Augmenting Period Three:					
AIM-9R (2 each)	–	–	$ 150	$ 150	$ 150
HARM (2 each)	–	–	520	520	520
Subtotal	–	–	$ 670	$ 670	$ 670
Augmenting Period Four:					
Cockpit Vision Protection	–	–	$ 20	$ 20	$ 20
Copperhead-type Syst	–	–	50	50	50
Laser Shield	–	–	*	*	*
Subtotal	–	–	$ 70	$ 70	$ 70

*To be determined.

Using Total Force Plan inventory levels and multiplying the costs derived in table 32 produces the MAC inventory cost for each period as shown in table 33.

TABLE 33

Incremental Buildup: Acquisition and Installation Costs for the MAC Inventory

	Number of Aircraft	*Cost per Aircraft*	*Total Fleet Cost*
Short-Term			
Core Suite:			
C-5	114	$ 540,000	$ 61,560,000
Airland C-141	118	500,000	59,000,000
C-17	180	520,000	93,600,000
Airdrop C-141	62	500,000	31,000,000
C-130	342	480,000	164,160,000
TOTAL	816		$ 409,320,000
Augmenting Period One:			
TOTAL	816	$ 50,000	$ 40,800,000
Intermediate-Term			
Augmenting Period One:			
C-5	114	$ 320,000	$ 36,480,000
Airland C-141	118	310,000	36,580,000
C-17	180	320,000	57,600,000
Airdrop C-141	62	310,000	19,220,000
C-130	342	300,000	102,600,000
TOTAL	816		$ 252,480,000
Long-Term			
Augmenting Period Two:			
C-5	114	$ 500,000	$ 57,000,000
Airland C-141	118	500,000	59,000,000
C-17	180	1,940,000	349,200,000
Airdrop C-141	62	1,940,000	120,280,000
C-130	342	1,900,000	649,800,000
TOTAL	816		$1,235,280,000
Augmenting Period Three:			
C-17	180	$ 670,000	$ 120,600,000
Airdrop C-141	62	670,000	41,540,000
C-130	342	670,000	229,140,000
TOTAL	584		$ 391,280,000
Augmenting Period Four:			
C-17	180	$ 70,000	$ 12,600,000
Airdrop C-141	62	70,000	4,340,000
C-130	342	70,000	23,940,000
TOTAL	584		$ 40,880,000

Comparing table 29 with table 33 illustrates that spreading the costs over five periods (core and four augmenting periods) versus three not only reduces cost in the initial period by $40 million but also reduces the peak period cost (augmenting period two) by $420 million. Altogether, the program shown in table 33 is much more fiscally manageable in a period of receding budgets than either the plan of table 29 or the all-at-once plan of chapter 5. Still, more can be done to delay the costs.

Strap-On and Partial Fleet Capabilities

Strap-on refers to a system that can be installed when needed and removed when not needed. By removing the strap-on system, it is possible to save the weight, drag, and fuel penalties associated with carrying the system and the wear and tear on the strap-on components themselves. Such systems tend to be good ideas if they are required on a predictable basis but are not needed every day. Compared to a permanently installed system, they introduce a logistics planning consideration that complicates operations.

Partial outfitting of the fleet refers to limiting the number of systems purchased compared to the number of aircraft that may receive them. By limiting the number of systems purchased, acquisition cost is usually less than 100-percent outfitting would be. In practice partial outfitting is a good idea if the need is limited and predictable. It is not a good idea if the demand for the system surges or is unpredictable.

With regard to defensive systems, strap-on is a good idea if 100 percent of the aircraft that need the system are covered and if the system can be installed in a timely fashion. Problems arise when strap-on is combined with partial outfitting to fulfill missions that are not limited, are not predictable, cannot be managed logistically, or cannot be flown according to doctrine when required.

On any given day every aircraft within a model designation will not fly that model's most demanding mission. Is it possible then to purchase less than a full complement of defensive systems and daily assign them to the critical missions? For example, instead of purchasing 180 sets of Sidewinder missiles (one set for every C-17), why not purchase only a fraction of the sets and allocate them on a daily basis to those missions in a category 2 threat environment? In theory such an approach is possible, but in practice there are limitations and doctrinal prohibitions. Since one of the strengths of air power is flexibility, any long-term effort that restricts that flexibility by equipping only a portion of the fleet to accomplish its primary mission is doctrinally unsound and is risky warfighting strategy. At best, attempts to achieve budgetary savings by use of partial outfitting should be short term, and full outfitting should be achieved as soon as practical.

Since short- and intermediate-term needs are driven by peacetime requirements and terrorist threats and since it is impossible to predict where countermeasures might be needed, it is unrealistic to apply a strap-on program to these needs. Considering long-term systems, only a few candidates appear feasible: the towed-decoy ECM system, the Sidewinder missile defense, the HARM defense, and the Copperhead-type system. All other long-term systems would appear to require that their major costs be spent up front on group A provisions (wiring, antennae, displays, and controls) or in integration efforts. The remaining group B provisions (interchangeable black boxes) would not appear to offer much in the way of savings. Nevertheless, considerable savings may be possible in augmenting periods two, three, and four. To determine if that is the case, it is necessary to consider each aircraft.

Since C-17s fly directly from main operating bases (MOBs) in the United States, as well as from other locations, to forward operating bases in the theater of operations, it is not likely that a workable strap-on system could be devised. Even those C-17s that initially fly between MOBs will also have to fly an intratheater leg. Therefore, neither stateside bases nor theater MOBs could exclusively serve as upload or download points for defensive equipment. That being the case, a large number of sets would have to be purchased and stationed at both stateside and theater MOBs. Since theater MOBs will require short ground times for aircraft if they are to maintain a high level of cargo throughput, additional ground time to equip transports with defensive equipment would be counterproductive.

Assigning the few available strap-on systems to certain tail numbers permanently would run counter to the doctrine of direct delivery because it would relegate a certain portion of the C-17 inventory to nondirect-delivery missions. In addition, it would place a greater burden on the C-130s to move intratheater cargo. In short, the C-17 does not appear to be a good candidate for a strap-on defensive system.

Since the 62 airdrop C-141s would all require defensive systems in the event of a brigade-size airdrop, a strap-on strategy for them would not result in savings even though it may appear to be appropriate. That leaves the C-130 fleet.

Determining what percentage of the C-130 fleet should be equipped with defensive systems is a subjective exercise. The variety of C-130 missions, scenarios, and tactics interact with total force structure issues to yield no optimum answer. Nevertheless, two approaches are offered here for the sake of discussion. The first is to discriminate according to geographical employment regions, the second is to discriminate according to active versus reserve status.

Exploring the possibilities of discriminating geographically, the first question that comes to mind is: "Which region is most likely to require the four candidate systems?" Clearly, Europe is the answer. Assuming that the C-130s permanently allocated to the Pacific and Southern command areas, plus a few stateside aircraft, would be withheld, it is possible to assess potential savings. Assuming that 24 C-130s would be withheld in the Pacific, eight would be withheld for Southern Command, and 32 would be withheld for stateside training and logistics purposes, a savings of 64 aircraft sets is produced. Of the 278 aircraft remaining for European duty, not all would be tasked on any given day to fly missions requiring the candidate systems. If one further assumes that 20 percent of the European C-130s would be grounded for maintenance or tasked on less-risky missions, an additional 55 aircraft sets could be saved.

By designing the four candidate systems for modular strap-on service on C-130s, a total of 119 aircraft sets could be saved.

Examining what is possible by discriminating along active duty and reserve lines, one finds that the *US Air Force Airlift Total Force Plan* projects 190 active duty C-130s and 152 reserve C-130s.[2] If only the active duty C-130s received the four candidate systems, a savings of 152 aircraft sets would be realized. Although such a plan would not entail a modular strap-on design, savings are, nevertheless, possible. The rationale for making this decision assumes that the towed-decoy ECM system, the Sidewinder system, the HARM system, and the Copperhead-type system impose significant additional training loads that active duty units would be better prepared to absorb.

Using the cost of each candidate system from table 34, the period in which the system would have been acquired, and the numbers of C-130s that would not be equipped produces the results shown in table 35.

TABLE 34

C-130 Strap-On Candidate System Costs

	System Cost
Augmenting Period Two	
Towed-Decoy ECM System	$500,000
Augmenting Period Three	
AIM-9R (2 each)	$150,000
HARM (2 each)	520,000
Subtotal	$670,000
Augmenting Period Four	
Copperhead-type System	$ 50,000

TABLE 35

Savings Potential of Not Equipping Certain C-130s

	Number of Aircraft	*Cost per Aircraft*	*C-130 Fleet Savings*
Geographical Solution			
Augmenting Period Two	119	$500,000	$ 59,500,000
Augmenting Period Three	119	$670,000	$ 79,730,000
Augmenting Period Four	119	$ 50,000	$ 5,950,000
Active-Reserve Solution			
Augmenting Period Two	152	$500,000	$ 76,000,000
Augmenting Period Three	152	$670,000	$101,840,000
Augmenting Period Four	152	$ 50,000	$ 7,600,000

Rather than arguing the merits of either the geographical or active-reserve approach, assume that the active-reserve plan is preferred because it saves more money. By subtracting the savings of this plan (table 35) from total program costs (table 33), the results depicted in table 36 are produced.

TABLE 36

Impact of Partial C-130 Equipage on Costs

	Total Fleet Cost
Short-Term	
Core Suite Total	$ 409,320,000
Augmenting Period One Total (table 33)	$ 40,800,000
Intermediate-Term	
Augmenting Period One Total (table 33)	$ 252,480,000
Long-Term	
Augmenting Period Two Total (table 33)	$1,235,280,000
Less Active-Reserve Plan C-130 Savings	-76,000,000
TOTAL	$1,159,280,000
Augmenting Period Three Total (table 33)	$ 391,280,000
Less Active-Reserve Plan C-130 Savings	-101,840,000
TOTAL	$ 289,440,000
Augmenting Period Four Total (table 33)	$ 40,880,000
Less Active-Reserve Plan C-130 Savings	-7,600,000
TOTAL	$ 33,280,000

As can be seen in table 36, some of the savings are, indeed, substantial, but they do not particularly help in the initial- or peak-funding periods. Given the risk associated with leaving a significant portion of the fleet without the protection of the defensive systems, other avenues of savings should be afforded priority.

Aircraft-Unique Considerations

If additional savings are needed to stay within fiscal limitations, aircraft service life considerations and follow-on acquisition plans might be factors in eliminating certain aircraft from being equipped with defensive systems. For example, the C-141 is rapidly using up its airframe life and will begin exiting the inventory in the 1990s. In the interest of spending defensive system capital only on aircraft that will be in the inventory for a longer period, one might conclude that airland C-141 defensive systems would not be a good investment.

Another reason for not equipping a particular aircraft with defensive systems might be excessively expensive maintenance and supply costs. For example, the C-130 avionics system is 1950's vintage technology with "steam-gauge" (analog) instrumentation. Over the last decade, aircraft avionics systems have been converted to a multiplexed, time-sharing data bus system specified by Military Standard 1553B. As a result, steam gauges have given way to electronic instruments to the extent that steam gauge suppliers have gone, or are in the process of going, out of business. At some point in the near future, unless C-130s are converted to the 1553B standard, the cost of maintaining C-130 avionics may be prohibitive. Moreover, with technology pointing toward the promise of an Advanced Tactical Transport, the longevity of the C-130 may come into question.

Assuming that deletion of both the airland C-141s and the C-130s from the defensive systems list is a prudent risk, acquisition costs of self-protective systems for the MAC inventory would drop considerably (table 37).

TABLE 37

Incremental Buildup: Acquisition and Installation Costs for C-5s, C-17s, and Airdrop C-141s

	Number of Aircraft	*Cost per Aircraft*	*Total Fleet Cost*
Short-Term			
Core Suite:			
Total (table 33)	816		$ 409,320,000
Less Airland C-141	-118	$ 500,000	- 59,000,000
Less C-130	-342	$ 500,000	-164,160,000
TOTAL	356		$ 186,160,000
Augmenting Period One:			
Total (table 33)	816	$ 50,000	$ 40,800,000
Less Airland C-141	-118	$ 50,000	- 5,900,000
Less C-130	-342	$ 50,000	- 17,100,000
TOTAL	356		$ 17,800,000
Intermediate-Term			
Augmenting Period One:			
Total (table 33)	816		$ 252,480,000
Less Airland C-141	-118	$ 310,000	- 36,580,000
Less C-130	-342	$ 300,000	-102,600,000
TOTAL	356		$ 113,300,000
Long-Term			
Augmenting Period Two:			
Total (table 33)	816		$1,235,280,000
Less Airland C-141	-118	$ 500,000	- 59,000,000
Less C-130	-342	$1,900,000	-649,800,000
TOTAL	356		$ 526,480,000
Augmenting Period Three:			
Total (table 33)	816		$ 391,280,000
Less C-130	-342	$ 670,000	-229,140,000
TOTAL	474		$ 162,140,000
Augmenting Period Four:			
Total (table 33)	816		$ 40,880,000
Less C-130	-342	$ 70,000	- 23,940,000
TOTAL	474		$ 16,940,000

From the results of table 37, it is clear that denying defensive systems to airland C-141s and all C-130s would reduce initial-period costs by approximately 55 percent and peak-period costs by approximately 57 percent. As mentioned earlier, such a step would be recommended only if the Air Force were prepared to replace the rapidly aging C-141 and the difficult to support C-130. As replacement aircraft take the place of the retiring C-141s and C-130s, the replacements will require the defensive systems that were "saved" earlier. At best, such a scheme will only delay costs, not avoid them.

Up to this point, the author has assumed that installation of defensive systems on the C-17 would take place sometime after initial assembly, because, at this relatively late date in the C-17's genesis, some aircraft would have to be built without defensive systems. As a result, no attempt has been made to speculate on the potential savings offered by initial installation. If installation could be accomplished while the aircraft were being built, significant installation savings could be achieved. Suffice it to say that an incentive exists for installation during initial assembly.

Conclusions

In part III of this study the concepts of affordability of defensive systems and budgetary realism were addressed. Chapter 5 showed that acquisition and installation costs of self-protective systems are not only affordable but are necessary to fulfill US national security strategy. Chapter 6 then introduced rational concepts to spread the fiscal burden out into manageable bites. Taken together, chapters 5 and 6 show decisively that it is economically realistic to equip airlift aircraft with self-protective systems.

Having shown that it is operationally necessary, technically possible, and economically realistic to equip airlift aircraft with self-protective measures, it is now appropriate to summarize findings and to make recommendations.

NOTES

1. US Air Force Scientific Advisory Board, *Report of the Ad Hoc Committee on the Enhancement of Airlift in Force Projection* (1982 Summer Study) (U), Washington, D.C., December 1982, 66. (SECRET) (Information extracted from this source is unclassified.) The 1982 Scientific Advisory Board report estimated installation costs for a similar system, plus a towed-decoy ECM system, at $400,000 for C-5s and C-141s, and $300,000 for

C-130s. In chapter 5 this was increased to $500,000 to account for the increase in complexity, the passage of time, and the complete fully capable system. While the near-term suite constitutes a small portion of the fully capable system, the near-term installation would have to include the avionics architecture to permit later incorporation of intermediate- and long-term suites. Therefore, the near-term cost is disproportionately higher.

2. *US Air Force Airlift Total Force Plan*, 17 September 1984, 29.

CHAPTER 7

SUMMARY AND RECOMMENDATIONS

The objective of this study was threefold: to determine if it is operationally necessary, technically feasible, and economically realistic to equip airlift aircraft with self-protective systems for inflight defense. Closer examination of the total problem, however, revealed an underlying, larger issue: Where does airlift fit in national security strategy, and can the Military Airlift Command fulfill its assigned wartime mission if called upon?

In answering the question of operational need, the discussion of national security strategy led to doctrinal roles, airlift force structure and capability, and the enemy threat. In answering the question of technical feasibility, the discussion of enemy and US airlift tasks led to electromagnetic warfare and how US airlift forces must wage it to survive in future battles. This, in turn, led to a discussion of what sort of technology would be responsive in future battles. In answering the question of economic realism, the discussion of affordability and fiscal reality each returned to the larger question of what US strategy required of airlift to be successful. While intellectually rewarding to airlift and air power enthusiasts, the journey was tortuous enough to require summation. Accordingly, the lessons of the journey and recommendations for the future follow.

Lessons Learned

Equipping airlift aircraft to defend themselves in combat would appear to be an obvious requirement, but strategy, doctrine, force structure, and capabilities all enter into the balance. The first part of this study addressed these factors in determining operational need.

Operational Need

National security strategy is the departure point for all military capability, and current US strategy depends on survivable airlift to succeed. Survivable airlift is required to defend US national interests as far from North America as possible. It, along with the other forms of transportation, permits relatively small active duty forces to provide the defense the United States requires. But airlift does what sealift and prepositioning of personnel and equipment cannot do, and that is to respond rapidly to the full range of security threats. Finally, airlift is a critical link in committing US resources to alliance relationships.

Since US national security strategy requires survivable airlift, doctrine must provide the architecture for determining roles and missions and for fleshing-out capability. Unfortunately, a large portion of Air Force doctrine, particularly at the operational and tactical level, is obsolete. It predates such current joint doctrine as AirLand Battle and is not responsive. New US doctrines (AirLand Battle, electronic combat, direct delivery, and joint airlift for combat operations) require airlift aircraft to carry self-protective systems.

The review of airlift forces showed that airlift missions, force structure, and aircraft are vulnerable to the threat. Tactical escort aircraft and defense suppression missions can no longer protect transports against modern weaponry. Furthermore, the goal of 66 million ton-miles of airlift per day is short of the real airlift requirement, will not be reached until the year 2000, and has no attrition reserve. Finally, individual transports have no onboard defensive systems.

The threat arrayed against airlift forces requires peacetime, and certainly wartime, defenses. Terrorists, insurgents, and Spetsnaz-type agents threaten airlift now. Peacetime contingencies and undeclared hostilities may expose MAC aircraft to radar-directed SAMs and airborne interceptors. Future weapons will increase airlifter vulnerability in all levels of conflict, and war would introduce carrier-based aircraft, AWACS-directed weapons, multiple-sensor-guided munitions, and laser-based threats.

Balancing the threat against national security strategy, Air Force doctrine, and airlift forces exposes a shortfall. The options available to resolve the shortfall include: providing transports with self-protection, buying more transports to allow attrition, changing Air Force and joint doctrine to insulate transports from danger, or changing national security strategy. Of these choices, equipping transports with defensive systems is the preferred solution and most consistent with strategy, doctrine, and the threat. Clearly, the operational need exists.

Technical Feasibility

Since the enemy's tasks are sequentially to detect, acquire, track, identify, intercept, and either intimidate, disable, or destroy the airlifter; the airlifter's tasks are to avoid the threat or to deceive, degrade, intimidate, disable, or destroy the threat if avoidance is not possible. All of the enemy's tasks must be done sequentially, in an unbroken chain, to be successful. Only one (and any one) of the airlifter's tasks need be done well to defeat the threat. Therefore the physical relationship of the engagement favors the airlifter.

Electromagnetic energy serves as a conduit for information. In the earth's atmosphere, however, only four bands are readily exploitable: the radio spectrum up to 300 GHz, the 2-to-5 and 8-to-14 micron bands in the infrared, and the visible spectrum. Controlling these "windows" to permit friendly usage while denying enemy exploitation is the essence of electronic combat. Denying the enemy information requires strict emission and reflection control at all window frequencies. As a result, passive, stealthy, camouflaged, and outwardly cold operations have an advantage.

The relationship of threats to the electromagnetic spectrum produces weaknesses that can be exploited. For example, category 1 threats (small arms, optical AAA up through .50 caliber, and hand-held SAMs) are exclusively dependent on infrared and electro-optical detection, acquisition, and tracking. Category 2 threats (category 1 threats plus early generation radar SAMs, radar AAA, and airborne interceptors without look-down, shoot-down or all-weather capability) add radar detection, acquisition, and tracking requirements. Infrared threats are subject to deception because the IR energy pattern is controlled by the target. Electro-optical threats have an inherent weakness in their human-sighting and -tracking function. Radar threats are vulnerable to noise and deception jamming and lethal countermeasures directed against their nonpassive mode of operation. Therefore, despite the myths attached to SAMs and interceptors, they can be countered, even by airlift aircraft.

MAC is at a unique juncture in history where a number of new technologies are emerging that can tip the odds in battle toward the defense. If MAC embraces the concept of passive operations (to make detection, acquisition, tracking, and other offensive tasks more difficult), threats will be forced to give away their positions to find airlifters. In doing so, the enemy becomes vulnerable to lethal defense on the part of the transport. Therefore, retaining passive operations while acquiring the right defenses can convert transports into formidable opponents. A key to achieving these capabilities will be using the correct design philosophy.

Current countermeasure programs tend to focus on the threat electronic order of battle with varying methods of predicting enemy advances. Such approaches are characterized by vulnerability to surprise and inefficient catch-up efforts. MAC should aim instead for integrated systems that do not depend on prior knowledge of specific threat operating characteristics for their effectiveness. Such a concept sounds like pie in the sky, but it really rests on sound principles. First, MAC aircraft should be "scrubbed" and treated to enable them to carry out nonemitting, nonreflecting operations. Second, MAC aircraft should be equipped to detect all enemy emissions in the electromagnetic spectrum windows. Third, sensors, avoidance systems, and countermeasures that are selected for transport use should be of modular construction to allow for preplanned improvements. Finally, software should be made to carry the burden of a changing operational environment.

Another capability that would greatly enhance MAC's defensive posture against a broad array of threats is the ability to perform passive terrain-following, terrain-avoiding flight in all weather conditions. Technology has now made this possible and MAC should take advantage of it.

Candidate self-protective systems that conform to the airlifter's task hierarchy while exploiting passive, low-altitude flight are grouped here by threat and include:

1. Self-protection against small arms.
    - (a) Passive TF/TA navigation system.
    - (b) Blinding laser.
2. Self-protection against IR missiles.
    - (a) Passive TF/TA navigation system.
    - (b) Silent attack warning system.
    - (c) Missile warning receiver.
    - (d) IR decoy system.
    - (e) Missile "break" maneuver.
    - (f) Engine-exhaust armor.
3. Self-protection against small, laser-guided missiles.
    - (a) Passive TF/TA navigation system.
    - (b) Laser energy detector.
    - (c) Blinding laser.
    - (d) Optical chaff.
4. Self-protection against radar systems.
    - (a) Radar threat-avoidance system.
    - (b) Passive TF/TA navigation system.
    - (c) Stealth treatment.
        - (1) Retinyl Schiff base salt paint.

(2) Lockheed graded dielectric skin.
(d) Electronic countermeasures.
(e) High-speed antiradiation missile.

5. Self-protection against airborne interceptors.
   (a) Radar threat-avoidance system with splash track.
   (b) Passive TF/TA system.
   (c) Silent attack warning system/infrared search and track system.
   (d) Blinding laser/rangefinder.
   (e) Copperhead-type system.
   (f) Sidewinder missile.
   (g) Air-to-air high-speed antiradiation missile.
6. Self-protection against radar missiles.
   (a) Radar threat-avoidance system.
   (b) Passive TF/TA navigation system.
   (c) Towed-decoy ECM system.
   (d) Chaff dispenser system.
7. Self-protection against directed-energy weapons.
   (a) Cockpit vision protection.
   (b) Laser shield.

Despite the array of threats facing airlift aircraft, each threat has weaknesses and ready countermeasures that airlifters can exploit. Therefore, it is technically feasible to provide transports with self-protective systems.

Economic Realism

By linking missions, aircraft, threats, and solutions, part III developed category 1 and category 2 threat defenses. Proposed category 1 threat defenses for all MAC aircraft would consist of a missile warning receiver, a missile "break" maneuver capability, a flare dispensing system, a laser energy detector, a blinding laser, and engine-exhaust armor/shielding. Proposed category 2 threat defenses for C-17s, C-130s, and airdrop C-141s would consist of category 1 threat defenses, a passive TF/TA navigation system, stealth treatment, a radar threat-avoidance system, a towed-decoy ECM system, a silent attack warning system, chaff and expendable decoys, a blinding laser/rangefinder, cockpit vision protection, laser shield armor, and lethal defense to include the Sidewinder, HARM, and Copperhead-type missiles.

If C-5s and airland C-141s get category 1 defenses plus radar threat-avoidance systems and C-17s, C-130s, and airdrop C-141s get category 2 threat defenses, the total cost comes to \$2.13 billion. To assess the affordability of this option, it is necessary to compare this cost with alternative courses of action, in particular the cost of doing nothing.

Using the *C-17 Defensive Systems Study* methodology, various system losses were projected over European and Southwest Asian scenarios. From this effort it was determined that C-17 loss avoidance alone, compared to doing nothing, would pay for equipping the MAC inventory and that loss avoidance for C-5s, airland C-141s, C-130s, and airdrop C-141s each more than compensated for their individual equipage with self-protective systems.

The trap in relying on a cost-effectiveness study of this nature is that it becomes irrelevant when war occurs and national survival is at stake. Since US national security strategy requires survivable airlift, the Air Force must recognize now that adoption of inadequate alternative measures, which leave airlift vulnerable, will produce wartime costs that are too high, no matter how many peacetime dollars are saved. After a war starts, it may well be too late to take corrective action. Therefore, self-protective systems for airlift are affordable.

Recognizing the need to spread out program costs into manageable bites, the study offered several schemes to delay costs: normal peacetime versus contingency and wartime needs, front-end loading of systems with multipurpose capabilities, strap-on and partial outfitting, and neglecting aircraft that will leave the inventory over the midterm. Each scheme was shown to be successful in delaying acquisition and installation costs.

Discriminating between normal peacetime versus contingency and wartime needs produced three acquisition periods. Short-term costs were $450 million, intermediate-term costs were $250 million, and long-term costs were $1.66 billion.

Front-end loading the acquisition with systems that fulfill multiple roles and incrementally adding the remaining systems in subsequent periods increased the acquisition periods to five. The core system purchase totaled $410 million and augmenting periods one through four totaled $292 million, $1.24 billion, $390 million, and $40 million, respectively.

Strap-on and partial outfitting strategies were shown to have drawbacks that tend to negate their use in equipping aircraft with defensive systems. For example, strap-on is a good concept if 100 percent of the aircraft that need the system are covered and the system can be installed in a timely fashion. Problems arise when strap-on is combined with partial outfitting to fulfill missions that are not limited, are not predictable, cannot be covered logistically, and cannot be flown according to doctrine when required. Strap-on concepts would work well with some of the defensive systems offered here, but since 100-percent outfitting is recommended, no acquisition cost would be saved. Partial outfitting of defensive systems would create doctrinal problems and is not recommended.

Neglecting airland C-141s (assuming insufficient air-frame life) and all C-130s (assuming unsupportable systems) in the front-end loaded solution creates significant savings. The core purchase is reduced to $190 million and the four augmenting periods are reduced to $130 million, $530 million, $160 million, and $20 million, respectively. In addition, other concepts to further delay costs could be developed.

If the reader is still tempted to say that the United States cannot afford self-protective systems for airlift aircraft, the author asks what is affordable. Can the United States afford to buy more airlift aircraft to compensate for attrition? Can it afford the reorganization of joint and Air Force doctrine and forces to insulate transports from the threat? Can the United States afford to change national security strategy by defending interests closer to home? Or can the United States afford to do nothing and hope that airlift will not be required to do its toughest missions?

Given the costs associated with alternative strategies and doctrines and the risk and cost associated with doing nothing, it is clear that the suggested defensive systems are affordable for each aircraft in the inventory. From the options offered, it is equally clear that acquisition and installation costs can be reduced to fiscally manageable increments. Therefore, it is economically realistic to equip airlift aircraft with self-protective systems.

Recommendations

1. AFM 1-1, *Basic Aerospace Doctrine of the United States Air Force*, should be updated to include direct delivery and its effects on airlift.

2. Airlift operational doctrine (AFM 2–XX) should address joint suppression of enemy air defenses, self-protection, airlift without air superiority, AirLand Battle, and electronic combat.

3. MAC and USTRANSCOM should revisit the *Congressionally Mandated Mobility Study* to show what the real airlift requirement is, especially with regard to realistic attrition.

4. All large MAC aircraft should be equipped with category 1 threat defenses now to cope with normal peacetime threats.

5. MAC aircraft assigned to employment and forward sustainment missions should be equipped with category 2 threat defenses.

6. MAC should ensure that systems being developed for MAC aircraft cover the electromagnetic spectrum windows to provide threat avoidance and countermeasures. Cast-off systems, such as the AN/ALR-69 RHAW set, are, unfortunately, obsolete on several scores.

7. Existing MAC aircraft should be studied and scrubbed to permit strict emission control when required.

8. A similar study effort should be undertaken to identify locations on MAC aircraft suitable for stealth paint and skin treatments.

9. MAC should ensure that threat-avoidance systems developed for its aircraft have suitable cockpit displays to predict and facilitate a no-detection flight path, if avoidance is possible; to activate appropriate ECM responses, if detection is unavoidable; and to predict and facilitate a minimum resistance flight path, if penetration is required.

10. MAC ECM equipment will need and should have both noise- and deception-jamming capability.

11. Design criteria for MAC ECM equipment should emphasize integrated system operations with the ability to detect and respond to threats without prior knowledge of threat operating parameters. That is, system characteristics should include coverage of the electromagnetic spectrum windows to the maximum extent possible, modular hardware design, and software that carries the operational burden.

Epilogue

A portion of this study effort concentrated on the evolution of US military airlift, intending to show how informal doctrine can shape an organization. In this case, the "Hump" and Berlin airlift served as powerful role models for airline-type operations and the Military Airlift Command is still transitioning from that tradition to the combat airlift role required by current national security strategy. Reflecting on MAC history, the author has realized that the question of how MAC got behind was interesting, but it is not nearly as important as keeping MAC from getting behind again. In pondering that issue, two subjects surfaced repeatedly: doctrinal debate and organizational "machinery."

Doctrinal Debate

Discussing doctrine in the Air Force has fallen out of vogue. Doctrine is all too often confused with dogma and the sorts of things that go on behind the Iron Curtain. Moreover, it is not "macho" to bring up the subject, and when it is brought up, eyes begin to glaze over. These attitudes must change.

The US Army's approach to doctrine is considerably different and has repeatedly spawned innovative concepts that have captured center stage. AirLand Battle, Follow-On Force Attack, and Army 21 are a few examples. Two factors seem to have greatly contributed to these results – the high level of the Army's Training and Doctrine Command (TRADOC) and Doctrine Review Advisory Group (DRAG) procedures. The effect of TRADOC's position in the Army's organizational structure is self-explanatory, but DRAG procedures may be unfamiliar territory for Air Force personnel.

In the Air Force a single general officer can kill a budding doctrinal concept, regardless of its merits. DRAG procedures ensure against that happening in the Army. When an idea is nominated to become doctrine, it is circulated for review and comment. If substantive negative arguments are not registered, a DRAG board consisting of select commanders is scheduled. Every attendee at a DRAG board is expected to voice his or her reservations. Silence is interpreted as acquiescence. The TRADOC commander, presiding over the DRAG board, weighs the pros and cons of the arguments and decides to send the idea back to the drafting board or to publish it as a draft field manual.

If published as a draft field manual, it is distributed to field units to test over a one-year period. Units are encouraged to experiment with the concept during training exercises and maneuvers. After a year, a DRAG board is convened to evaluate the draft doctrine. If no significant faults are found, the draft doctrine becomes official doctrine. Free-spirited debate is encouraged throughout the cycle and progress or lack thereof is visible.

The Air Force and MAC would benefit from such doctrinal debate. The potential for synergistically enhancing professional thought, the MAC Warrior Program, and even pilot retention is significant.

Organizational Machinery

The author's second recurring idea was that MAC needed an organizational structure to drive technology development into productive channels for airlift, to acquire that technology in the form of useful systems, and to train operators to employ it. Too often the development of technology is disproportionately shaped by the originating agency or the office with the biggest budget to the detriment of other users. This need not be the case. Commands with sporadic and generally limited developmental programs, as MAC historically has had compared to Tactical Air Command and Strategic Air Command, can still have a say.

In view of the discussions of doctrinal debate and organizational machinery, the author makes the following recommendations (numbered in sequence with the earlier recommendations).

12. MAC should encourage doctrinal debate within the command by establishing DRAG-type proceedings.

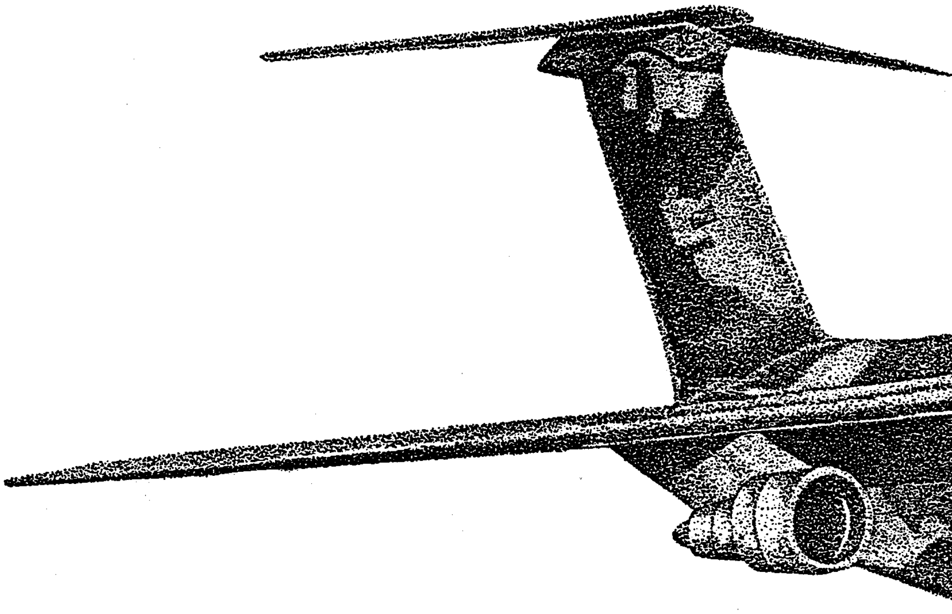
13. MAC should broaden the charter of its staff technology office (including the creation of a chief scientist position) to control study money for finding emerging technologies applicable to MAC's mission; to increase contact with government, industry, and academic research institutions; to keep needs before those same research organizations; and to monitor SDI program "spin-off" technologies.

14. MAC should broaden the charter of its analysis and advisory group to include wargaming and quantifying the benefits of self-protective technologies, such as equipping transports with air-to-air missiles, towed decoys, and unducted fan engines. The group should also prototype and fly in joint

exercises (i.e., Red Flag and Green Flag) emerging technologies that could favorably influence MAC operations.

15. MAC should create electronic combat offices in the Directorate of Tactics and Special Operations (DOX) and the Directorate of Operational Requirements (XPQ) to facilitate a total force transition to electronic combat. These offices should help MAC expand into emission control, low-probability-of-intercept communications, stealth modifications, antivision technologies, and electro-optical defenses, and they should manage the acquisition of and training in new electronic combat systems.

16. MAC should develop an electronic combat course, perhaps under the auspices of the Airlift Operations School, the Combat Aircrew Training School, or the replacement training units at Altus AFB, Oklahoma, and Little Rock AFB, Arkansas, to instill a minimum level of warfighting expertise among MAC officers and senior NCOs.



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