AIR COMMAND AND STAFF COLLEGE

AIR UNIVERSITY

A NEW AGE FOR AEROSTATS:

PROVIDING AIRFIELD-CENTRIC MANPADS DEFENSE FOR CIVIL AIRCRAFT SUPPORTING MILITARY OPERATIONS

by

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ABSTRACT

Both the U.S. and its allies have increasingly relied upon civilian transport aircraft, such as the Civil Reserve Air Fleet (CRAF), to augment organic military airlift. However, the widespread proliferation of Man Portable Air Defense Systems (MANPADS) poses a significant threat to unprotected civilian aircraft. Previous research focused on installing the military's counter-MANPADS systems, such as Infrared Countermeasures (IRCM), on civilian aircraft. However, the unique CRAF operating environment makes such an aircraft-centric approach economically unfeasible. Instead, future counter-MANPADS programs should shift focus from protecting individual aircraft to an area-wide system that protects entire airfields. Aerostats possess unique capabilities that enable them to provide an area-wide counter-MANPADS defense using existing IRCM technology.

Table of Contents

Illustrations

Biography

Maj Justin Riddle, USAFR, is a graduate of Air Command and Staff College, Class of 2010. Previously, he served as the Chief of Training, 326th Airlift Squadron, Dover AFB, Delaware. He also completed tours at Charleston AFB, South Carolina and Altus AFB, Oklahoma.

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Introduction

Since the end of the Cold War, the U.S. and its NATO allies have adopted increasingly expeditionary capabilities that depend extensively upon air mobility. In addition to traditional military aircraft, both the U.S. and NATO also rely upon civilian contract air carriers. For instance, the U.S. Civil Reserve Air Fleet (CRAF) performs both day-to-day channel airlift as well as wartime surge operations such as the troop buildups prior to Desert Shield and Iraqi Freedom.[1] Likewise, NATO recently adopted a Strategic Airlift Interim Solution (SALIS) program in which NATO leases civilian aircraft to fulfill its airlift needs.[2] Unfortunately, the growing reliance upon civilian airlift may expose an *Achilles heel* in the fact that civilian aircraft are vulnerable to surface-to-air missile attack. In 2003, U.S. Secretary of State Colin Powell proclaimed: "no threat is more serious to aviation than lightweight, guided, portable surface-to-air missiles."[3]

Imagine a scenario in which U.S. and coalition troops must respond to military aggression and a humanitarian crisis in Darfur. Months of tenuous negotiations result in the deployment of 30,000 peacekeepers in an attempt to stabilize the region. Following the model of previous large-scale deployments, several civilian airlines operate under various provisions to supplement military aircraft and fly troops and equipment to staging bases located near the defined area of operations. Unlike previous campaigns, our adversaries orchestrate a coordinated attack against three civilian airliners carrying allied troops and equipment, thus pre-empting the coalition's force build up. First, rebels use an SA-7 to severely damage a World Airways MD-11 flying into a U.N. staging base in Djibouti. Due to the loss of an engine and severely degraded flight controls, the aircraft experiences a hard landing just short of the runway; a post-crash fire kills 150 of its 250 passengers. Nearly simultaneously, another rebel cell uses a pair of SA-14

shoulder-launched missiles to destroy a United Airlines 777 carrying nearly 300 soldiers into a staging base in Aswan Egypt. Finally, still within minutes of the original attack, another cell employs two SA-16 missiles to shoot down a Volga-Dnepr An-124, leased by NATO, as it attempts to land in Khartoum. Within hours of the attacks, civilian airlines withdraw from existing contracts, citing their pilots' refusal to fly into hostile territory, and more importantly, their aircraft insurers' refusal to pay for any aircraft damage resulting from "acts of war." Spending a mere $43,000 ($1,500 for each SA-7 and $10,000 for each SA-14 and SA-16) yielded the rebels a disproportionate return on their meager investment.[4] They didn't merely shoot down three aircraft -- they killed hundreds of coalition soldiers, shattered public support, and disintegrated the coalition's ability to conduct expeditionary operations.

Fortunately, such an event has not occurred yet. Although commercial and military airlift endure several threats ranging from small arms to hijacking and bombing, this paper focuses on the MANPADS threat to airlift, and in particular, civilian airlift conducted on behalf of a military organization. Unlike unprotected civilian aircraft, military transports have received sufficient defensive system upgrades, such as flares and Infrared Countermeasures (IRCM). Although some studies recommend installing IRCM on civilian aircraft, it is not a cost-effective method of protecting an immense civilian-owned airlift fleet. Instead of aircraft-specific countermeasures, future initiatives should focus on airfield or area-specific anti-MANPADS countermeasures to better protect civilian aircraft flying military charter missions.

The Civil Reserve Air Fleet

In addition to the military's C-5, C-17, and C-130 transports, America's expeditionary capabilities also rely upon civilian carriers. In fact, a 1995 *Airpower Journal* article by Robert Owens claims, "the central tenet of airlift policy is that the commercial airline fleet is the heart of

the national airlift fleet."[5] Under the provisions of the Civil reserve Air Fleet (CRAF), civilian airlines commit a certain number of aircraft for possible Department of Defense (DOD) requirements and in return the DOD provides a pre-determined share of peacetime passenger and cargo business.[6] The CRAF fleet is much larger than the U.S. military airlift fleet, consisting of 1,240 total civilian aircraft.[7] These aircraft are allocated as follows: 512 passenger long-range international, 312 cargo long-range international, 50 aeromedical evacuation, 245 passenger short-range international, 11 cargo short-range international, 36 domestic, and 4 assigned to augment Alaskan transportation.[8] Thus, the military can tap in to vast airlift resources in time of need without having to manage and maintain such a huge fleet during peacetime. In fact, Robert Owens contends that the CRAF arrangement is 6-8 times less costly than maintaining and equivalent military fleet.[9]

CRAF aircraft are traditionally utilized in two manners. The first is "stage activation" in which the U.S. Transportation Command (USTRANSCOM) Commander obtains Secretary of Defense approval to activate increasing percentages of the CRAF, ranging from Stage I (Regional Crisis), Stage II (Theater Crisis), or Stage III (Nationwide Mobilization).[10] In this manner, CRAF has been officially activated twice in its 57-year history. The first was a passenger Stage I and cargo Stage II Activation for Desert Shield/Storm (August 1990 through May 1991), and the second was a Stage I Activation for Operation Iraqi Freedom (February through June 2003).[11] During Desert Shield/Storm, CRAF flew 60% of passengers and 27% of cargo during the deployment and 84% of cargo and 40% of passengers during redeployment.[12]

Despite the limited number of formal CRAF activations, the DOD has dramatically increased its use of civilian aircraft in recent years. In 1998, the CRAF consisted of 657 aircraft; today, there are nearly twice as many CRAF aircraft.[13] Even prior to the terror attacks of 2001,

Air Mobility Command (AMC) has been slowly shifting routine cargo missions from military to civilian aircraft. For instance, from 1981 to 1999, CRAF cargo aircraft experienced an average annual growth rate of 7% per year and by 1999, civilian aircraft transported 41% of channel (non-contingency) cargo.[14] Since the events of 2001, CRAF responded to a five-fold increase in cargo and passenger airlift needs at a cost of approximately $2.5B per year.[15] Even following the brief CRAF activation in 2003, a Congressional Research Service report illuminated the fact that civilian airlines doubled the amount of troops transported overseas between January 2004 and January 2005.[16] Moreover, in 2006, the DOD initiated a program aiming to deliver 20% of DOD cargo to Afghanistan and Iraq via CRAF aircraft.[17] As of May 2009, USTRANSCOM plans on 40% of cargo and 90% of passengers to move via CRAF aircraft.[18] In fact, USTRANSCOM Commander General Duncan McNabb points out that CRAF currently accounts for up to half the nation's strategic airlift capability.[19] As such, CRAF and its civilian aircraft are a strategically important part of our nation's defense even though they might not be formally activated.

Unique CRAF Operating Environment

Although immensely important, CRAF aircraft operate in a unique environment differentiating them from both military and "fully" civilian aircraft. Even though civilian companies typically insure CRAF aircraft, the DOD works with the Federal Aviation Administration (FAA) to provide additional war-risk insurance when commercial insurance is unavailable.[20] This is because most civilian insurance carriers will not fully reimburse combat related damages. However, CRAF carriers claim that the program is underfunded and bureaucratically unwieldy.[21]

Due to the nature of DOD airlift, CRAF aircraft have lower utilization rates than their civilian counterparts. For instance, CRAF cargo aircraft fly an average of 195 hours per month,

while non-CRAF civilian cargo aircraft fly 360 hours per month; lower CRAF utilization rates make it harder for CRAF operators to invest in new aircraft or existing aircraft upgrades.[22] On behalf of the National Air Carrier Association, Robert K. Cortez, Chairman of Omni Air International (a CRAF carrier), testified before the U.S. Congress in 2009. Cortez stressed the difficulty of operating in the unique and extremely cost-sensitive CRAF environment.[23] In particular, he cited that CRAF carriers couldn't afford to conduct high capital investments on their older aircraft fleets because the nature of CRAF results in lower fleet utilization and longer economic breakeven points.[24] As such, it is impractical to expect CRAF carriers to fund their own MANPADS countermeasures.

Finally, CRAF aircraft and their crews are vulnerable to threats associated with flying into and near combat zones. A RAND study of the first Gulf War reported, "morale suffered [and] volunteerism fell" in response to Iraqi Scud missile attacks on Riyadh and Dhahran, Saudi Arabia. The RAND study concluded, "because crews fly voluntarily, any real unease over personal safety could significantly impact crew availability."[25] Scud missiles constituted a perceived threat in 1990-1991. However, the proliferation of MANPADS, as discussed in the next section, will likely threaten future CRAF operations.

The MANPADS Threat to Civilian Aircraft

As of 2004, the U.S. General Accounting Office (GAO) estimates that there are between 500,000 and 750,000 MANPADS in service throughout the world.[26] A subsequent GAO report concluded that approximately 1% of all MANPADS – up to 7,500 missiles – are outside of government control.[27] Moreover, thousands of additional missiles under the control of nefarious governments still find their way into the hands of rebel groups and terrorist organizations.[28] Such significant proliferation means that the MANPADS threat is worldwide in scope.

This extensive MANPADS proliferation combines with their relative ease of use to create an inexpensive asymmetric threat to aviation. It remains important to note that a MANPADS engagement requires nothing more than a missile, a target aircraft, and a person to pull the trigger. MANPADS do not require a centralized command and control structure, sophisticated radar tracking, night vision devices, or extensive training to employ.

One need not look far to find examples of MANPADS missile attacks against undefended civilian aircraft. Since the 1970s, the U.S. State Department claims that MANPADS attacks hit 40 civilian aircraft and killed 859 people.[29] Furthermore, a GlobalSecurity report finds that civilian aircraft have a 70% probability of being destroyed after a MANPADS hit.[30] In fact, our fictitious example in Africa becomes quite plausible when viewed against historical attacks.

The hypothetical scenario in Rwanda is not far from the truth. According to Jeff Abramson, Deputy Director of Arms Control Association, Zimbabwe Peoples Revolutionary Army rebels used a shoulder-fired missile to shoot down an Air Rhodesia flight that carried both the Rwandan and Burundi national leaders in 1978.[31] Abramson further points out that the MANPADS attack served as a catalyst for a subsequent war that killed over 800,000 Rwandans.[32] In December 1998 and January 1999, MANPADS attacks destroyed two United Nations (UN) C-130 aircraft in Angola, killing 23 people.[33] In November 2002, terrorists attempted to destroy an Israeli chartered Boeing 757 while departing Mombasa Kenya.[34] In this incident, rebels shot two SA-7 MANPADS at a 757-300 carrying 261 passengers and 10 crewmembers; fortunately, the relatively old SA-7s missed their target.[35] More recently in March of 2007, bandits shot down a civilian IL-76 in Mogadishu Somalia, killing all 11 occupants.[36] Interestingly, the UN chartered this IL-76 to carry humanitarian cargo in support of peacekeeping operations in Somalia.

The MANPADS threat is not limited to Africa. Terrorist groups have also used MANPADS in Nicaragua, Costa Rica, Vietnam, Georgia, Azerbaijan, and Afghanistan.[37] In New York, officials arrested three Americans and one Haitian, allegedly tied to a Pakistani Jihadist group, after attempting to purchase MANPADS in May 2009.[38] To date, no aircraft have been attacked by MANPADS on American soil.

In November 2003, terrorists attacked a Belgian-registered DHL Airbus 300, carrying DOD mail, as it departed Baghdad climbing through 8000 feet.[39] Despite massive damage, the aircraft safely executed a crash landing and all three crewmembers survived. The timing of the DHL attack was particularly noteworthy, as it occurred in November of 2003 – several months after President Bush declared the end of major combat operations in Iraq (May 1, 2003). Although the DOD acknowledges that it does not intend to fly civilian aircraft into dangerous situations, Thomas Zoeller (Chairman of the National Air Carrier Association), points out that MANPADS remain significant threats to civil aircraft operating in areas deemed safe.[40] Thus, the DHL incident represents a case in which a civilian aircraft, operating in the growing gray area between "combat" and "non-combat," suffered a MANPADS attack.

MANPADS Implications for NATO Allies

The U.S. is not the only nation that relies upon civilian aircraft to support military operations. NATO and the European Union suffer even greater reliance upon civilian transport aircraft. Since coalition and NATO operations are increasingly common and likely to remain so, this paper briefly addresses our allies' military airlift shortage.

The 1999 Helsinki Headline Goal stated that by 2003, the European Union (EU) should be able to deploy 50 to 60 thousand troops within 60 days and sustain them for a year.[41] Likewise, a 2002 NATO summit in Prague called for the formation of the expeditionary NATO

Response Force (NRF), consisting of 25,000 multinational forces that could be deployed within five days.[42] Unfortunately, EU and NATO airlift capabilities fall well short of those requirements. A 2005 NATO Joint Air Power Competence Centre study, conducted by Italian Colonel Carlo Massai, concluded that most NRF equipment can't fit into existing C-130 or C-160 transports and that NATO needs more oversize airlift capability.[43] Furthermore, he projects that the capability gap will exist until approximately 2015 when Airbus A400Ms should be available in sufficient numbers to move some oversized equipment.[44]

Massai's sentiments were in line with a previous 1999 NATO Washington Summit that identified a European shortfall of 19 strategic lift aircraft.[45] As a result, NATO adopted two simultaneous initiatives. First, NATO's Strategic Aircraft Interim Solution (SALIS) consists of 18 chartered Russian and Ukranian An-124 aircraft (C-5 equivalent).[46] Because of high demand for these aircraft in Afghanistan, the existing contract has already been extended until 31 Dec 2010 with option to further extend until 31 Dec 2012.[47] However, the Volga-Dnepr contract constrains that its defenseless An-124s may fly "only to non-hostile environments, and strictly for humanitarian assistance purposes."[48] As the 2003 DHL incident in Baghdad shows, distinguishing between hostile and non-hostile environments may be quite difficult at best.

In addition to SALIS, NATO has also embarked on a Strategic Airlift Capability (SAC) program, which was first announced in September 2006.[49] This program, unlike SALIS, will provide Europe with organic heavy lift military transport aircraft. Through an innovative consortium of European nations, 13 NATO and 2 Partnership for Peace nations have purchased three brand new C-17 aircraft based in Papa Hungary.[50] International crews operate these aircraft in support of national, NATO, EU, or UN missions.[51] Although this represents a slight

improvement in NATO's strategic airlift shortfalls, it does fully close the airlift gap. Thus, NATO remains dependent upon civilian airlift.

Current MANPADS Mitigation Efforts

To understand current methods of defeating MANPADS, one must have an understanding of a basic shoulder-launched MANPADS engagement. First, shooters on the ground must visually acquire the target aircraft. Next, they must arm their battery-powered missiles, activate the missile's infrared (IR) seeker head, and lock onto an IR source emanating from the aircraft (typically aircraft engines). Next, they launch the missile provided that the aircraft if it is within the specific missile's operating envelope. From that point, the missile's onboard seeker head constantly monitors the target's IR energy. As the target maneuvers or the missile veers off course, the target's IR energy will deviate away from the center of the seeker head's field of view.[52] Consequently, the seeker head directs the missile to maneuver to keep the target's IR energy centered in the seeker head, and the missile continues to home to its target.[53]

There are numerous MANPADS mitigation efforts currently underway, ranging from improved airport security, counter-proliferation, aircraft hardening, and improved aircrew tactics. First, the U.S. Transportation Security Administration (TSA) has conducted MANPADS vulnerability assessments at 400 U.S. airfields.[54] Furthermore, the TSA maintains MANPADS mitigation plans for those airfields and an additional 23 overseas locations as of 23 July 2009.[55] Although this approach likely improves security at participating airfields, it does nothing to mitigate MANPADS threats at non-participating airfields likely to be used for future military operations.

A second mitigation effort is counter-proliferation; the U.S. is already conducting a counter-MANPADS campaign consisting of multilateral MANPADS export control

agreements.[56] Along those lines, the U.S. State Department seized over 21,000 MANPADS to date, supposedly making illicit MANPADS acquisition more costly and difficult.[57] However, in 2003, over 4,000 Iraqi MANPADS were lost following the collapse of Saddam's regime.[58] Coalition soldiers attempted to limit the supply of Iraqi missiles by actively purchasing several hundred MANPADS. Despite a multitude of counter proliferation efforts, missile prices remain low, ranging from $1,500 for a complete SA-7 to $10,000 for a complete SA-14 or SA-16.[59] First Generation missiles such as the SA-7 lack "all aspect" capabilities, cooled seeker heads, and flare rejection technology found on the more capable Second and Third Generation SA-14 and SA-18 missiles.[60] Also, Third Generation MANPADS have more robust seeker head scanning techniques.[61]

A third mitigation focus involves improved aircrew approach and departure tactics and new air traffic control procedures to minimize the time that aircraft remain within the MANPADS weapons engagement zone. In general, most shoulder fired MANPADS have a range of approximately 4 miles and operate up to 20,000 feet.[62] Thus, it may be possible to minimize exposure to possible missiles by minimizing the amount of time spent below 20,000 feet, particularly during approach and departure. A recent article in the *American Institute of Aeronautics and Astronautics Journal* concludes that revised air traffic control procedures and pilot techniques reduces an aircraft's MANPADS vulnerability footprint from 154 square miles down to approximately 60 square miles.[63] Although an improvement, aircrews must still find other means of mitigating the threat in the smaller geographic area. Moreover, the article did not assess the new tactics in terms of air traffic control flow and ability to rapidly reroute aircraft in and around dynamic combat airspace as found in Iraq and Afghanistan.

A fourth mitigation effort lies in aircraft vulnerability reduction; this approach aims at making aircraft more survivable after getting hit. In 2004, the USAF and NASA collaborated on a project assessing civilian aircraft MANPADS and electronic attack vulnerability.[64] They gathered infrared signatures of 737, 747, and 757 aircraft and tested commercial jet engines against missile hits. This study attempted to make aircraft more resilient through improved fire suppression, redundant systems, and fuel tank inerting systems designed to replace combustible fuel tank oxygen with inert nitrogen. However, such aircraft modifications are more suited towards new aircraft production instead of existing aircraft modification. Furthermore, in light of high operating costs and low utilization rates, CRAF airlines may resist hardening their existing aircraft even when technically feasible. In fact, a *Transportation Journal* article by Ira Lewis points out: "If [participation in] CRAF is going to cost the airlines money or business, carriers lose interest very quickly."[65]

A fifth method to deal with MANPADS is to equip aircraft with various systems designed to prevent missiles from hitting them. Traditional aircraft pyrotechnic flares decoy airborne missiles by mimicking the aircraft's infrared signature. Thus, it is possible for an aircraft to dispense flares in the hopes that the missile's seeker head tracks the flares instead of the actual aircraft. However, flares are not as effective against newer generation MANPADS that have better flare rejection capabilities and more advanced seeker head scanning technology.[66] Despite this limitation, the Israeli Aircraft System's "Flight Guard" has already been tested and installed on some civilian aircraft. However, Flight Guard has been banned in Switzerland and other European countries because of fears that dispensed flares could pose a fire hazard to cities and towns beneath the flight path of the aircraft.[67] Because flares are not as effective against

more modern missiles, and because flares are already banned in several countries, they are not a viable counter-MANPADS option for civilian cargo aircraft.

A sixth method, infrared countermeasures (IRCM), represents a more modern approach to defeating airborne MANPADS. While flares present "false targets" to a missile, IRCM uses directed electromagnetic energy (including lasers) to degrade or destroy an incoming missile's actual seeker head. According to the Federation of American Scientists, IRCM technology involves directing an intense energy beam at the missile's seeker head; this beam fools the seeker head into thinking it is off course.[68] The IRCM continues directing the energy beam at the missile until it no longer possesses a threat to the aircraft. Examples of this technology includes the DOD's AN/AAQ-24 Large Aircraft Infrared Countermeasures systems (LAIRCM). This system is installed on numerous military aircraft, such as the C-17. Stemming from the DOD's AN/AAQ-24 system, many civilian corporations have built similar technology designed solely for commercial use.

According to Saab, a manufacturer of one such civilian system, modern IRCM systems are all-weather capable, can simultaneously defeat multiple threats, weighs as little as 200 to 500 pounds, and operate with existing 26 to 28 volt aircraft electrical systems.[69] Furthermore, the Saab CAMPS system offers 360 degrees of lateral coverage, detects missile launches within a 110-degree conical field of view, and can target incoming missiles provided that the missile remains within plus or minus 30 degrees in elevation.[70] Figure 1 provides a graphical depiction of the Saab CAMPS system's ability to detect a MANPADS launch, and Figure 2 provides a graphical depiction of the CAMPS system's ability to defeat an incoming missile.

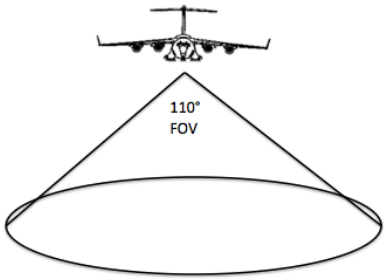

Figure 1. IRCM missile detection field of view. Figure not drawn to scale. This represents the area that a single IRCM sensor scans to detect missile launches. Multiple missile detection sensors greatly increase the entire system's field of view to eliminate any blind spots.

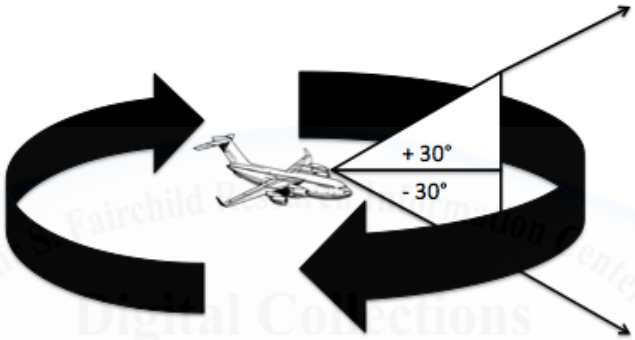

Figure 2. Representative IRCM missile engagement field of view. This figure (not drawn to scale) represents the area protected by a single turret capable of swiveling 360 degrees and providing plus or minus 30-degree elevation coverage. For maximum protection, some aircraft use multiple turrets to eliminate gaps in directed energy coverage.

Many other companies have also developed IRCM technology. For instance, Northrop Grumman installed its Guardian IRCM prototypes, derived from similar USAF IRCM systems, on 10 of FedEx's MD-10 cargo aircraft.[71] Similarly, American Airlines installed BAE's JetEye system on some of its 767 airliners.[72] BAE's commercialized version consists of 12 line replaceable units (LRUs) and a directed energy laser turret mounted in an external canoe-shaped pod. BAE's commercial system is based off the US Army Advanced Threat Infrared Countermeasures Program (ATIRCM).[73] Similarly, BAE created their MATADOR system designed to work on smaller business jets.[74] The MATADOR system only weighs 200 pounds

and requires an additional 200 pounds of interface hardware; furthermore, it requires only 7.5 KVA of electrical input. For comparison, modern aircraft electrical generators routinely generate 45 to 90 kVA per engine.

Despite IRCM's high potential, it also has noteworthy downsides. First, civil testing is not complete. Early tests showed that systems broke after only 300-400 hours of use – the equivalent of only two months flying time for most CRAF aircraft.[75] Second, IRCM systems are very expensive; even assuming full rate production and economies of scale, building 1,000 units would still cost $1 million per aircraft.[76] Finally, General Duncan McNabb, USTRANSCOM Commander, proclaimed in June 2009 that, "commercial aircraft ferrying Defense Department personnel and cargo into danger zones like Iraq have no need for onboard surface-to-air missile defenses."[77] His rationale was simple: such systems are extremely expensive and require extensive aircrew training. Although General McNabb did not elaborate, CRAF aircrews would likely require classified threat identification and reaction training and aircraft-specific tactical approach and departure training.

Future Methods to Counter MANPADS

Because of the limitations of existing systems, civilian aircraft require alternative counter-MANPADS programs. Thomas Zoeller, president of National Air Carrier Association, advocates an alternate allocation strategy for existing IRCM technology. He recommends a pilot program to investigate a portable counter MANPADS shared use system that would be owned and managed by the DOD and installed on CRAF aircraft only on higher risk missions.[78] Thus, DOD personnel could prioritize civilian aircraft and install the portable IRCM system on the most appropriate missions. Zoeller contends that such a system would cost approximately $20 million.[79] Zoeller's approach remains technically feasible. However, the relatively low utilization

rate of CRAF aircraft makes this approach economically unpalatable. Moreover, USAF reluctance to install any missile defense equipment on civilian aircraft makes this option unlikely.

The U.S. Department of Homeland Security (DHS) adopted another variation of existing IRCM technology. DHS Project CHLOE integrates existing IRCM technology onto a high-altitude unmanned aerial vehicle (UAV) platform.[80] According to Kerry Wilson, Project CHLOE Program Manager, the combination of IRCM and UAVs provides a persistent (day, night, all weather), high-altitude (broad area coverage from 65,000 feet), autonomous, single platform capable of protecting a large geographic area. Project CHLOE not only aimed at protecting aircraft from the very real MANPADS threat, but it also integrated maritime and border patrol surveillance sensors. Moreover, CHLOE involved a real-time interface with air traffic control and law enforcement officials.

Although Project CHLOE is in its infancy, it has already identified a few challenges that must be overcome.[81] First, atmospheric disturbances limit long-range launch detection ability. Second, the limited number of available UAV platforms hampered Project CHLOE testing. Finally, critics argue that Project CHLOE could not possibly achieve large enough implementation to protect all U.S. commercial traffic.[82] Despite this criticism for its limited potential as a nation-wide system, Project CHLOE's technology seems feasible for employing in an airfield or area MANPADS defense role.

Aerostat Characteristics

Project CHLOE offers valuable insight concerning the ability to provide an airfield-centric approach, as opposed to existing aircraft-centric approaches. Along those lines, the DOD should take interest in developing a deployable airfield-centric counter-MANPADS system. For

instance, aerostats, deployable erected towers, or other aircraft could serve as platforms for a geographically-based IRCM system.

Of those, the aerostat holds the most potential as a viable solution, particularly in its ability to provide persistent airborne surveillance around a specific geographic area. Aerostats are lighter-than-air platforms that consist of an inflatable balloon-type surface that provides lift, a payload, and a mooring line that keeps the aerostat anchored to a specific location. A *Military Technology* article cites that aerostats make ideal electronic sensor platforms because of their inherent extended line-of-sight, long sortie duration, low acquisition and maintenance cost, large payload, and aerodynamic stability.[83] Moreover, a Congressional Research Service report specifically cites that aerostats have lower life cycle costs and longer dwell times compared to UAVs.[84] Thus, aerostats are an ideal platform for airborne electronic equipment such as IRCM.

TCOM is a civilian company that manufactures a wide variety of small, medium, and large aerostats that are currently used in military applications. According to TCOM, their 71M is an exceptional platform for large airborne electronic systems. In particular, the 71M offers continuous operations above 20,000 feet, uninterrupted mission times of 30 days, and secure fiber optic communications links to ground stations.[85] Moreover, the 71M is 71 meters long, can lift 3,500 pounds to 15,000 feet, offers 22 kVA of electrical power, and can operate in up to 70 knot winds.[86] According to Jodi Sokol, TCOM's Director of Business Development, all of their aerostat systems are deployable using standard sized shipping containers that fit in C-17 or C-5 aircraft.[87] Even their larger systems, such as the 74M, can be field assembled in 72 hours or less.[88] However, some large systems such as the 71M require a poured concrete foundation for the mooring mast.[89] Finally, their large aerostats already support 22 kVA electrical power, and

their mid-sized line (32M and 38M) are currently equipped with 5.5 kVA power systems that could be easily modified to provide the 7.5 kVA needed by some current IRCM systems.[90]

In other words, existing aerostats can easily handle the weight and sensor payloads associated with existing Northrop Grumman Guardian, BAE MATADOR, Saab CAMPS, or BAE JetEye IRCM systems. Thus, it remains plausible that existing IRCM equipment could easily be mounted on an existing aerostat, thus saving developmental costs and time.

Existing Aerostat Uses

Surprisingly, aerostats have been used for airborne surveillance operations for several decades. Since 1980, the TARS system (Tethered Aerostat Radar System) has already deployed along U.S. southern border and Caribbean to support counterdrug operations.[91] As early as 1996, TCOM 71M aerostats hoisted complex electrical radar equipment up to high altitude. The Joint Land Attack Cruise Missile Defense Elevated Network (JLENS) uses a 71M aerostat and airborne radar to track aircraft and cruise missiles at ranges up to 150 miles.[92] In addition to traditional search and tracking radars currently used by JLENS, the Army is developing an aerostat-based fire control radar that will guide an intercepting missile to defeat any incoming threats.[93] Thus, aerostats have the proven ability to carry and employ increasingly complex electrical equipment.

Although JLENS and TARS require rather large aerostats, other smaller aerostat systems have been specifically developed for rapid deployment directly into a combat zone. One such system is the Raytheon Rapid Aerostat Initial Deployment (RAID), which was fielded in 2003 and can lift a 91-kilogram payload up to 1,000 feet.[94] RAID aerostats typically remain airborne for five days and then require only a single hour of maintenance.[95] Similarly, Lockheed Martin's Persistent Threat Detection System (PTDS) can lift a 225 kg payload to 2,500 feet.[96] RAID and

PTDS were designed for improved base surveillance and not counter-MANPADS. However, they both represent rapidly deployable systems that have the potential for adaptation into counter-MANPADS roles.

Analysis

Although aerostats provide much promise regarding the future of implementing the first-ever area-wide IRCM system, they also have some downsides. First, aerostats impact Air Traffic Control (ATC) procedures since they are tethered to the ground and operate upwards of 20,000 feet. Despite this limitation, aerostats are already in use in and near runways in Yuma Arizona and Baghdad Iraq. Overcoming these ATC hurdles is possible by equipping aerostats with an air traffic control transponder, military IFF (Identification Friend or Foe), or civilian TCAS (Traffic Collision Avoidance Software). These systems would alert both air traffic control and other aircraft of the aerostat's presence. Furthermore, revised approach and departure procedures could ensure lateral and/or vertical separation between aircraft and aerostats. Air Force Manual 11-217 Volume 1 already provides insight pertaining ATC implications of vertical obstructions such as aerostats.[97] Specifically, ATC can vector aircraft no closer than 3 nautical miles (NM) of a fixed vertical obstruction provided that the obstruction is located within 40 NM of the actual radar antenna. If the obstruction is further than 40 NM from the radar station, then ATC can legally vector aircraft no closer than 5 NM from the obstruction.

Another limitation is altitude. Although larger aerostats are capable of reaching 20,000 feet, smaller ones generally operate at or below 5,000 feet. It has yet to be determined whether or not an IRCM system can effectively provide a large enough area of coverage when operating at lower altitudes. This is because operating at lower altitudes reduces the IRCM sensor field of view and increases ground clutter. Additionally, lower altitudes may hinder the detection of

missile launches as a result of terrain masking. Thus, providing true geographic counter-MANPADS coverage may ultimately require more than one aerostat mounted at various locations throughout the area. Figure 3 provides a simplified representation of an aerostat-based sensor coverage area for a single 110° field of view (FOV) sensor such as the Saab CAMPS system.

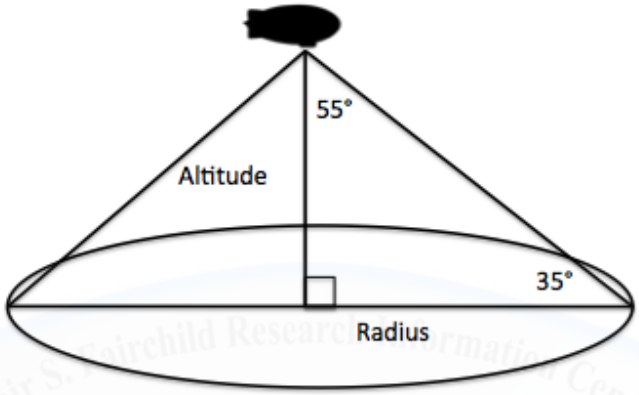

Figure 3. Geometric representation of aerostat coverage area (not to scale), assuming a single 110° sensor field of view.

It is possible to calculate the minimum effective coverage area for a single sensor with a known field of view and known operating altitude. It is important to note that the subsequent calculations assume a downward-looking sensor that operates orthogonally toward the surface of the earth. First, the known altitude and FOV are used to calculate the sensor's effective downward-looking radius as follows:

$$radius = altitude \times \tan\left(\frac{FOV}{2}\right)$$

And the protected area, in square nautical miles, is calculated as follows:

$$Area = \pi \times \left(\frac{radius(ft)}{6076\,{}^{ft}/_{NM}}\right)^2$$

Following this logic, one can calculate the theoretical protected area for a single downward-looking sensor operating at a known altitude. Table 1 depicts the results.

Altitude (ft)	FOV (degrees)	Radius (ft)	Minimum Protected Area (NM^2)	FOV (degrees)	Radius (ft)	Minimum Protected Area (NM^2)
1000	110	1428	0.17	179	1830	0.29
2000	110	2856	0.69	179	3661	1.14
5000	110	7141	4.34	179	9152	7.13
10000	110	14281	17.36	179	18305	28.51
15000	110	21422	39.05	179	27457	64.15
20000	110	28563	69.43	179	36610	114.05

Table 1. Relationship between altitude, FOV, and protected area.

Table 1 shows that sensor coverage is highly dependent upon sensor altitude. As depicted in Table 1, a single IRCM missile launch detection sensor does not provide much coverage until the sensor is elevated to at least 5,000 feet. Of course, this oversimplified arithmetic does not account for important factors such as terrain variations. Moreover, it fails to account for atmospheric disturbances such as ground clutter that would negatively affect sensor performance. Finally, it does not address cases in which sensors aim outward towards the horizon (as opposed to straight down towards the ground).

In addition to increasing altitude, adding additional overlapping sensors can also boost performance. Table 1 also shows the results of boosting orthogonal FOV from 110 to 179 degrees. It remains important to note that adding additional sensors will not just improve the ability to look "down" but more importantly, the ability to scan outward towards the horizon. Adding non-orthogonal (with respect to the ground) sensors will greatly increase the IRCM's effective radius. Overlapping sensors would be able to detect missile launches from horizon to horizon, beyond the figures published for the 179 degree FOV in Table 1. As such, Table 2 also includes a column depicting the distance between the sensor and the earth's horizon. This distance represents the maximum theoretical effective radius. Actual sensor performance will fall

between the two extremes. Unfortunately, unclassified or non-proprietary sensor information is not publicly available.

Altitude (ft)	Horizon Distance[98] (NM)
1000	37
2000	52
5000	83
10000	117
15000	143
20000	165

Table 2. Relationship of altitude and horizon distance.

In summary, an aerostat-based system should be capable of lifting existing sensors to approximately 5,000 feet. Moreover, the addition of an extra sensor greatly boosts performance, particularly if that sensor remains able to detect missile launches at longer range and more shallow launch angles. Furthermore, it verifies that an effective area-based IRCM system should contain multiple sensors with overlapping fields of view. Unfortunately, actual sensor performance is difficult to speculate, but will fall between the Radius depicted in Table 1 and the Horizon Distance in Table 2.

In addition to field of view limitations, aerostat-based IRCM systems also suffer from another important geometric limitation. Notably, existing aircraft-mounted IRCM systems direct their IR energy at missiles flying towards the specific aircraft. In other words, aircraft-mounted IRCM systems are designed to defeat missiles that expose their seeker heads to the targeted aircraft since the missiles fly towards the aircraft. On the other hand, an aerostat-based IRCM system is not necessarily the target of every missile launch. The worst-case scenario is one in which both the missile and targeted aircraft fly directly away from the aerostat. In that case, the aerostat-mounted IRCM system would not obtain a clear shot at the missile's seeker head. For

this reason, an area-based IRCM system must contain multiple IRCM installations. As a minimum, an airfield should have two overlapping aerostats. For instance, one aerostat could be tethered five miles from the approach end of the runway, and the other could be tethered five miles from the departure end of the runway. Furthermore, they should be sufficiently offset from runway centerline so that they do not impede approach procedures. Figure 4 provides a simplified depiction of a runway protected by two aerostats.

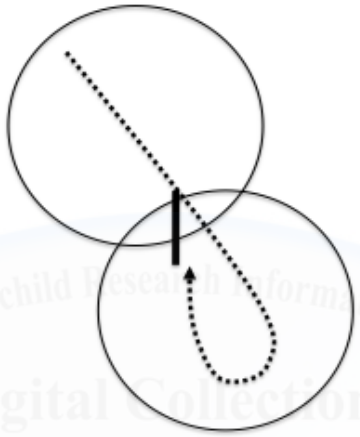

Figure 4. Two aerostat coverage area (not to scale). Notice that an aircraft's flight path could be tailored to optimized counter-MANPADS coverage.

Finally, because of their vital role in aircraft defense, aerostats may become targets for insurgents or other hostile forces. However, aerostats are inherently surveillance platforms. Although it may remain impossible to prevent someone from attempting to attack an aerostat, it is possible to detect an impending attack. Furthermore, since aerostats require a secure ground tether site, the presence of friendly troops is a must to dissuade potential attackers.

Recommendations

Aerostats clearly have the potential to revolutionize counter-MANPADS technology and tactics. However, developing an aerostat-based MANPADS defense requires additional testing in several areas. The most critical area is determining the minimum altitude required for sufficient

protection. The minimum altitude will depend upon actual sensor field of view, sensor range, and ability to integrate multiple sensors onto a single platform. Likewise, it is possible to use a network of aerostats with overlapping sensor coverage. It naturally follows that a multiple-aerostat network could provide effective coverage while minimizing the required altitude for each aerostat. With enough sensors placed within a geographic area, it may be feasible to use a network of dispersed sensor towers and fewer aerostat-mounted directed energy turrets. Along those lines, further research is required to determine the optimal geometry of aerostats for a given airfield. Depending on the results of those tests, air traffic procedures could be developed to maximize traffic flow with respect to the number of vertical aerostat obstructions.

Implications for the Future

Using aerostats to provide a geographic MANPADS defense has positive implications for future military operations. Aerostats could feasibly mitigate the MANPADS threat that General Colin Powell earlier described as the most serious threat to aviation.[99] Doing so would protect both civilian and military airlift for the U.S. and our allies. With vastly more airlift resources at our disposal at earlier stages of conflict, the U.S. and our coalition partners could dramatically alleviate logistic strains and more rapidly project combat power. Aerostats would also provide the flexibility to eliminate staging bases and logistic bottlenecks by enabling CRAF aircraft to deliver equipment directly where it is needed. Aerostats would also minimize the number of military aircraft that require expensive IRCM systems. Finally, technological innovations perfected while constructing aerostat-based MANPADS networks could revolutionize other forms of warfare. For instance, data sharing advancements could lead to the ability for individual aircraft, while transiting high above the battlefield, to automatically provide an ad-hoc counter-MANPADS defense for helicopters engaged in low altitude flight.

Conclusion

In summary the U.S. and its allies are dependent upon civilian aircraft to support military operations. Unfortunately, these unprotected civilian aircraft and their crews are vulnerable to the MANPADS threat. Although numerous counter-MANPADS programs already exist, none of them are well suited for the unique CRAF environment. Fortunately, existing IRCM technology could easily be mated with existing aerostat technology to provide a deployable and geographically based MANPADS defense network.

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