# THE KEY TO DEFEATING ARMY AFTER NEXT: MAN-PORTABLE AIR DEFENSE SYSTEMS AGAINST THE AIR-MECHANIZED FORMATION


A MONOGRAPH
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## ABSTRACT

THE KEY TO DEFEATING ARMY AFTER NEXT: MAN-PORTABLE AIR DEFENSE SYSTEMS AGAINST THE AIR-MECHANIZED FORMATION by MAJ Roger A. Pretsch, USA, 44 pages.

In 1996 the United States Army established the Army After Next (AAN) project. This project is tasked with the development of a military force capable of decisively nullifying any major military competitor. The cornerstone the AAN's strategic deployment and tactical maneuver capability is the air-mechanized formation. The air-mechanized formation will be able to strategically deploy from the United States to the theater of operations in less time than current modern military airlift, and immediately establishing a dominant military force. Essential to the development of the AAN concept is the analysis of its weaknesses and vulnerabilities. As the Army proceeds with the analysis of the air-mechanized formation concept, the identification of viable threat weapons is essential to the development of realistic and challenging wargaming models. In wargaming models, teams working as the enemy force have effectively used various weapons to defeat the air-mechanized formation. Among the weapons used, the man-portable air defense system (MANPADS) has proven to be an integral part of the enemy force defense

While every air defense system offers substantial advantages and capabilities to ground commander, MANPADS are the distinctive weapon for use against the AAFs of the air-mechanized formation. Nations will spend a great deal of resources to develop ways of defeating the United States future military force. As part of our efforts to make the concept viable and effective, the determination of weapon systems that can be effective against the force must be used in every modeling and wargaming for proper analysis.

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# INTRODUCTION

> How can men attune their minds as clearly as possible to the constantly changing conditions and demands of war? How do military institutions adjust to new realities, what forces carry innovation forward, and what obstacles stand in its way?
>
> -Peter Paret[1]

In 1996 the United States Army established the Army After Next (AAN) project. This project is tasked with the development of a military force capable of decisively nullifying any major military competitor.[2] The United States national security relies heavily on maintaining a rapidly deployable force with an offensive capability. The ability to rapidly deploy and establish military dominance anywhere in the world is a goal of AAN. To achieve this goal AAN is expected to exploit future advancements in technology. The cornerstone the AAN's strategic deployment and tactical maneuver capability is the air-mechanized formation. The air-mechanized formation will be able to strategically deploy from the United States to the theater of operations in less time than current modern military airlift, and immediately establishing a dominant military force.[3]

Essential to the development of the AAN concept is the analysis of its weaknesses and vulnerabilities. It is reasonable to assume that other countries will develop methods of countering the threat posed by the AAN concept. It is imperative for the developers of the AAN project to extend a considerable effort toward learning how to defeat the capabilities of this new force. In recent wargaming, teams working the AAN project have identified several low cost and relatively low technology methods of reducing the effectiveness of the air-mechanized formation.[4] As the Army proceeds with the analysis of the air-mechanized formation concept, the identification of viable threat weapons is essential to the development of realistic and challenging wargaming models.

In wargaming models, teams working as the enemy force have effectively used various weapons to defeat the air-mechanized formation. Among the weapons used, the man-portable air defense system (MANPADS) has proven to be an integral part of the enemy force defense.[5] The technological developments of MANPADS have significantly increased their popularity throughout the world. As AAN analysts attempt to develop a picture of future warfare, it is important to discuss the part MANPADS will play. The evidence shows that MANPADS are the most effective air defense means of attacking the air-mechanized formation. This is based on an examination of the fundamentals of the air-mechanization concept, review the various families of air defense systems, and conduct a systematic comparison of these systems relative to the tactical employment of the AAN's air-mechanized formation.

The superiority of MANPADS will be clearly demonstrated by a systematic examination of the relative effectiveness of the various families of air defense weapon systems against the transport aircraft of the AAN's air-mechanized formation. This examination includes a comparison of each family of air defense weapon systems against a defined set of criteria. The analysis then rank orders them in terms of the defined criteria.

The AAN's air-mechanized force partly consists of aircraft capable of flying great distances at relatively high rates of speed, and of having maneuvering characteristics like a helicopter.[6] The closest example of an aircraft with this capability is the US Marine Corps V-22 Osprey. Using a tilt-rotor concept, the V-22 flies forward at a speed equal to propeller driven airplane and maneuvers vertically and horizontally like a helicopter. The AAN's air-mechanized force will employ aircraft that exceed the capability of the current V-22.

The aircraft associated with the air-mechanized force will come in two basic forms. Known as the Advanced Airframe (AAF), the transport version is a fixed-wing cargo aircraft with vertical takeoff and landing (VTOL) capability. The AAF can have a strategic deployment range of 2,100 nautical miles at speeds exceeding 300 knots and a tactical planning radius of 1000 kilometers. The AAF will internally carry all models of the Advanced Fighting Vehicles (AFV) and performs as a resupply asset for the battle force when tactically employed. The AAF is equipped with active protection systems that employ countermeasures to assist in evading enemy anti-aircraft systems. Although a transport, the AAF is expected to have a 30 millimeter turret-mounted cannon for defense. Similar to the AAF, the Advanced Attack Airframe (AAAF) has the same strategic deployment ranges, speeds, and tactical employment radius. The AAAF does not have a cargo-carrying capability, but is armed with Hellfire and Sidewinder missiles. The AAAF will use active protective countermeasures as well as incorporating low observable, low radar cross section, heat signature reducing stealth type of materials which will reduce the effectiveness of acquisition by thermal, infra-red (IR) and radar anti-aircraft systems.[7]

The primary mission of the air-mechanized formation is the delivery of the AAN battle force into the operational area. Tactical employment is arguably the most critical time for both the battle force and air-mechanized formation.[8] During ingress, the AAFs will be fully loaded and less maneuverable. Decelerating the fully loaded AAF from cruise airspeeds to hovering flight in a landing zone (LZ) will take tens of kilometers. During the ingress into the LZ, the AAFs will be vulnerable to all forms of weaponry. Enemy air defenses will have the primary mission to detect and destroy the air-mechanized force as quickly as possible. The final leg of ingress into the LZ is when the AAFs will be the most vulnerable to air defense weapons.

Many aspects of the AAN concept are tested and analyzed under simulated conditions. Among the situations key to the AAN concept is the tactical delivery of the battle force. In the wargaming scenario, a significant intelligence gathering effort to determine the location and distribution of enemy forces precedes the deployment of the battle force. Before the air-mechanized formation is committed, the battle space is significantly prepared with both lethal and non-lethal means. Recognizing the potential vulnerability of the air-mechanized formation to the air defense threat, the current wargaming models have the AAFs delivering the AFVs approximately forty to fifty kilometers from the main enemy force.[9]

While the AAFs will be an integral part of the AAN's offensive network of sensors and weapons, the fact remains that these aircraft will be vulnerable during ingress to the LZ. A great deal of emphasis is given in the current wargaming to the study of survivability and vulnerability. This study focuses on examining the potential effectiveness of various air defense systems on the AAFs of the air-mechanized formation.

The varieties of modern air defense systems are as vast as the range of missions they are intended to cover. Countries employ air defense systems based on military necessity and on available resources. It is impractical for this study to individually analyze every type of air defense weapon system currently in the inventory. A more practical approach is to determine major varieties of current air defense systems. Furthermore, this study will limit the analysis to those systems that are employed tactically. According to the Jane's Information Group, air defense systems are divided into five families: man-portable surface-to-air missile systems (MANPADS), self-propelled anti-aircraft guns, self-propelled surface-to-air missiles, towed anti-aircraft guns, and static and towed surface-to-air missile systems.[10] The individual types of systems within these families are still too numerous to conduct an analysis of each system. For the purpose of the study, characteristics common and best representing the family of air defense system are used for analysis and comparison.

The first family of air defense systems for examination is MANPADS. Characteristically, these systems are shoulder-fired surface-to-air missiles (SAMS), like the Russian Igla (SA-18) and US Stinger. Typically these systems use infrared passive homing for guidance and advertise effective engagement ranges from 3,000 to 8,000 meters. Minimum engagement altitudes range from the surface to up to an altitude of fifty meters for some systems. More advanced systems, such as the French Mistral and the British Starstreak, also fall into the category of MANPADS.[11] These systems are operated from a portable launcher. Characteristically, these systems are laser guided, and have generally greater effective ranges. For this study, the MANPADS family of air defense systems is defined as a shoulder-fired, IR homing SAM with a range of 5,200 meters and a minimum engagement altitude of 10 meters.

Self-propelled anti-aircraft guns are the next family of air defense systems. These systems are armed with large-caliber guns, are vehicle mounted (track or wheel), and are typically employed with some sort of active acquisition and tracking system to direct the guns. The Russian ZSU-23-4 is one of the most recognized systems and is still used by many nations.[12] Other representative systems include the French AMX-30 and the German Gepard. While these systems are all mounted on heavy-tracked vehicles, there are numerous systems that are truck mounted. Generally, these systems have effective ranges of 3,000 to 4,000 meters and employ a variety of active radar systems for fire control. In the past few years, advanced systems integrating both guns and missiles are becoming more popular. The Russian Tunguska (2S6) and the US Bradley Stinger Fighting Vehicle (BSFV) are representatives of these advanced systems. With the inclusion of a SAM to the system, maximum effective engagement ranges extend out to 8,000 meters.[13] Although requiring greater technical competence to operate and having higher operating cost over the common track-mounted anti-aircraft gun, an integrated system, like the 2S6, is highly effective and represents the high-end future of the self-propelled anti-aircraft guns. For this study, an integrated system like the 2S6 will represent the family of self-propelled anti-aircraft guns. The system is a track-mounted integrated gun and missile system that employs an active radar system for acquisition, tracking and fire control.

The self-propelled surface-to-air missile systems offer similar, but often more advanced capabilities than the family of self-propelled anti-aircraft guns. Also mounted on a tracked or wheeled vehicle, these systems are highly mobile, rugged systems that can engage on the move, or shortly after stopping. A variety of missiles are used in these systems. Infrared, laser, and radar are all common methods of missile guidance. Characteristically, these systems incorporate an active radar system for detection and acquisition. Determining representative characteristics of this family of air defense system is difficult due to their wide range of capabilities. Grand systems like the Russian Buk-2m

(SA-17) are complex systems employing several tracked vehicles each having specialized roles.[14] The overall system employs a phased array radar and launches a missile with an impressive range of over 40,000 meters. On the other end of the spectrum are systems like the German Atlas Short-Range Air Defense (ASRAD) system. The ASRAD is a track-mounted system that employs a variety of IR-seeking missiles from the RBS 90 and SA-16 to the Mistral and Stinger.[15] The most common representative systems within the self-propelled surface-to-air missile family are the French Roland and Britain's Rapier and Starstreak. For the purpose of this study, a weapon system representing the self-propelled surface-to-air missile family will be a track-mounted, fully integrated system, employing active radar for acquisition, and having an effective engagement range of approximately 8,000 meters.

The most common air defense system is the family of towed anti-aircraft guns. These systems are high-caliber gun systems similar to their self-propelled counterparts. These systems are inexpensive to purchase and are comparatively easy to maintain. These systems may employ a target acquisition radar for fire control, or may be operated manually. China and the Commonwealth of Independent States (CIS) offer the greatest variety of towed anti-aircraft guns.[16] The ranges of these weapons vary widely. The smaller of these systems are intended for short-range defense, and have effective ranges of approximately 1,500 meters. The larger of the systems like the KS-30 from the CIS employs a 130mm gun with a maximum range of approximately 27,000 meters. More common among the systems are the 23mm and the 37mm variety of anti-aircraft guns. Maximum ranges of these weapons range from 7,000 to 8,500 meters respectively.[17] All of the large caliber systems require a crew of two or more. Characteristics typifying the capabilities of the 37mm class of towed anti-aircraft guns will be used for the study.

The last family of air defense systems is the static or towed surface-to-air missiles. These systems characteristically fall into the strategic air defense and the medium-range surface-to-air missile defense categories. These are robust, complex systems that are integrated into an overall network of long-range air defense. Often employing powerful radar systems for long-range detection and acquisition, these systems have the capability to engage low-level targets, but are more effective against long-range medium-to-high-altitude targets. This family of air defense systems typically requires a great deal of technical support and a high degree of technical competence among the crews operating the systems.[18] Being that they are towed or static systems, they are not intended to support maneuvering forces, but to protect high-value targets or national airspace for foreign intrusion. While the CIS offers the greatest variety of stationary and towed SAM systems like, the SA-2, SA-3, and SA-5, other countries offer similar systems, such as the European Sparrow Air Defense System and the US Patriot Missile System.[19] While other systems are included in this family of air defense, such as the Roland and Rapier, capabilities similar to those of the advanced versions of the SA-2 will be used to represent the static and towed SAM family of air defense systems.

## ANALYSIS AND EVALUATION

The criteria used for this study are intended to generate thought toward the development of future wargaming models, and potentially focus the technical and tactical development of the AAFs. In some analyses, technical criteria would better serve the development of modeling parameters for AAN wargaming. The primary concern regarding the use of technical criteria is potential security considerations. During the research phase of this study, it became clear that Department of Defense agencies, and private defense contractors were interested in maintaining a high level of security regarding the potential capabilities of many aspects of the AAN project. It is the intent of this study not to use technical criteria and to keep this study of an unclassified nature. While there are many possible combinations of criteria that would contribute to the focus of this study, the following criteria were selected in order to discuss the known advantages and disadvantages of each family of air defense systems.

Essential to the evaluation of the effectiveness of various air defense systems against the AAF is the development of a set of criteria. The criteria are based on commonly understood terms used specifically for the employment of air defense systems, or terms common to the employment to military weapons systems in general. Being that the target (AAF) is still in the conceptual stages, it makes it more difficult to apply hard technical data of current air defense systems to the issue of weapons effectiveness on a conceptual target. The intent is to apply general current air defense capabilities, while discussing projected future developments as part of the general analysis. Following are brief definitions of the criteria that are used in this analysis.

The term acquisition includes all aspects of targeting up to but not including the engagement of weapons (SAMS or anti-aircraft guns) on a target. This includes the detection and tracking functions. This study examines the characteristic strengths and weakness of each family of air defense system by analyzing methods used to acquire targets. Additionally, this section discusses the various weapon system developments relating to acquisition and the potential impact these developments will have on the AAN air-mechanized formation.

Based on the two primary acquisition functions of detection and tracking, this analysis considers early detection and accurate tracking as the desired capabilities necessary for effective engagement of the air-mechanized formation.[20] Using the information describing the deployment distance of the battle force in the explanation of the AAN wargaming model, a distance of 100 kilometers extending from the enemy ground force is considered the acquisition area and used as the primary measurement in this analysis. The capability to detect beyond the acquisition area is beneficial, but any gaps of detection within the acquisition area are detrimental. Additionally the ability of an air defense system to track multiple targets is desirable.

The section on survivability focuses on the vulnerability of air defense weapon systems to detection and suppression by the collective systems associated with the AAN concept. The analysis focuses on detectability in terms of various signatures including electromagnetic, IR, and radar emissions. Under the basic AAN concept, knowledge superiority is of premium importance.[21] The AAN will employ a vast array of sensors to achieve knowledge superiority in order to develop a detailed picture of the potential threats on the battlefield.[22] Assuming that if a system can be detected it can be destroyed or suppressed, air defense systems must be able to minimize detectable signatures not only to survive, but also to be effective.

In order analyze and compare the different air defense systems in terms of survivability, a description of the various types of detectable signatures is essential. Detectable signatures, or emissions, come in various forms and require different sensors for detection. The AAN will use a collective array of sensors to gather information on the location and type of potential threats within the mission area. Assuming that every air defense systems emits some type of signature, the analysis and comparison focuses on the type and amount of signature produced by each type of air defense system. The type of emission has an impact on the distance from which it can be detected. Another factor is the amount of emission. Some weapon systems produce similar emission, but at different amounts. For the purpose of this analysis, emission types are ranked ordered in terms of delectability. Weapons systems with low emission levels are preferred over air defense systems easily detectable due to strong emissions.

The employment criteria represent two primary aspects of weapons effectiveness. The first aspect is the basic simplicity, or technical complexity of operating an air defense system under combat conditions. The intent of this analysis is to discuss the training and personnel resource requirements to effectively operate various systems. The second aspect of employment is the ease by which the commander may move and support his forces in the defense. Transportation, logistic, and maintenance support requirements are all included in this section of the analysis.

The section studying employment rank orders air defense systems in terms of simplicity. The weapon system with the minimal dedicated crew requirement and with a general assessment of the training required to properly employ the systems is preferred. Secondly, air defense systems are rank ordered in terms of transportability, maintainability, and supportability. The weapon system that is easily transported, maintained, and logistically supported is preferred over other systems.

The 1997 Chief of Staff of the Army's annual report on the Army After Next project states that the AAF of AAN will employ a variety of active and passive countermeasures against various threats.[23] The term "counter-countermeasures" in regards to this study focuses on the aspect of the air defense system ability to defeat or to overcome the countermeasures employed by the AAF. It is reasonable to assume that air defense systems will continue to incorporate advanced technologies to improve the overall capability or to reduce the weaknesses of the system. It is expected that the AAF will employ the most advanced means of defeating all known air defense systems.[24] While not totally effective, the means employed by the AAF will significantly reduce the probability of kill (PK) percentages of the various air defense systems. Air defense systems that are unaffected by known countermeasure systems will be preferred over other systems that can be readily defeated by active or passive means. Air defense systems are then rank ordered in terms of the general reduction of PK percentages due to countermeasure employment by the AAF.

Mass is the final criteria. The focus of this analysis is to examine the engagement ranges of air defense systems relative to a required air defense coverage requirement. The air-mechanized formation is expected to deliver the battle force approximately forty to fifty kilometers from the enemy force.[25] Air defense engagement beyond that distance is essential. Assuming that the enemy force commander demands air defense coverage of his main ground force, air defense systems must be arrayed to cover a specified distance from the main enemy force. This analysis considers only the engagement of the AAFs in terms of air defense coverage.

For the purpose of this analysis, the battle force will be delivered 50 kilometers from the enemy force. An additional twenty kilometers will represent the distance the AAFs are preparing for landing and the period that they are most vulnerable to attack. A total distance of seventy kilometers from the enemy force is the minimum air defense coverage requirement. An air defense system's engagement range will determine the percentage of coverage and provide an estimate of the number of systems required to provide coverage. Fewer required air defense systems are preferred.

Of the five defined criteria, survivability and employment are the two criteria that are most important and essential to the effectiveness of a force opposing the AAN. The weapon system must be able to survive against an opponent with capabilities like those of the AAN. The most capable air defense system is ineffective if it is readily detectable and vulnerable to destruction or suppression. Similarly, the ease of employment is critical because of the necessity of a defending force to rapidly field, employ, and sustain an air defense network. A defending commander must appreciate the destructive potential of the AAN, and be prepared to endure the initial losses and be able to rapidly replace lost capabilities.

Applying the defined criteria to the families of air defense systems is the next step of the analysis and evaluation process. The following analysis and evaluation is divided into five sections that represent each criteria. A general discussion of the various aspects of the criteria will lead the analysis followed by the evaluation of the air defense systems.

Essential to the analysis of any weapon system, but keenly important to air defense systems is the ability to acquire aerial targets. Air defense systems generally face airborne threats that have the capability to maneuver rapidly, and engage effectively from greater ranges than can the air defense system. To be effective, air defense systems need the capability to acquire and engage targets from extended ranges. The altitude or elevation of the target is a factor in an air defense system's ability to acquire targets. Depending on the method of acquisition, targets closer to the earth's surface are generally more difficult to acquire.[26] Modern air defense systems use multiple methods to acquire and engage targets. The method by which an air defense system acquires targets is a definable characteristic of the system. Acquisition methods include both passive and active means. Generally, there are two basic acquisition methods.

The primary active acquisition method is radar. Similar to sonar, radar is a system that emits radio frequency energy. The radio energy is reflected off of a target and returns to a receiver. The returned radio energy provides essential information to determine a target's range, azimuth, and course. Detection and tracking are the two primary functions of radar systems.[27] Tracking data is essential for the effective engagement of a target by a SAM or anti-aircraft gun.[28] Both detection and tracking functions can all be performed by radar systems integrated into the overall air defense weapon. In the past, the detection and tracking functions were performed by separate radar systems, but with the development of multifunctional radar systems, enable a single system to perform both functions.

Radar systems provide several obvious benefits and one significant drawback. Primarily, radar provides the ability to acquire targets at ranges far beyond passive methods. Radar can continuously monitor the airspace surrounding the air defenses system, and provides an acquisition capability during poor visibility both natural and man made. Most importantly, radar provides the ability to monitor multiple targets simultaneously. No other acquisition method provides the same capabilities as radar.[29] The primary disadvantage to any radar system is the fact that it is an active system, meaning that it (radar) emits a signal that is easily detectable. The vulnerabilities of radar systems are discussed later in this study. Even with all of the advantages radar provides, air defense weapons designers readily incorporated passive methods of detecting and tracking targets.

Visual acquisition is the most common passive method of detecting and tracking targets. The primary advantage to visual acquisition is its relative inexpensive, and invulnerable to countermeasures. The limitations to visual acquisition are obvious; (1) visual acuity detracts from the ability to acquire targets at extended ranges, (2) inability to accurately determine course, range and velocity of a target, (3) reduced capability to acquire do to poor visual conditions (weather and periods of darkness), and (4) limitations due to human factors all contribute to a very simple but limited method of acquisition.[30] To overcome some of these limitations many air defense systems use night vision devices, optics, and low light television to improve the general capability of visual acquisition. Night vision devices only increase visual acquisition by enhancing available light during periods of darkness. Night vision devises generally do not enhance visual acuity, or magnify images.[31] Optical systems are designed to enhance visual acuity, but are generally limited to operations during daylight. Low light television systems offer both light intensification, and magnification. These systems are very effective and only partly limited to environmental visibility. The use of low light television systems provides the best enhancement to the most common passive method of acquisition.

IR guided SAMS offers an additional benefit to passive acquisition. IR is the non-visible wavelength of light associated with heat that provides a significant contrast to a cooler background. The case of air defense weapon systems, IR receivers detect the contrast of a heat signature produced by flying objects against the cool background of the surrounding air. There are several advantages to IR systems. First it is a passive system and nearly impossible to detect before engagement. Second, IR technology has enabled effective IR systems to fit into very small spaces allowing for the development of smaller, and highly accurate air defense systems. This technological improvement is directly related to the development of MANPADS in the recent decades. The weaknesses of IR systems are their susceptibility to countermeasures, and various weather conditions.[32] Weaknesses are discussed in greater detail in the countermeasure section. Although the primary function of IR missile guidance is to provide a fire and forget capability of the weapon system, before engagement, IR guided missiles can aid in the acquisition function. Associated with air defense systems employing both active and passive acquisition methods, the IR guided missile is beneficial to passive (visual) acquisition.[33] When activated, the missile uses the IR related technology to acquire a target. The benefit is that normally IR systems produce an audible tone notifying the operator that the tracking function is being performed by the guidance system.[34] It would seem particle to incorporate an IR system specifically to meet the needs for a flexible and passive method of acquisition. While it may be particle for an air defense system to incorporate a dedicated IR system for acquisition, weapons designers have favored radar and enhanced visual systems as the primary methods of air defense acquisition.

Based on the definition of the acquisition criteria, the following systematic analysis shows that air defense systems employing active radar systems for acquisition have a clear advantage over other systems. Self-propelled and static SAMS, and self-propelled anti-aircraft guns are far more effective in acquiring aerial targets. Following is an expanded discussion of each family of air defense in regards to acquisition.

Among the family of man-portable air defense systems, MANPADS generally employ the visual method of acquisition. If the system uses passive IR homing for engagement, the IR system can provide an additional limited capability to the acquisition function of the weapon system. Advanced militaries employ an active radar system as part of an air defense network to link the MANPAD positions with communications in order to provide cueing information to improve the overall collective effectiveness of the systems.[35] The inclusion of an active radar system changes the description of the MANPAD family of air defense systems. For the purpose of comparison, an active radar system will not be incorporated with the MANPAD for improved acquisition capability. Individually, MANPADS are limited to visual acquisition, and therefore are affected by changing weather conditions and limited to periods of adequate illumination. Additionally, one MANPAD system would not be able to cover the entire acquisition area and would require the deployment of multiple systems.

Many examples of self-propelled anti-aircraft guns rely on an active radar system for the purpose of acquisition and fire control. While the systems can be operated manually, the active radar provides far better and more accurate performance. Acquisition ranges on many of the systems is approximately fifteen kilometers.[36] These systems normally can be linked electronically to increase the area of coverage and provide cueing information to other systems. Radars associated with modern self-propelled anti-aircraft guns are generally very advanced and very effective for tactical applications. The advanced radars these systems employ provide accurate and timely information for all aspects of acquisition. Individually, self-propelled anti-aircraft guns, such as the Russian 2S6 or German Gepard, have few limitations concerning acquisition.[37] When employed, the radar system is constantly searching the sky for possible targets. Many systems are fully automated and notify the operator upon any changes to the radar return picture. While a single self-propelled anti-aircraft gun system would not be able to cover the entire acquisition area, it would be able to cover approximately 15 percent.

Particular to the aspect of acquisition, self-propelled SAMS are very similar to self-propelled ant-aircraft guns using an active radar system for the purpose of acquisition. While the general capabilities are much greater than with anti-aircraft guns, the radar systems employed by self-propelled SAMS are generally more powerful because of the increased engagement capability of the SAM. Weapon systems such as the Crotale and the Roland have radars that can detect targets from ranges of 19 to 46 kilometers.[38] More advanced systems like the Russian SA-17 and SA-10 detect target at ranges exceeding 120 kilometers.[39] Characteristically, the radar used by this family of air defense systems is very sophisticated, and accurate at generally greater distances than radar systems employed by anti-aircraft guns. For this study, the radar from a single representative SAM system, like the Roland, has the capability to cover approximately half of the acquisition area. The use of radar as part of an integrated air defense system greatly increases acquisition effectiveness, but with the increased capability of radar systems associated with self-propelled SAMS the benefit is even greater

Regarding acquisition, the limitations of the towed anti-aircraft gun are similar to those associated with MANPADS. These systems are normally not fielded with fire control radar. While many nations do employ their towed anti-aircraft guns with fire control radar, there are many examples of these systems acquiring targets visually.[40] The limitations of visual acquisition were discussed earlier in the analysis of MANPAD acquisition. Towed anti-aircraft guns will also require multiple systems to properly cover the entire acquisition area.

The most sophisticated and capable of all of the air defense systems are the static and towed SAM family. These systems are designed primarily for long-range and high-altitude engagement often intended for strategic defense. With engagement ranges exceeding 200 kilometers for some systems, this family of air defense is required to have the greatest acquisition capability technology can provide.[41] The sophistication of these systems is unparalleled among air defense weapons. Characteristically, these systems can not only acquire targets at unmatchable ranges, but can also track and manage the engagement of more targets than any other family of air defense weapons. The family of static and towed SAMS exceeds the required coverage of the acquisition area.

Based on the distance required to acquire targets, air defense systems employing radar systems for acquisition are the clear preference. More accurate and distant acquisition are made possible by radar, and among the air defense families, static and towed SAMS clearly displays the capability to acquire targets from the greatest ranges, and under the most demanding conditions. The family of self-propelled SAMS provides a similar, but somewhat reduced capability to acquire targets. Generally, self-propelled anti-aircraft guns employ accurate, but less powerful radar systems. Visually acquiring targets is the least preferred method. Air defense systems using passive acquisition are extremely limited without the use of an integrated radar system for cueing and fire control. For the purpose of acquisition, the MANPAD family has a slight advantage over the towed anti-aircraft gun because of IR guidance. IR guidance gives the operator the potential to track targets more accurately than optically tracked gun systems.

While the capability to acquire aerial targets is necessary of any air defense system, the ability to survive in the highly lethal environment posed by the AAN is essential to these weapons remaining an effective defense. Survivability of any system opposed by the AAN will be a challenge for a defending force. In the case of air defense systems, MANPADS are definitively the most survivable systems currently available. Several aspects of survivability contribute to MANPADS overall effectiveness. Following is a general discussion of the different aspects pertaining to survivability, and an evaluation of each air defense family.

Essential to the discussion of weapon system survivability is the aspect of detectability. The AAN is expected to incorporate multiple arrays of sensors with weapons systems in order to develop a seamless network of defensive and offensive capability. The only air defense systems that will be able to survive and potentially engage the air mechanized formation is one that is difficult to detect, both before and during engagement. Based on current technology, air defense weapons produce three different types of detectable emissions: radar, infrared and electromagnetic. In order to analyze the potential survivability of air defense systems, the three basic types of emissions will be discussed and rank ordered in terms of detectability. Next, the study will compare the relative levels each air defense system produces. The final analysis of survivability will be the rank order of the air defense systems in terms of detectability.

Radar (Rf) emissions are the most detectable of the signatures. For the same reasons that radar was the most effective means of acquisition, radar is also the most vulnerable to detection.[42] Radar emissions are easily detectable by simple radio receiving antennas tuned to the correct bandwidth. The vulnerability of radar to detection is well known, and air defenders have employed numerous tactics to reduce detectable emissions. Still, for many systems, radar must be activated in order to gain the tracking information necessary for engagement. When an air defense system activates its radar, the location of that system is easily determined. Considering the network of sensors and weapons systems associated with the AAN, a radar system activated against the air- mechanized formation can expect to be suppressed electronically, or with a variety of weapons.

The basic concept of IR was discussed previously. Heat signatures are not unique to aircraft. Any machinery producing heat emits a detectable IR signature. Vehicle engine, generators, electronic equipment all produce detectable IR signatures. Detectability of IR signatures is directly related to the size of the object producing the IR emission, and the level of thermal contrast. IR emissions can be reduced by certain environmental conditions that reduce the contrast between the object producing heat and the surrounding environment.[43] Due to the heating and cooling of the earth's surface, there are two periods each day when IR emissions are more difficult to detect. IR emissions can also be reduced by design. Thermal covering and heat exchangers are among the methods used to reduce IR emissions. Advancements in IR technology have significantly improve the clarity and level of detectable IR emissions. With the advancements in IR technology, and the emphasis AAN is placing on sophisticated sensors for detection, it is unlikely that sophisticated air defense systems will go undetected.

Associated with the previous two types of detectable emissions is electromagnetic. Electromagnetic emissions are associated with electric generation and usage. Any system that uses electricity produces some level of electromagnetic signature. While emphasis is placed on reducing the detectable signature, sensors can readily receive electromagnetic emissions. It is more complicated to determine the exactly locate the source of electromagnetic emissions.[44] Still, it is a detectable signature that can be localized, suppressed, or destroyed.

Based on the definition of the criteria survivability, the following systematic analysis shows that MANPADS have a clear advantage over other systems. The passive means used by MANPADS along with the relative small size of the weapon, allows these SAMS to avoid early detection and directly contributes to their overall survivability. Following is an expanded discussion of each family of air defense in regards to acquisition.

MANPADS use passive methods for acquisition and engagement. MANPADS do not produce Rf emissions, and the electromagnetic signature is nearly undetectable. The relative size of the weapon makes the MANPAD almost undetectable to IR sensors. In fact, the greatest IR signature produced by the system is the operator using the weapon. Improved IR sensors will continue to have difficulty identifying MANPADS. Their relative size can easily be confused with numerous lethal and non-lethal objects on the battlefield. The only time the MANPAD produces a discernible signature is during launch.

Any missile being launched produces a detectable IR signature; however, MANPADS produce the smallest signature and for the shortest duration of any of the modern SAMS.[45] Even with advancements in IR sensor technology, the MANPAD will remain nearly undetectable for many years into the future.

As with most of the complex air defense systems, self-propelled anti-aircraft guns are capable of producing all three types of emissions. Detectable Rf emissions are produced when the radar is active. IR emissions are produced primarily by the engine used to propel the vehicle, or just by the absorbed solar heat on the surface of the vehicle. These complex systems also produce a detectable level of electromagnetic energy. All three types of emissions, or any combination of them makes the self-propelled anti-aircraft gun very detectable to the AAN sensor array.

Self-Propelled SAMS are vulnerable to detection for the same reasons as the self-propelled anti-aircraft guns. The increased capability of radar systems associated with self-propelled SAMS make them more detectable to Rf sensors. Generally, SAMS employ sophisticated and powerful radars. Rf detectability is directly associated with the level of Rf emissions. IR and electromagnetic emission are similar to those produced by self-propelled guns.

Like MANPADS, the simple anti-aircraft gun system is very hard to detect. The system that does not employ radar does not produce an Rf signature. Most anti-aircraft gun systems are manually controlled and do not require electricity to operate. Even the systems that are electrically controlled, the generation of electricity is relatively low and difficult to detect. Similarly, the IR signature produced by the anti-aircraft gun is negligible. This system will be very difficult to detect by sensors, and with any reasonable attempt to mask its signature make the anti-aircraft gun almost undetectable.

The largest and most sophisticated of all the air defense systems, static SAMS have the capacity of being the most detectable by a variety of sensors. These systems use sophisticated and powerful radars, have relatively large surface areas for producing IR energy, and generate electricity for weapon system operation. The combination and relative limited maneuverability make this family of systems very easy to detect and very susceptible to lethal and non-lethal means of suppression.

Definitively, MANPADS and towed anti-aircraft guns produce the least detectable signatures of the other air defense systems. Likewise, they are more survivable against the sensor/weapon networked employed by the AAN. Based on size alone, MANPADS are more difficult to detect than anti-aircraft guns. MANPADS reflect less energy, and are easier to conceal. MANPADS do produce a detectable IR signature during launch, but the towed anti-aircraft gun is generally more detectable earlier and generally easier to suppress or destroy. The remaining systems that produce a combination of all emissions should be ranked in order of the level of Rf emissions and relative size. Self-propelled guns produce slightly less of a signature than the self-propelled SAMS followed by the static SAMS.

As important as survivability, the aspects of employment are key to the force defending against the AAN. The AAN will have the capability to detect and defeat a vast array of enemy weapon systems. The commander opposing the AAN must be able to rapidly replace lost systems and support them in a combat environment. Again, MANPADS are definitively superior to other air defense systems in terms of employment. Following is a general discussion of the different aspects pertaining to employment, and an evaluation of each air defense family.

Employment considerations are important to the commander in developing his overall defensive network. Weapon systems that require minimal training, are easily transported, and require little or no logistical support are ideally the commander's preference. Technologically, air defense systems are becoming increasing more capable and rugged.[46] Conversely, as air defense capability increase, so does their technical sophistication. This implies the requirement for technical training and maintenance. Although a weapon system's lethality is predominant, commanders must consider training and logistical support requirements as essential aspects of selecting any weapon system.

In analyzing training requirements of an air defense system, two basic aspects must be taken into consideration. First is the question of required training on the system, and second is the crew requirement to effectively operate the system. The complexity of training will indicate the simplicity of the system and the relative ease by which personnel can be made ready to employ the weapon system in combat. Complex air defense systems require extensive technical training of crews in order to effectively operate the system. Additionally, sophisticated air defense systems often require multiple crew members in order to operate the systems to its fullest. Multiple crews requirements are directly related to the number of trained personnel dedicated to air defense and removed from other combat related duties. From a training standpoint, the easier the weapon system is to employ the less time and effort will be required to effectively field the system. From a personnel standpoint, the easier the weapon system is to employ, the fewer personnel will be needed relative to the number of systems desired for employment.

The second set of considerations for employing an air defense system are the aspects of transportability, maintainability, and supportability. A weapon system that is easily transportable is preferred. Air defense transportation requirements come in several forms. Transportation can be an integral part of the air defense system such as the self-propelled families of air defense systems. Other systems require dedicated transportation. Towed air defense systems commonly require additional vehicle assets to transport the system. MANPADS are unique because size of the system makes transportation requirements inconsequential. Maintainability is another aspect requiring discussion. Generally, the more sophisticated the system the greater amount of maintenance is required to keep the system combat ready. Air defense systems incorporating radar or mounted on tracked or wheeled vehicles require significantly more maintenance than static or self-contained systems. Similarly, supportability is directly related to system sophistication. Repair parts and consumables require dedicated resources in order to keep the air defense system at a combat ready condition. Unless properly coordinated, transportation, maintenance, and support are inherently more difficult under combat conditions.

Based on the definition of the employment, the following systematic analysis shows that MANPADS have a clear advantage over other systems. Training and sustainment issues are common considerations for the selection and fielding of a weapon system. Air defense systems require careful consideration to many aspects pertaining to employment. The following analysis will discuss each family of air defense systems in terms of training and logistic requirements.

In considering the employment requirements, MANPADS favor well in both aspects. While operated more effectively, by a trained operator, MANPADS are designed for operations by soldiers with minimal training.[47] MANPADS have been effectively employed by military personnel with just a short period of formal training. Although it is a very sophisticated system, the actual operation of the MANPAD is relatively easy. Many militaries deploy MANPADS in teams of two, but the actual operation of the system requires only one operator.[48] Additionally, the operator is not necessarily dedicated to operating the system. The operator has the ability to perform other duties as well as performing air defense duties. From the transportation and supportability aspects of employment, MANPADS fare very well. MANPADS are self-contained weapons. They are ready for use upon issue. Transportability is inconsequential due to the size of the weapon. MANPADS are easily carried by a single soldier or on a vehicle. MANPADS do not require dedicated transportation assets in order to position them around the battlefield. Being that they are self-contained, MANPADS require minimal care and maintenance to remain serviceable.[49] Logistically, MANPADS have a resupply requirement. The missile is self-contained, and additional missiles are required for multiple engagements.

Self-propelled anti-aircraft guns are sophisticated and complex systems. From a training standpoint, the self-propelled anti-aircraft gun system like the Russian 2S6 requires specialized technical training. As an example, the 2S6 require a crew of four. The commander, gunner, radar operator, and driver are all required to operate the system effectively.[50] A 2S6 crew would require extensive initial and regular sustainment training in order to maintain the systems effectiveness. While it is reasonable to assume that some cross training occurs at the crew level, any loss of a crewmember seriously degrades the weapons effectiveness. Along with the specialized training requirement, the system requires dedicated personnel. These personnel are unable to perform other combat related duties. From a transportation aspect, the self-propelled anti-aircraft gun family is specifically designed to be maneuverable. These systems do not rely on transportation assets for tactical deployment. Being that these systems are vehicle mounted and normally employing sophisticated systems like radar, these systems can be expected to require regular maintenance. The effort to maintain a tracked vehicle and radar system is extensive and constant. Likewise, consumption of repair parts and other consumables demands a coordinated and well-managed supply effort.

Self-propelled SAMS will require comparatively the same training, and logistic requirements as the self-propelled anti-aircraft guns. Self-propelled SAMS generally have similar crew and specialized training requirements as their anti-aircraft gun brothers. Similarly, the maintenance required, although varies between systems, is still extensive, and requires a dedicated effort. Depending on the system, supplying the system can have additional challenges. Some systems require specialized carriers for the resupply of the missile system. For the purpose of this study, a system similar to the French Roland is used for the comparison. The Roland missile does not require specialized transportation assets.

The towed anti-aircraft gun family has both positive and negative aspects in regards to employment. While the systems are relatively easy to operate, many anti-aircraft gun systems require crews of two or more with some technical training. As with most weapons, the effectiveness of the system is directly related to the training level.

Towed anti-aircraft guns are highly transportable. Although requiring dedicated transportation assets for mobility, the guns are easily moved between different locations. These systems also require only minimal maintenance to remain serviceable. Supplying these systems is relatively easy. These are no special supply requirements other than the ammunition used by the system. From an employment standpoint, the family of towed anti-aircraft guns is simple to man and maintain.

The static and towed SAMS rank lowest in the analysis of employment. While the static and towed family of SAMS does not share the complexity of having a vehicle-mounted system, this family of SAM is generally a complex, technically sophisticated, and maintenance intensive system. Based on the sophistication of these systems, the training requirement of the crew must be extensive. Transportability is another major issue. These bulky systems are intended for long term positioning, and are not easily moved. These systems require extensive transportation assets to move between positions. Maintenance on these systems can be extensive and very technically oriented. Along with an extensive maintenance requirement, the supportability of these systems is a challenge. Many systems require special support vehicles to keep the weapon operational. Although these systems provide an assumed capability, the training and support effort is extensive.

In regards to employment, the leader of this comparison is the MANPAD followed by the towed family of anti-aircraft guns. The training and crew requirements for both are relatively low. MANPADS have the lowest training and crew requirement over the towed anti-aircraft gun. Training requirements for anti-aircraft guns are not nearly as technical as the other systems. The comparison of transportability is similar for both systems. The anti-aircraft gun family does require dedicated transport assets for deployment, but a wide variety of vehicles can accomplish the requirement. From a maintenance and support standpoint, MANPADS are superior to all other systems. Towed anti-aircraft guns are much easier to support then most other systems. Both families of self-propelled air defense systems are very maneuverable and rate high on transportability. These systems are very complex and require highly trained personnel, and regular technical maintenance to keep them functional. In terms of employment, static SAMS are the most difficult to operate, move and maintain. These highly technical systems require the personnel, resources, maintenance, and support expected of a weapon with such great and specialized capabilities.

The measure of effectiveness of the actual engagement will largely depend on the air defense system's ability overcome the passive and active countermeasures used by the AAF and the AAN. Optically directed air defense systems are less vulnerable to countermeasures and have a distinct advantage over air defense systems employing counter-countermeasures. Following is a general discussion pertaining to the various aspects of counter-countermeasures and an evaluation of the air defense families.

AAFs are designed to employ active and passive countermeasure systems intended to disrupt the guidance mechanism or fire control system of nearly all air defense weapons. modern combat aircraft are equipped with a suite of air survivability equipment (ASE). Most common systems are radar detectors, laser detectors, radar jamming equipment, and infrared jamming equipment.[51] All of these systems are designed to disrupt the acquisition and engagement functions of air defense weapons. The AAFs may also incorporate advanced ASE like the Advanced Technology Radar Jammer (ATRJ) and the Advanced Threat Infrared Countermeasures System (ATIRCM) currently under development.[52]

Working together as an integrated system could significantly reduce the vulnerability of aircraft to missile threats. The ATRJ will perform the functions of radar warning receiver, pulse-type jammer, continuous wave jammer, and precision direction finder. The ATIRCM will possess an increased capability to confuse infrared guided missile over current systems by the use of a xenon arc lamp jammer and a directable laser IR jammer.[53] While these systems are potentially very effective in degrading the lethality of air defense systems, they cannot degrade all systems completely.

While technological advancements are improving the effectiveness of the ASE, technology is also improving the ability of air defense systems to overcome aircraft countermeasures. Radar counter-countermeasures focus on "burning through" the ASE's attempt at disrupting the radar signal.[54] While radar jammers attempt to disrupt the radar signal by sending increased radar signals or invalid radar signals, the air defense counter-countermeasure is intended to clarify the radar signal by interpreting a very specific range of radar returns. Counter-countermeasure effectiveness depends greatly on the air defense system and the aircraft ASE suite it encounters. The AAFs of the air-mechanized formation will enjoy the combined effects of multiple radar jammers associated with AAN. It is difficult to determine the true effectiveness of radar guided air defense systems when faced combined assets of the AAN.

Disrupting infrared signals is another common countermeasure associated with ASE. Typically, an IR jammer emits excessive IR energy an attempt to confuse the missile's tracking and course corrections to the target. Current IR counter-countermeasures have the missile's guidance system focus on a very specific IR wavelength and signature aspect.[55] This function reduces the confusing effects of IR jamming and the use of flares. Future systems intended to enhance or replace IR guided systems for SAMS will visual picture of the target for guidance.[56] Flares and other means of jamming will be virtually ineffective. AAFs will have to rely on installed systems to overcome IR seeking missiles. IR SAMS must be able to incorporate the latest counter-countermeasures to remain effective against the air-mechanized formation.

Optically directed air defense systems are the most effective systems in regards to the effects of countermeasures. Even counter-countermeasures have some potential degradation of effectiveness. Following is the evaluation of each air defense family in terms of the effectiveness of counter-countermeasures.

Most MANPADS use IR guidance for engagement and therefore are vulnerable to IR jamming.[57] Developments in MANPADS have decreased the effectiveness of flares and IR jamming on the performance of the SAM. Modern SAMS are very effective in deciphering between IR decoys or jamming and the original IR target signature.[58] Effectiveness against systems like the ATIRCM is difficult to determine, but the expected result is a decrease in the overall capability of the air defense system. Assuming for every advancement in countermeasures there will be an equal development in counter-countermeasures, the effectiveness of the MANPAD will fluctuate, but will remain relatively the same in the future.

The most debilitating effect on the self-propelled anti-aircraft gun family is the combined effectiveness of multiple jammers of the combined AAN assets. The radar associated with the self-propelled gun has limited capability to overcome the effects of sophisticated radar jamming. As discussed earlier, the radar makes this family of air defense vulnerable to suppression or destruction. The self-propelled gun system does have the advantage to optically engage targets. In the case of the Russian 2S6, optical engagements can only be achieved with the gun system and effectively eliminates the use of the SAMS. The 2S6 must be stationary to optically engage targets.[59]

Self-propelled SAMS have the same limitation. Some systems like the French Roland and the German Gepard use command signals to guide the SAMS to target.[60] These systems can be operated optically. The difference between the SAMS and gun systems is that the SAM is still linked electronically for course correction guidance. While this makes the missile the more accurate system, it also is vulnerable to the combined effects of AAN countermeasures.

Operated optically, towed anti-aircraft guns are invulnerable to electronic, or IR jamming. The only effective countermeasure to anti-aircraft guns is suppression. Unless effectively targeted, the anti-aircraft gun will continue to effectively engage targets within its capabilities.

Unlike the family of self-propelled SAMS, most types of static SAMS are unable to engage optically. These complex systems will have to rely on effective countermeasures to overcome the combined effects of jamming by AAN assets. Depending on the system, the effectiveness of the counter-countermeasures can vary significantly. It is difficult to determine the effectiveness of the static and towed SAMS counter-countermeasures against the AAN jamming assets. It is reasonable to assume that there will be significant degradation to the air defense system.

The anti-aircraft gun system that engages optically is the least vulnerable to electronic and IR countermeasures. The towed and self-propelled anti-aircraft gun families can still operate effectively as long as they are engaging optically. SAMS must relay on effective counter-countermeasures to overcome jamming. It appears that there is a great deal of emphasis placed on jamming radar-guided systems. Developments in IR counter-countermeasures could significantly increase the effectiveness of the system. For the purpose of the study, optically guided missiles are preferred over IR guided and radar guided missiles in order.

The previous analysis and evaluation have focused on the strengths and weakness of individual weapon system. This analysis and evaluation pertains to the mass required to provide the necessary level of air defense coverage for the defending force. In this case, the self-propelled anti-aircraft gun family provides the best overall coverage. A general discussion on the aspects of mass is necessary for the evaluation of air defense systems.

The defense of military forces from aerial threats is the primary mission of air defense weapons. The placement of air defense weapons to provide the most effective coverage depends on numerous variables. Commanders concern themselves with defense from aerial threats, and rely on air defense experts within his command to determine the proper placement of these critical assets. Not all air defense systems provide the same amount of coverage. Depending on distribution of forces, key terrain, and likely avenues of possible air attack, air defense weapons are concentrated where they will be able to do the most good. They are not necessarily located with the military force, but positioned so to provide the necessary protective coverage.

Not all air defense systems are designed to engage the same type of target, but this analysis is focused on the air-mechanized formation as the aerial threat. As stated earlier, the AAFs of the air-mechanized formation pose a low flying relatively slow moving target. The greatest challenge facing the enemy ground force commander is covering the 50+

kilometers from his military force to the suspected landing zone of the AAFs. While it is impractical to analyze all the possible variations of covering area targets with a radius of 50 kilometers, analyzing the coverage of the 50 kilometer distance based on air defense engagement ranges will provide a basis for comparison.

In doctrinal terms, mass refers to the effects of overwhelming combat power at a decisive place and time.[61] There is no difference to the application of air defense combat power. The mass of air defense systems must provide the defense coverage to protect the ground force. Mass can be achieved through the use of a network of highly capable air defense weapons, or the concentration of weapons positioned at critical locations. Employed in the right numbers, less sophisticated systems can be as effective in engaging multiple targets as the highly capable and complex air defense system. If mass equates to overwhelming combat power, then the measurement of air defense weapons is effective engagement range.

Based on the basic concept of mass as it relates to air defense, the family of self-propelled anti-aircraft guns provides the best overall coverage in a tactical environment. Following is the evaluation of each air defense family in regards to mass and air defense coverage.

Improvements in MANPAD performance has significantly increased the effectiveness of the system. With engagement ranges exceeding 5 kilometers, MADPAD effectiveness rivals that of more complex SAMS. If using the SA-18 as a model for comparison, MANPADS would cover an engagement area greater than 10 kilometers. The only limitation to engagement is a minimum engagement altitude of 10 meters.[62] MANPADS can be effectively employed by properly spaced defensive rings for protective coverage or concentrated in key areas. Assuming that the coverage in this case is a series of defensive rings, a factor of seven systems is required to cover the 70-kilometer distance as prescribed in the criteria.

Self-propelled anti-aircraft gun systems that incorporate both a gun and missile system have a tremendous advantage. The missile system provides effective engagement of distant targets while the guns system is effective for close targets and immediate threats. That advantage was the primary reason why systems like the 2S6 were designed. The gun system is intended to cover some, but not necessarily all of the missile engagement limitations. Case in point, the 2S6's SA-19 missile has a maximum engagement range of 8 kilometers with a minimum engagement range of 2,400 meters and a minimum engagement altitude of 15 meters.[63] The 2S6 also incorporates twin 30mm cannons. Their effective engagement range is 4,000 meters, and can engage from the surface to altitudes of 3,000 meters. The overlapping coverage provides the 2S6 with an unavoidable and lethal combination at least out to the first half of the total engagement range. The 2S6 has the capability to cover a total distance of 16 kilometers with only limited area of the surface to 15 meters that are not covered for the outer 4 kilometer ring. Using the 2S6 to represent the family of self-propelled anti-aircraft guns for this analysis, a factor of 4.4 systems is required to cover the necessary distance.

Among the SAM family of air defense systems, self-propelled SAMS have generally greater capabilities yet harbor a few limitations necessary for consideration. Systems like the French Roland have maximum engagement ranges of 8 kilometers and a minimum engagement range of 500 meters. While the overall performance of the ROLAND missile is more capable than the 2S6 missile, there is a minimum range the system is unable to defend itself. Additionally, the system has a minimum engagement altitude of 10 meters. Arguably the system was not designed to operate independently in a high threat environment, but as a network of complimentary air defense systems. The individual analysis of each representative system requires a discussion of advantages and limitations. Like the self-propelled gun family, a factor of 4.4 is necessary to provide the necessary coverage.

As stated earlier, anti-aircraft gun capabilities vary greatly. Medium caliber systems like the Chinese NORINCO 37mm twin barreled system boasts a maximum range of 8,500 meters. The reality is that without an effective fire control system, the gun is capable of engaging targets effectively at 1,500 meters. Based on that information, a planning factor of 23.3 systems are necessary for providing the necessary coverage. Although that number seems impractical, from an economic standpoint, acquiring large numbers of these types of weapons may be a viable alternative to purchasing highly capable, but very expensive systems. Towed anti-aircraft guns are the most prolific forms of air defense. Many nations do not consider the limited capability of the towed anti-aircraft gun system a disadvantage.

In simple terms, sophisticated static SAMS appear to have a clear advantage in terms of mass. Systems like the Russian SA-2 can easily manage the necessary coverage. With a maximum engagement range of over 40 kilometers, SA-2s require less than a factor of 2 to provide the necessary coverage. Before an enemy force commander goes out buying SA-2s to protect him from the AAN, a discussion on the system's limitations is necessary. Although the SA-2 missile covers a range of over 40 kilometers, the missile is limited in both minimum range and altitude. Seven kilometers and at an altitude greater than 250 meters is the minimum engagement parameters of the missile. Approximately 18% of the missile's engagement range is not covered. With a 250 meter altitude limitation, low flying aircraft could pass beneath the SA-2 coverage and deliver military assets, or provide effective suppression. AAFs are expected to tactically fly at altitudes less than 250 meters, and theoretically remain mission effective even under SA-2 coverage.

While both the self-propelled anti-aircraft gun and SAM families were numerically the same in this analysis, it appears that the gun system and its integrated SAM has a slight advantage. The self-propelled gun provides the overall greatest coverage. In terms of mass, MANPADS have the next lowest factor. MANPADS are limited slightly by the overall effective engagement range compared to other systems, but the coverage they do provide the most complete of all other SAMS. Complete coverage is also provided by the towed family of anti-aircraft guns; however, the systems are limited in terms of overall range. The static and towed family of SAMS is not necessarily designed for engagements against low flying tactical targets. Specifically in this case, the representative system had a critical area not covered and therefore not effective in terms of mass and comparison against more tactical systems.

## CONLUSION AND SUMMARY

The previous series of discussions concerning the various strengths and weaknesses of the five primary families of air defense weapon systems reveals that no one system dominates in this analysis. What is a strength in one system is a weakness in another. Without placing emphasis on the criteria, all the families of air defense systems are nearly equal; however, by placing emphasis on survivability and employment, MANPADS become the definitive system.

From the perspective of a major military competitor contemplating the possibility of facing the AAN, systems that were both survivable and easy to employ is essential. More capable weapons are great, but useless if detected and destroyed by the array of AAN fires preceding the ingress of the air-mechanized formation. Additionally, systems that can be employed by soldiers with minimal military training would greatly benefit the combat utilization of personnel. Emphasizing survivability and employment is essential to the considerations and course of action selection of a major military competitor.

Although MANPADS will provide the most effective means of air defense, many militaries will rely on a variety of systems to provide air defense coverage. In-depth air defense coverage is a common employment principle that requires a variety of systems. Following is a review of the advantage and disadvantage of each family of air defense.

MANPADS are definitively the superior system in the areas of survivability and employment. MANPADS are nearly undetectable prior to engagement. Being that

MANPADS do not emit a detectable signature, the survivability of these systems is much higher than other more complex systems. From an employment standpoint, MANPADS have no equal. Even the closest system requires technical crew training and regular maintenance support. The self-contained MANPAD requires the fewest actions to make it operational, and a solider with minimal training can effectively operate the system. In terms of mass, MANPADS rank below more complex systems. Engagement ranges, although impressive, are less than more advanced systems which requires greater number of MANPADS to provide coverage for the same given area. Even against effective countermeasures, MANPADS can be expected to provide viable probability of kill levels. The area MANPADS have the greatest limitations is acquisition. Limited by visibility, MANPADS cannot provide the same level of continuous acquisition capability as their radar-equipped counterparts.

Self-propelled anti-aircraft guns are highly effective and lethal systems. Especially with the incorporation of a missile capability, these systems offer one of the most complete weapons in the air defense arsenal. In terms of mass, self-propelled guns offer the greatest amount of coverage for a given defensive area. Additionally, in the areas of acquisition, and effective countermeasures, self-propelled gun systems had distinct advantages. From an acquisition standpoint, most self-propelled guns incorporate active radar, which greatly enhances the range of identifying targets. The advantage anti-aircraft guns have in general over SAMS is that most systems can be operated optically whereby negating the effectiveness of active countermeasures. The two primary disadvantages associated with these systems are in the areas of survivability and employment. Various sensors can easily detect the size and complexity of the system. Assuming that detection equals destruction, complex systems will not likely survive the combined engagement efforts of the AAN arsenal. With all complex systems, self-propelled guns require extensive technical training and substantial maintenance and logistic support.

Likewise, self-propelled surface-to-air systems have similar strengths and weakness to their anti-aircraft gun counterparts. The similarities include the acquisition capability. While both systems employ active radar, generally, SAMS incorporate more capable radars. From a countermeasure standpoint, these systems are designed to overcome both active and passive countermeasures. SAMS can be directed optically, but any form of command guidance can be jammed and made ineffective. In terms of mass, self-propelled SAMS have impressive capabilities and need only a few systems to provide defensive coverage. Self-propelled SAMS share the same limitations as their gun counterparts in terms of survivability and employment. These are relatively large and complex systems that can be detected by a variety of means, and the level of resources necessary to support these systems is substantial.

Of all the air defense systems evaluated, anti-aircraft guns successfully competed with MANPADS in nearly every area. The main advantage that anti-aircraft guns have over SAMS is the invulnerability to countermeasures. Generally these systems are simple, manually operated, and optically directed systems. Active countermeasures are ineffective against these systems. From an acquisition standpoint, anti-aircraft guns are limited, but still provide a viable threat. Although they are not as efficient as SAMS are, these guns still command the respect of aviation forces. In terms of survivability and employment, anti-aircraft guns are nearly equal to MANPADS in both respects. These systems are relatively small, but many emit some sort of detectable IR or electromagnetic signature.

Anti-aircraft guns also require a level of technical training for crews, and require transportation, logistic, and maintenance support.

Static and towed surface-to-air missiles are the most sophisticated and complex air defense systems in existence. While some SAMS have tactical applications, the system representing this family did not have an effective tactical capability. These systems have the greatest overall capability in terms of engagement, but lacked the low level and minimum engagement ranges necessary to provide the proper coverage. These systems are highly vulnerable to active countermeasures, and require extensive crew training, maintenance and logistic support. The sophistication of these systems makes them easily detectable against the AANs combined sensors. The primary advantage of these systems is the ability to detect and track aerial targets from great distances. No other system in this study can compare to these SAMS in terms of acquisition.

While every air defense system offers substantial advantages and capabilities to ground commander, MANPADS are the distinctive weapon for use against the AAFs of the air-mechanized formation. Nations will spend a great deal of resources to develop ways of defeating the United States future military force. As part of our efforts to make the concept viable and effective, the determination of weapon systems that can be effective against the force must be used in every modeling and wargaming for proper analysis.

While this study is just one facet of an entire series that is necessary for the proper analysis of the Army After Next concept, it will provide a starting point in terms of wargaming model development, and the development of tactical concepts for the employment of the air-mechanized formation. As the AAN concept development proceeds and wargaming is conducted to analyze various aspects of the concept.

MANPADS as part of the enemy force must be included in all simulations involving the tactical employment of the air-mechanized formation. Wargame developers must consider the addition of MANPADS with night vision capability. In addition to the reliance of gaining information dominance as part of the preparatory requirements in employing the air-mechanized formation, employment during period of poor or limited visibility is necessary for the survivability of the force. Developers must focus on systems that will enhance aviation crews to operate at night and under adverse weather conditions.

The Army After Next stands potentially as the next evolutionary process of the United States' pursuit of developing technically advanced and mobile forces to impose the nation's will in areas of strategic interest. The air-mechanized formation is the future cornerstone of a force that will maneuver and operate like no other force before. With all of the technological advantages the United States military currently enjoys and is expected to enjoy in the future, there will always be intelligent and innovative foes that will posses the necessary initiative to develop viable means of threatening even the most capable of forces. The greater effort that is put forth in identifying the means that a threat force could defeat the AAN, and address weaknesses either tactically or technologically, the fewer options will be available to potential opponents.

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